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Risk Evaluation for Perchloroethylene (Ethene, 1,1,2,2-Tetrachloro-)

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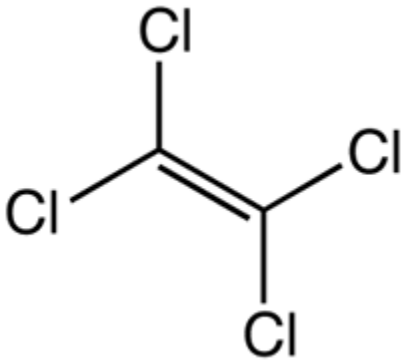

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ABBREVIATIONS

°C	Degrees Celsius
µg	Microgram(s)
1-BP	1-Bromopropane
1Q10	Lowest 1-day average flow that occurs (on average) once every 10 years
30Q5	Lowest 30-day average flow that occurs (on average) once every 5 years
7Q10	Lowest 7-day average flow that occurs (on average) once every 10 years
AAP	Alanine aminopeptidase
ABC	ATP Binding Cassette
AC	Acute Concentration
ACGIH®	American Conference of Government Industrial Hygienists
ADC	Average Daily Concentrations
ADME	Absorption/Distribution/Metabolism/Elimination
ADR	Acute Dose Rate
AEGL	Acute Exposure Guideline Level
AF	Assessment Factor
ALS	Amyotrophic Lateral Sclerosis
ALT	Aminotransferase
AML	Acute Myeloid Leukemia
ANCA	Antineutrophil-Cytoplasmic Antibody
APF	Assigned Protection Factor
ASD	Autism Spectrum Disorder
Atm	Atmosphere(s)
ATSDR	Agency for Toxic Substances and Disease Registries
AUC	Area Under the Curve
Avg	Average
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BIOWIN	EPI Suite biodegredation module
BLS	US Bureau of Labor Statistics
BMD	Benchmark Dose
BMDL/BMCL	Benchmark Dose/Concentration Lower Bound
BMR	Benchmark Dose Response
BW	Body Weight
CAA	Clean Air Act
CARB	California Air Resources Board
CASRN	Chemical Abstracts Service Registry Number
CBI	Confidential Business Information
CCI	Color Confusion Index
CCL_4	Carbon Tetrachloride
CD	Cluster of Differentiation
CDC	Centers for Disease Control and Prevention
CDR	Chemical Data Reporting

CDSMF	California Death Statistical Master File
CEHD	Chemical Exposure Health Data
CEM	Consumer Exposure Model
CEPA	Canadian Environmental Protection Agency/Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CF	Conversion Factor
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CHIRP	Chemical Risk Information Platform
ChV	Chronic Toxicity Value
CI	Confidence Interval
cm^3	Cubic Centimeter(s)
CNS	Central Nervous System
CoA	Coenzyme A
COC	Concentration of Concern
COPD	Chronic Obstructive Pulmonary Disease
CoRAP	Community Rolling Action Plan
COU	Condition of Use
cP	Centipoise
CPCat	Chemical and Product Categories
CPS	Current Population Survey
CPSC	Consumer Product Safety Commission
CSCL	Chemical Substances Control Law
CT	Central Tendency
CWA	Clean Water Act
CYP	Cytochrome P
DCA	Dichloroacetic Acid
DF	Dilution Factor
DLBCL	Diffuse Large B-cell Lymphoma
DMR	Discharge Monitoring Report
DNA	Deoxyribonucleic Acid
DNAPL	Dense Non-Aqueous Phase Liquid
DNP	Dinitrophenol
DoD	Department of Defense
DQE	Data Quality Evaluation
EC50	Half Maximal Effective Concentration
ECHA	European Chemicals Agency
ECHO	Enforcement and Compliance History Online
ECOTOX	ECOTOXicology knowledgebase
EDC	Ethylene Dichloride
EEG	Electrocochleogram
E-FAST	Exposure and Fate Assessment Screening Tool
EG	Effluent Guidelines

ELCR	Excess Lifetime Cancer Risk
EPA	Environmental Protection Agency
EPANET	EPA water distribution system model
EPCRA	Emergency Planning and Community Right-to-Know Act
EPISuite	Estimation Programs Interface (EPI) Suite
ESD	Emission Scenario Documents
EU	European Union
FDA	Food and Drug Administration
FFDCA	Federal Food, Drug and Cosmetic Act
FHSA	Federal Hazardous Substance Act
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
FR	Federal Register
G	Gram(s)
GACT	Generally Available Control Technology
GD	Gestation Day
GIS	Geographical Information System
GM	Geometric Mean
GPS	Global Positioning System
GS	Generic Scenario
GSD	Geometric Standard Deviation
GSH	Glutathione
GST	Glutathione S-transferase
HAP	Hazardous Air Pollutant
HCFC	Hydrochlorofluorocarbon
HCl	Hydrochloric Acid
HE	High End
HEC	Human Equivalent Concentration
HED	Human Equivalent Dose
HERO	Health and Environmental Research Online (database)
HFC	Hydrofluorocarbon
HPV	High Production Volume
Hr	Hour(s)
HRs	Hazard Ratios
HSIA	Halogenated Solvents Industry Association
HUC	Hydrologic Unit Codes
i.p.	Intraperitoneal
IARC	International Agency for Research on Cancer
ICD	International Classification of Diseases
IDLH	Immediately Dangerous to Life and Health
IgA	Immunoglobulin A
IgE	Immunoglobulin E
IRIS	Integrated Risk Information System
IRTA	Institute for Research and Technical Assistance

ISHA	Industrial Safety and Health Act
IUR(s)	Inhalation Unit Risk(s)
kg	Kilogram(s)
L	Liter(s)
LADC	Lifetime Average Daily Concentration
lb	Pound(s)
LC50	Lethal Concentration 50
LDH	Lactate Dehydrogenase
LOAEC	Lowest Observable Adverse Effect Concentration
LOAEL	Lowest Observed Adverse Effect Level
LOD	Limit of Detection
LOEC	Lowest Observed Effect Concentration
Log K_{OC}	Logarithmic Organic Carbon:Water Partition Coefficient
Log K_{OW}	Logarithmic Octanol:Water Partition Coefficient
m^3	Cubic Meter(s)
MACT	Maximum Achievable Control Technology
Max.	Maximum
MCCEM	Multi-Chamber Concentration Exposure Model
MCL	Mononuclear Cell Leukemia (Hazard sections)
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MF	Mycosis Fungoides
Mfg	Manufacturing
mg	Milligram(s)
Min	Minute
Min.	Minimum
MLD	Million Liters per Day
MM	Multiple Myeloma
mmHg	Millimeter(s) of Mercury
MOA	Mode of Action
MOE	Margin of Exposure
mRNA	Messenger RNA
MSDS	Material Safety Data Sheet
n	Number variable (also N)
N/A	Not Available; Not Applicable
NAAQS	National Ambient Air Quality Standards
NAC	National Advisory Committee
NAcTCVC	N-acetylate TCVC
NAG	N-acetyl glucuronidase
NAICS	North American Industry Classification System
NATA	National Air Toxics Assessment
NAWQA	National Water-Quality Assessment

NCEA	National Center for Environmental Assessment
NCHS	National Center for Health Statistics
ND	Non-detect
NDI	National Death Index
NEI	National Emissions Inventory
NESHAP	National Emission Standards for Hazardous Air Pollutants
NHANES	National Health and Nutrition Examination Survey
NHD	National Hydrological Dataset
NHEXAS	National Human Exposure Assessment Survey
NHL	non-Hodgkin lymphoma
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NITE	National Institute of Technology and Evaluation
NOACC	Nordic Occupational Cancer Study
NOAEC	No Observable Adverse Effect Concentration
NOAEL	No Observed Adverse Effect Level
NOEC	No Observable Effect Concentration
NOEL	No Observable Effect Level
NPDES	National Pollutant Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NPL	National Priorities List
NR	Not Reported
NRC	National Research Council
NTP	National Toxicology Program
NWIS	National Water Information Systems
OAQPS	Office of Air Quality Planning and Standards
OCPSF	Organic Chemicals, Plastics and Synthetic Fibers
OCSPP	Office of Chemical Safety and Pollution Prevention
ODS	Ozone Depleting Substance
OECD	Organisation for Economic Co-operation and Development
OEHHA	Office of Environmental Health Hazard Assessment
OEL	Occupational Exposure Limit
OEM	Original Equipment Manufacturer
OES	Occupational Exposure Scenarios
ONU	Occupational Non-User
OPPT	Office of Pollution Prevention and Toxics
ORs	Odds Ratios
OSHA	Occupational Safety and Health Administration
OTPR	Oily Type Paint Removers
OTVD	Open Top Vapor Degreasing
PAPR	Power Air-Purifying Respirator
RPB	Retinol-binding protein

PBPK	Physiologically Based Pharmacokinetic
PBZ	Personal Breathing Zone
PCA	Passive Cutaneous Anaphylaxis
PCE	Perchloroethylene
PCO	Palmitoyl CoA Oxidation
PDM	Probabilistic Dilution Model
PECO	Populations, Exposures, Comparators and Outcomes
PEL	Permissible Exposure Limit
PESS	Potentially Exposed Susceptible Subpopulation
PF	Protection Factor
pH	Potential for Hydrogen (also Power of Hydrogen)
PND	Postnatal Day
POD	Point of Departure
POTW	Publicly Owned Treatment Works
PPARα	Peroxisome Proliferator-Activated Receptor alpha
ppb	Part(s) per Billion
PPE	Personal Protective Equipment
ppm	Part(s) per Million
P_{trend}	P-value trend
PWS	Public Water System
RCRA	Resource Conservation and Recovery Act
RDD	Relative Delivered Dose
RESO	Receptors, Exposure, Setting (or Scenario), Outcome
RfC(s)	Reference Concentration(s)
RQ	Risk Quotient
RR	Risk Ratio
S9	Fraction of an organ tissue homogenate used in biological assays to add metabolic activity
SAR	Supplied-Air Respirator
SARA	Superfund Amendments and Reauthorization Act
SCBA	Self-Contained Breathing Apparatus
SCEs	Sister Chromatid Exchange(s)
SCHER	Scientific Committee on Health and Environmental Risks
SD	Standard Deviation
SDS	Safety Data Sheet
SDWA	Safe Drinking Water Act
SEMS	Superfund Enterprise Management System
SF	Stream Flow
SHIELD	School Health Initiative: Environment, Learning, Disease
SIC	Standard Industry Classification
SIDS	Screening Information Data Set
SIR	Standardized Incidence Ratios
SMR	Standard Mortality Ratio

SNAP	Significant New Alternatives Policy
SpERC	Specific Environmental Release Category
SSADMF	Social Security Administration Death Master File
STEL	Short-Term Exposure Limit
STEWARDS	USDA ARS Sustaining the Earth's Watersheds - Agricultural research Database System
STORET	EPA STORage and RETrieval data warehouse
STP	Standard Temperature and Pressure
SUSB	U.S. Census Statistics of US Businesses
SWC	Surface Water Concentration
$t_{1/2}$	Half-life
TCA	Trichloroacetic Acid
TCAC	Trichloroacetyl Chloride
TCCR	Transparent, Clear, Consistent, and Reasonable
TCE	Trichloroethylene
TCOH	Trichloroethanol
TCVC	S-(1,2,2-trichlorovinyl) cysteine
TCVCS	TCVC sulfoxide
TCVG	S-(1,2,2-trichlorovinyl) glutathione
TCVMA	N-acetyl-S-(trichlorovinyl)-l-cystine
TEAM	Total Exposure Assessment Methodology
TLV®	Threshold Limit Value
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
TTO	Total Toxic Organics
TWA	Time-Weighted Average
U.S.	United States
UFs	Uncertainty Factors
USGS	United States Geological Survey
VA	Veteran's Affairs
VACCR	Veteran's Affairs Central Cancer Registry
VOC	Volatile Organic Compound
WBC	White Blood Cells
WHO	World Health Organization
WOE	Weight of Evidence
WQP	Water Quality Portal
WQX	Water Quality Exchange
WWR	Waste Water Release
WWTP	Wastewater Treatment Plants
Yr	Year(s)

EXECUTIVE SUMMARY

This risk evaluation for perchloroethylene (PCE) was performed in accordance with the Frank R. Lautenberg Chemical Safety for the 21st Century Act and is being issued following public comment and peer review. The Frank R. Lautenberg Chemical Safety for the 21st Century Act amended the Toxic Substances Control Act (TSCA), the Nation's primary chemicals management law, in June 2016. Under the amended statute, EPA is required, under TSCA Section 6(b), to conduct risk evaluations to determine whether a chemical substance presents unreasonable risk of injury to health or the environment, under the conditions of use, without consideration of costs or other non-risk factors, including an unreasonable risk to potentially exposed or susceptible subpopulations, identified as relevant to the risk evaluation. Also, as required by TSCA section (6)(b), EPA established, by rule, a process to conduct these risk evaluations: *Procedures for Chemical Risk Evaluation Under the Amended Toxic Substances Control Act* (82 FR 33726)(Risk Evaluation Rule). This risk evaluation is in conformance with TSCA section 6(b), and the Risk Evaluation Rule, and is to be used to inform risk management decisions. In accordance with TSCA section 6(b), if EPA finds unreasonable risk from a chemical substance under its conditions of use in any final Risk Evaluation, the Agency will propose actions to address those risks within the timeframe required by TSCA. However, any proposed or final determination that a chemical substance presents unreasonable risk under TSCA section 6(b) is not the same as a finding that a chemical substance is "imminently hazardous" under TSCA section 7. The conclusions, findings, and determinations in this final Risk Evaluation are for the purpose of identifying whether the chemical substance presents unreasonable risk or no unreasonable risk under the conditions of use, in accordance with TSCA section 6, and are not intended to represent any findings under TSCA section 7.

TSCA sections 26(h) and (i) require EPA, when conducting risk evaluations, to use scientific information, technical procedures, measures, methods, protocols, methodologies and models consistent with the best available science and to base its decisions on the weight of the scientific evidence.[1] To meet these TSCA section 26 science standards, EPA used the TSCA systematic review process described in the *Application of Systematic Review in TSCA Risk Evaluations* document (U.S. EPA, 2018b). The data collection, evaluation, and integration stages of the systematic review process are used to develop the exposure, fate, and hazard assessments for risk evaluations.

PCE is subject to federal and state regulations and reporting requirements. PCE has been a reportable Toxics Release Inventory (TRI) chemical under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) since 1987. It is designated a Hazardous Air Pollutant (HAP) under the Clean Air Act (CAA), and is a hazardous substance under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). It is subject to National Primary Drinking Water Regulations (NPDWR) under the Safe Drinking Water Act (SDWA) and designated as a toxic pollutant under the Clean Water Act (CWA) making it subject to effluent limitations.

PCE is currently manufactured, processed, distributed, used, and disposed of as part of a wide range of industrial, commercial, and consumer conditions of use, including production of fluorinated compounds, and as a solvent in dry cleaning and vapor degreasing. A variety of consumer and commercial products contain PCE such as adhesives (arts and crafts, as well as light repairs), aerosol degreasing, brake cleaners, aerosol lubricants, sealants, stone polish, stainless steel polish and other cleaners used for

[1] Weight of the scientific evidence means a systematic review method, applied in a manner suited to the nature of the evidence or decision, that uses a pre-established protocol to comprehensively, objectively, transparently, and consistently identify and evaluate each stream of evidence, including strengths, limitations, and relevance of each study and to integrate evidence as necessary and appropriate based upon strengths, limitations, and relevance.

wiping surfaces. EPA evaluated the following categories of conditions of use: manufacturing; processing; distribution in commerce, industrial, commercial and consumer uses and disposal. The yearly aggregate production volume for PCE ranged from 388 to 324 million pounds between 2012 and 2015 according to CDR (Section 1.2).

Approach

EPA used reasonably available information (defined in 40 CFR 702.33 in part as "*information that EPA possesses, or can reasonably generate, obtain, and synthesize for use in risk evaluations, considering the deadlines … for completing such evaluation"*), in a fit-for-purpose approach, to develop a risk evaluation that relies on the best available science and is based on the weight of the scientific evidence. EPA used previous assessments, for example EPA's IRIS assessment (U.S. EPA, 2012d), as a starting point for identifying key and supporting studies to inform the exposure, fate, and hazard assessments included in this risk evaluation. EPA also evaluated other studies published since the publication of previous analyses. EPA reviewed reasonably available information and evaluated the quality of the methods and reporting of results of the individual studies using the evaluation strategies described in *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018b). To satisfy requirements in TSCA section 26(j)(4) and 40 CFR 702.51(e), EPA has provided a list of studies considered in carrying out the risk evaluation and the results of those studies in several supplemental files (Appendix B).

In the Problem Formulation (U.S. EPA, 2018d), EPA identified the conditions of use within the scope of the risk evaluation and presented three conceptual models and an analysis plan for this risk evaluation. These have been carried into the risk evaluation where EPA has quantitatively evaluated the risk to the environment and human health, using both monitoring data and modeling approaches, for the conditions of use (identified in Section 1.4.1 of this risk evaluation) and exposure pathways within the scope of the risk evaluation.[2] While PCE is present in various environmental media, such as groundwater, surface water, and air, EPA stated in the Problem Formulation that EPA did not expect to include certain exposure pathways (*e.g.*, general population human exposures) in the risk evaluation that are under the jurisdiction of other EPA-administered statutes in this risk evaluation as described in Section 1.4.2.

EPA quantitatively evaluated the risk to aquatic species from exposure to surface water from the manufacturing, processing, use, or disposal of PCE. EPA used environmental fate parameters, physical-chemical properties, modelling, and monitoring data to assess ambient water exposure to aquatic species. During the systematic review process, EPA identified and evaluated studies that pertained to this risk evaluation. Therefore, exposures to aquatic organisms from ambient surface water, are assessed and presented in this risk evaluation and used to inform the risk determination. These analyses are described in Sections 2.1, 2.3, 4.1.

EPA evaluated exposures to PCE in occupational and consumer settings for the conditions of use included in the scope of the risk evaluation, listed in Section 1.4 (Scope of the Evaluation). In occupational settings, EPA evaluated acute and chronic inhalation exposures for two subcategories of

[2] EPA did not identify any "legacy uses" (i.e., circumstances associated with activities that do not reflect ongoing or prospective manufacturing, processing, or distribution) or "associated disposal" (i.e., future disposal from legacy uses) of PCE, as those terms are described in EPA's Risk Evaluation Rule, 82 FR 33726, 33729 (July 20, 2017). Therefore, no such uses or disposals were added to the scope of the risk evaluation for PCE following the issuance of the opinion in *Safer Chemicals, Healthy Families v. EPA*, 943 F.3d 397 (9th Cir. 2019). EPA did not evaluate "legacy disposal" (i.e., disposals that have already occurred) in the risk evaluation, because legacy disposal is not a "condition of use" under *Safer Chemicals*, 943 F.3d 397.

workers, occupational users (workers) and occupational non-users (ONUs)[3], and acute and chronic dermal exposures to workers. EPA used inhalation monitoring data from literature sources that met data evaluation criteria, where reasonably available. EPA also used modeling approaches to estimate potential inhalation exposures. Dermal doses for workers were estimated in occupational exposure scenarios since dermal monitoring data was not reasonably available. In consumer settings, EPA evaluated acute inhalation exposures to both consumers and bystanders, and acute dermal exposures to consumers. Inhalation exposures for consumers and bystanders and dermal doses for consumers in these scenarios were estimated since inhalation and dermal monitoring data were not reasonably available. These analyses are described in Section 2.4 of this risk evaluation.

EPA reviewed the environmental hazard data using the data quality review evaluation metrics and the rating criteria described in the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018b). EPA identified PCE hazard endpoints to environmental aquatic receptors with invertebrates being the most sensitive taxa for exposures. The results of the environmental hazard assessment are in Section 3.1.

EPA evaluated reasonably available information for human health hazards and identified hazard endpoints including acute and chronic toxicity for non-cancer effects and chronic toxicity for cancer. EPA used the Framework for Human Health Risk Assessment to Inform Decision Making (U.S. EPA, 2014c) to evaluate, extract, and integrate PCE's human health hazard and dose-response information. EPA reviewed key and supporting information from previous hazard assessments, EPA's IRIS Toxicological Review (U.S. EPA, 2012d), an ATSDR Toxicological Profile (ATSDR, 2019), the AEGL (NAC/AEGL, 2009), and other international assessments listed in Table 1-3. EPA also screened and evaluated new studies that were published since these reviews (*i.e.,* from 2012 - 2018).

EPA developed a quantitative hazard and dose-response analysis using endpoints observed in inhalation and oral hazard studies, evaluated the weight of the scientific evidence considering EPA and National Research Council (NRC) risk assessment guidance, and selected the points of departure (POD) for acute and chronic non-cancer endpoints and inhalation unit risk and cancer slope factors for cancer risk estimates. Potential health effects associated with PCE exposure are described in Section 3.2.

Risk Characterization

Environmental Risks: For environmental risk, EPA utilized a risk quotient (RQ) to compare the environmental concentration to the effect level to characterize the risk to aquatic organisms. The results of the risk characterization are described in Section 4.1, including a table that summarizes the RQs for acute and chronic risks.

EPA identified expected environmental exposures for aquatic species under the conditions of use in the scope of the risk evaluation. The estimated releases from specific facilities result in modeled surface water concentrations that were equal to or exceed the aquatic benchmark (RQ $\geq$ 1) for two conditions of use, indicating that exposures resulting from environmental concentrations were greater than the effect concentration or the concentration of concern. Details of these estimates are described in Section 4.1.2.

Human Health Risks: Risks were estimated following both acute and chronic exposures (for workers and ONUs) and acute exposures (for consumer users and bystanders) for various endpoints covering

[3] ONUs are workers who do not directly handle PCE but perform work in an area where PCE is present. See Section 2.4.1.1 for more details on the distinction between workers and ONUs.

multiple hazard domains/organ systems. EPA identified potential cancer and non-cancer human health risks. The studies that support the health concerns address neurotoxicity (CNS effects) from acute exposures, neurological, kidney, liver, immune system and developmental effects from chronic exposures, and liver cancer.

EPA estimated risk to workers from inhalation and dermal exposures, and risk to ONUs from inhalation exposures by comparing the estimated exposures to acute and chronic human health hazards. For workers and ONUs, EPA estimated the cancer risk as the product of the chronic exposure to PCE and the inhalation unit risk (IUR) or dermal cancer slope factor (SF) value for each OES. For dermal exposure to workers, cancer risk was estimated as the product of the dermal exposure and the cancer slope factor for each occupational exposure scenario (OES). For workers and ONUs, EPA estimated exposure and used the MOE approach to assess the margin of exposure (MOE) for non-cancer health effects. For workers, EPA estimated risks using several occupational exposure scenarios, which varied assumptions regarding the use of personal protective equipment (PPE) for respiratory and dermal exposures for workers directly handling PCE. EPA also separately evaluated inhalation risks to children of employees present at dry cleaners (Section 4.2.2.13.2) using the assumption that HECs could be scaled based on their increased breathing rate/body weight ratio compared to adults (Section 3.2.5.4.1). More information on respiratory and dermal protection, including EPA's approach regarding the occupational exposure scenarios for PCE, is in Section 2.4.1.

For the majority of occupational exposure scenarios, risk to workers were identified for multiple endpoints in both acute and chronic exposure scenarios. Based on the PODs selected from among the acute and chronic endpoints, acute and chronic non-cancer and cancer risks were indicated for all but one exposure scenario and occupational conditions of use under high-end inhalation or dermal exposure levels without the use of PPE. Use of PPE during the assessed conditions of use is expected to reduce worker exposure. This resulted in fewer conditions of use with indicated risks for acute, chronic non-cancer, or cancer inhalation or dermal exposures. With assumed use of respiratory protection, cancer risks from chronic inhalation exposures were not indicated for most conditions of use. With assumed use of dermal protection, acute, chronic non-cancer, and cancer risks were not indicated for some conditions of use. However, some conditions of use continued to present non-cancer inhalation risks to workers under high-end occupational exposure scenarios even with assumed PPE (*i.e.*, respirators APF 10, 25 or 50). EPA's estimates for worker risks for each occupational exposure scenario are presented in Section 4.2.1 and summarized in Table 4-125.

ONUs are expected to have lower exposure levels than workers in most instances, but exposures could not always be quantified based on reasonably available data and risk estimates for ONUs may be similar to workers in some settings. While the difference between the exposures of ONUs and the exposures of workers directly handling PCE generally cannot be quantified, ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical. In these instances, EPA considered the ONU exposures to be equal to the central tendency risk estimates for workers when determining ONU risk attributable to inhalation. While this is likely health protective as it assumes ONU exposure is as high as it is for the majority of workers (greater numbers are likely to be exposed near the middle of the distribution), this is uncertain. EPA did not assess dermal exposures to ONUs because EPA does not expect ONUs to have routine dermal exposures in the course of their work. Depending on the condition of use, ONUs may have incidental dermal exposures due to surface contamination. However, data (*e.g.*, frequency and amount of liquid on the skin after contact) were not reasonably available to assess this exposure.

Based on central-tendency exposure levels, acute and chronic non-cancer risks to ONUs were

indicated for the majority of exposure scenarios. ONUs are not assumed to be using PPE to reduce exposures to PCE used in their vicinity. EPA's estimates for ONU risks
for each occupational exposure scenario are presented alongside worker risk estimates in Section 4.2.2.

EPA also evaluated the risk to consumers from inhalation and dermal exposures, and to bystanders, from inhalation exposures, by comparing the estimated exposures to acute human health hazards. For consumers and bystanders for consumer use, EPA estimated non-cancer risks resulting from acute inhalation or dermal exposures that were modeled with a range of user intensities, described in detail in Section 2.4.1.29. EPA assumed that consumers or bystanders would not use PPE and that all exposures would be acute rather than chronic.

For consumer users and bystanders, risks identified for acute exposures were indicated for some conditions of use. For consumers, medium and high intensity acute inhalation and dermal exposure scenarios indicated risk. Conditions of use that indicated risks following acute exposures to consumer users (for inhalation and dermal exposure) also indicated risks to bystanders (for inhalation exposures only). One scenario, dry cleaning solvent, presented risks for consumers in the dermal scenario. Some consumer conditions of use did not indicate risks for consumer or bystanders. EPA's estimates for consumer and bystander risks for each consumer use exposure scenario are presented in Section 4.2.4 and summarized in Table 4-126 in Section 4.4.2. Estimates of MOEs were calculated for consumers for acute inhalation and dermal exposures, because the exposure frequencies were not considered sufficient to cause the health effects that were observed in chronic animal studies typically defined as at least 10% of the animal's lifetime.

Uncertainties: Key assumptions and uncertainties in the environmental risk estimation include the uncertainty around modeled releases that have surface water concentrations greater than the highest concentration of concern for algae. Data were reasonably available for three algal species and may not represent the most sensitive species at a given site. For the human health risk estimation, key assumptions and uncertainties are related to the estimates for ONU inhalation exposures because monitoring data were not reasonably available for many of the conditions of use evaluated. Assumptions and key sources of uncertainty for consumer exposure are detailed in Section 2.4.2.3 for consumer products, Section 2.4.2.4 for consumer articles, and Section 2.4.2.6 for overarching uncertainties.

EPA used reasonably available information, in a fit-for-purpose approach, to develop a risk evaluation that relies on the best available science and is based on the weight of the scientific evidence to account for uncertainties throughout the risk evaluation. For instance, systematic review was conducted to identify reasonably available information related to PCE hazards and exposures. If no applicable monitoring data were identified, exposure scenarios were assessed using a modeling approach that requires the input of various chemical parameters and exposure factors. When possible, default model input parameters were modified based on chemical-specific inputs available in literature databases. The consideration of uncertainties supports the Agency's risk determinations, each of which is supported by substantial evidence, as set forth in detail in later sections of this final Risk Evaluation.

Potentially Exposed and Susceptible Subpopulations: TSCA section 6(b)(4) requires that EPA conduct risk evaluations to determine whether a chemical substance presents unreasonable risk under the conditions of use, including unreasonable risk to a potentially exposed or susceptible subpopulation identified as relevant to the risk evaluation. TSCA § 3(12) defines potentially exposed or susceptible subpopulation (PESS) as *"a group of individuals within the general population identified by the Administrator who, due to either greater susceptibility or greater exposure, may be at greater risk than*

the general population of adverse health effects from exposure to a chemical substance or mixture, such as infants, children, pregnant women, workers, or the elderly."

In developing the risk evaluation, EPA analyzed reasonably available information to ascertain whether some human receptor groups may have greater exposure or greater susceptibility than the general population to the hazard posed by PCE. For consideration of the most highly exposed groups, EPA considered PCE exposures among both workers using PCE and ONUs in the vicinity of PCE use to be higher than the exposures experienced by the general population. Consumer users and bystanders are also expected to be more highly exposed than the general population. Potentially exposed or susceptible subpopulations include the developing fetus (and by extension, women of childbearing age) as well as those with pre-existing health conditions, higher body fat content, or particular genetic polymorphisms. See additional discussions in Section 4.3.1. EPA's decisions for unreasonable risk are based on high-end exposure estimates for workers and high intensity use scenarios for consumers and bystanders in order to capture individuals who are PESS.

Aggregate and Sentinel Exposures: Section 6(b)(4)(F)(ii) of TSCA requires EPA, as a part of the risk evaluation, describe whether aggregate or sentinel exposures under the conditions of use were considered and the basis for their consideration. EPA has defined aggregate exposure as "*the combined exposures to an individual from a single chemical substance across multiple routes and across multiple pathways*" (40 CFR § 702.33). Exposures to PCE were evaluated by inhalation and dermal routes separately. Inhalation and dermal exposures are assumed to occur simultaneously for workers and consumers. EPA chose not to employ simple additivity of exposure pathways at this time within a condition of use because of the uncertainties present in the current exposure estimation procedures. Without a PBPK model containing a dermal compartment to account for toxicokinetic processes the true internal dose for any given exposure cannot be determined, and aggregating exposures by simply adding exposures from multiple routes could inappropriately overestimate total exposure. Conversely, not aggregating exposures in any manner may potentially underestimate total exposure for a given individual.

EPA defines sentinel exposure as "*the exposure from a single chemical substance that represents the plausible upper bound of exposure relative to all other exposures within a broad category of similar or related exposures"* (40 CFR § 702.33). In this Risk Evaluation, EPA considered sentinel exposure the highest exposure given the details of the conditions of use and the potential exposure scenarios. EPA considered sentinel exposures in this Risk Evaluation by considering risks to populations who may have upper bound (*e.g.*, high-end, high intensities of use) exposures. In cases where sentinel exposures result in MOEs greater than the benchmark or cancer risk lower than the benchmark (*i.e.*, risks were not identified), EPA did no further analysis because sentinel exposures represent the worst-case scenario. EPA's decisions for unreasonable risk are based on high-end exposure estimates to capture individuals with sentinel exposure.

Additional details on how aggregate and sentinel exposures were considered in this Risk Evaluation are provided in Section 4.3.2.

Unreasonable Risk Determination

In each risk evaluation under TSCA section 6(b), EPA determines whether a chemical substance presents an unreasonable risk of injury to health or the environment, under the conditions of use. The determination does not consider costs or other non-risk factors. In making this determination, EPA considers relevant risk-related factors, including, but not limited to: the effects of the chemical substance on health and human exposure to such substance under the conditions of use (including cancer and non-

cancer risks); the effects of the chemical substance on the environment and environmental exposure under the conditions of use; the population exposed (including any potentially exposed or susceptible subpopulations, as determined by EPA); the severity of hazard (including the nature of the hazard, the irreversibility of the hazard); and uncertainties. EPA also takes into consideration the Agency's confidence in the data used in the risk estimate. This includes an evaluation of the strengths, limitations, and uncertainties associated with the information used to inform the risk estimate and the risk characterization. The rationale for the unreasonable risk determination is in Section 5.2. The Agency's risk determinations are supported by substantial evidence, as set forth in detail in later sections of this final Risk Evaluation.

Unreasonable Risk of Injury to the Environment: EPA evaluated environmental exposures for aquatic organisms and determined whether any risks are unreasonable. The drivers for EPA's determination of unreasonable risks to aquatic organisms are immobilization from acute exposure, growth effects from chronic exposure, and mortality to algae. Algae was assessed separately and not incorporated into acute or chronic COCs, because durations normally considered acute for other species (*e.g.*, 48, 72 hours) can encompass several generations of algae. EPA estimated site-specific surface water concentrations for discharges using upper and lower bounds for the range of predicted surface water concentrations. For the percentage of the chemical removed from wastewater during treatment before discharge to a body of water, EPA estimated 88% removal of PCE from indirect discharging facilities and estimated 0% removal of PCE for direct releases to surface water. PCE has low bioaccumulation potential and moderate potential to accumulate in wastewater biosolids, soil, or sediment. The risk estimates, the environmental effects of PCE, the exposures, physical chemical properties of PCE, and consideration of uncertainties support EPA's determination that there is no unreasonable risk to the environment from all conditions of use of PCE. A full description of EPA's determination of risk of injury to the environment is in Section 5.2.

Unreasonable Risks of Injury to Health: EPA's determination of unreasonable risk for specific conditions of use of PCE listed below are based on health risks to workers, occupational non-users, consumers, or bystanders from consumer use. As described below, EPA did not evaluate unreasonable risk to the general population in this risk evaluation. For each hazard domain there are several endpoints, and often a single endpoint was examined by multiple studies. The non-cancer effects selected for risk estimation were neurotoxicity (*i.e.,* increased latencies for pattern reversal visual-evoked potentials) from acute exposure. For chronic exposures, EPA evaluated multiple effects including CNS, kidney, liver, immune system and developmental toxicity as well as cancer (liver tumors).

Unreasonable Risk of Injury to Health of the General Population: General population exposures to PCE may occur from industrial and/or commercial uses; industrial releases to air, water or land; and other conditions of use. During the course of the risk evaluation process for PCE, OPPT worked closely with the offices within EPA that administer and implement regulatory programs under the Clean Air Act (CAA), the Safe Drinking Water Act (SDWA), the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Through this intra-agency coordination, EPA determined that PCE exposures to the general population via surface water, drinking water, ambient air and sediment pathways fall under the jurisdiction of other environmental statutes administered by EPA, *i.e.*, CAA, SDWA, CWA, RCRA, and CERCLA. As explained in more detail in Section 1.4.2, EPA believes it is both reasonable and prudent to tailor TSCA risk evaluations when other EPA offices have expertise and experience to address specific environmental media, rather than attempt to evaluate and regulate potential exposures and risks from those media under TSCA. EPA believes that coordinated action on exposure pathways and risks addressed by other EPA-administered statutes and regulatory programs is consistent with

statutory text and legislative history, particularly as they pertain to TSCA's function as a "gap-filling" statute, and also furthers EPA aims to efficiently use Agency resources, avoid duplicating efforts taken pursuant to other Agency programs, and meet the statutory deadline for completing risk evaluations. EPA has therefore tailored the scope of the risk evaluation for PCE using authorities in TSCA sections 6(b) and 9(b)(1). EPA did not evaluate hazards or exposures to the general population in this risk evaluation, and as such the unreasonable risk determinations for relevant conditions of use do not account for exposures to the general population.

Unreasonable Risk of Injury to Health of Workers: EPA evaluated non-cancer effects from acute and chronic inhalation and dermal occupational exposures and cancer from chronic inhalation and dermal occupational exposures to determine if there was unreasonable risk to workers' health. The drivers for EPA's determination of unreasonable risk for workers are neurotoxicity from acute and chronic inhalation exposures, neurotoxicity from chronic dermal exposures, and cancer resulting from chronic inhalation and dermal exposures.

EPA generally assumes compliance with OSHA requirements for protection of workers, including the implementation of the hierarchy of controls. In support of this assumption, EPA used reasonably available information, including public comments, indicating that some employers, particularly in the industrial setting, are providing appropriate engineering or administrative controls or PPE to their employees consistent with OSHA requirements. While EPA does not have reasonably available information to support this assumption for each condition of use, EPA does not believe that the Agency must presume, in the absence of such information, a lack of compliance with existing regulatory programs and practices. Rather, EPA assumes there is compliance with worker protection standards unless case-specific facts indicate otherwise, and therefore existing OSHA regulations for worker protection and hazard communication will result in use of appropriate PPE in a manner that achieves the stated Assigned Protection Factor (APF) or Protection Factor (PF) for gloves. EPA's decisions for unreasonable risk to workers are based on high-end exposure estimates, in order to account for the uncertainties related to whether or not workers are using PPE. EPA believes this is a reasonable and appropriate approach that accounts for reasonably available information and professional judgment related to worker protection practices, and addresses uncertainties regarding availability and use of PPE.

For each condition of use of PCE with an identified risk for workers, EPA assumes, as a baseline, the use of a respirator with an APF of 25 or 50. Similarly, EPA assumes the use of gloves with PF 10 or 20. However, EPA assumes that for some conditions of use, the use of appropriate respirators is not a standard industry practice, based on best professional judgement given the burden associated with the use of supplied-air respirators, including the expense of the equipment and the necessity of fit-testing and training for proper use. Similarly, EPA does not assume that as a standard industry practice that workers wear gloves for the industrial and commercial use of PCE for dry cleaning and spot cleaning, wipe cleaning and metal/stone polishes, other spot cleaning/spot remover, and other commercial uses.

The unreasonable risk determinations reflect the severity of the effects associated with the occupational exposures to PCE and incorporate EPA assumptions of PPE use. A full description of EPA's unreasonable risk determination for each condition of use is in Section 5.2.

Unreasonable Risk of Injury to Health of Occupational Non-Users (ONUs): ONUs are workers who do not directly handle PCE but perform work in an area where PCE is present. EPA evaluated non-cancer effects to ONUs from acute and chronic inhalation occupational exposures and cancer from chronic inhalation occupational exposures to determine if there was unreasonable risk of injury to ONUs' health. The unreasonable risk determinations reflect the severity of the effects associated with the occupational

exposures to PCE and the assumed absence of PPE for ONUs, since ONUs do not directly handle the chemical and are instead doing other tasks in the vicinity of PCE use. Non-cancer effects and cancer from dermal occupational exposures to ONUs were not evaluated because ONUs are not dermally exposed to PCE. For inhalation exposures, when there was reasonably available information, EPA estimated ONUs' exposures and described the risks separately from workers directly exposed. When the difference between ONUs' exposures and workers' exposures cannot be quantified, EPA assumed that ONU inhalation exposures are lower than inhalation exposures for workers directly handling the chemical substance, and EPA considered the central tendency risk estimate when determining ONU risk. A full description of EPA's unreasonable risk determination for each condition of use is in Section 5.2.

Unreasonable Risk of Injury to Health of Consumers: EPA evaluated non-cancer effects to consumers from acute inhalation and dermal exposures to determine if there was unreasonable risk to consumers' health. Generally, risks for consumers were indicated by acute inhalation and dermal exposure at low, medium, and high intensity use. The exposure scenarios supporting the unreasonable risk determinations for the conditions of use are listed in the detailed description of each consumer use in Section 5.2.

Unreasonable Risk of Injury to Health of Bystanders (from Consumer Uses): EPA evaluated non-cancer effects to bystanders from acute inhalation exposures to determine if there was unreasonable risk of injury to bystanders' health. EPA did not evaluate non-cancer effects from dermal exposures to bystanders because bystanders are not dermally exposed to PCE. A full description of EPA's unreasonable risk determination for each condition of use is in Section 5.2.

Summary of Unreasonable Risk Determinations: In conducting risk evaluations, "EPA will determine whether the chemical substance presents an unreasonable risk of injury to health or the environment under each condition of use within the scope of the risk evaluation…" 40 CFR 702.47. Pursuant to TSCA section 6(i)(1), a determination of "no unreasonable risk" shall be issued by order and considered to be final agency action. Under EPA's implementing regulations, "[a] determination by EPA that the chemical substance, under one or more of the conditions of use within the scope of the risk evaluation, does not present an unreasonable risk of injury to health or the environment will be issued by order and considered to be a final Agency action, effective on the date of issuance of the order." 40 CFR 702.49(d).

EPA has determined that the following conditions of use of PCE do not present an unreasonable risk of injury to health or the environment. These determinations are considered final agency action and are being issued by order pursuant to TSCA section 6(i)(1). The details of these determinations are in Section 5.2, and the TSCA section 6(i)(1) order is contained in Section 5.4.1 of this final Risk Evaluation.

Conditions of Use that Do Not Present an Unreasonable Risk
• Distribution in commerce • Industrial and commercial use in lubricants and greases as solvent for penetrating lubricants and cutting tool coolants

EPA has determined that the following conditions of use of PCE present an unreasonable risk of injury. EPA will initiate TSCA section 6(a) risk management actions on these conditions of use as required under TSCA section 6(c)(1). Pursuant to TSCA section 6(i)(2), the unreasonable risk determinations for these conditions of use are not considered final agency action. The details of these determinations are in Section 5.2.

Manufacturing that Presents an Unreasonable Risk

- Manufacturing (domestic manufacturing)
- Manufacturing (import)

Processing that Present an Unreasonable Risk

- As a reactant/intermediate
- Incorporation into formulation, mixture or reaction product in cleaning and degreasing products
- Incorporation into formulation, mixture or reaction product in adhesive and sealant products
- Incorporation into formulation, mixture or reaction product in paint and coating products
- Incorporation into formulation, mixture or reaction product in other chemical products and preparations
- Repackaging
- Recycling

Industrial and Commercial Uses that Present an Unreasonable Risk

- Industrial and commercial use as solvent for open-top batch vapor degreaser
- Industrial and commercial use as solvent for closed-loop batch vapor degreaser
- Industrial and commercial use as solvent for in-line conveyorized vapor degreaser
- Industrial and commercial use as solvent for in-line web cleaner vapor degreaser
- Industrial and commercial use as solvent for cold cleaning
- Industrial and commercial use as solvent for aerosol spray degreaser/cleaner
- Industrial and commercial use as a lubricant and grease in aerosol lubricants
- Industrial and commercial use as an adhesive and sealant in solvent-based adhesives and sealants
- Industrial and commercial use in paints and coatings as solvent-based paints and coatings
- Industrial and commercial use in paints and coatings as a maskant for chemical milling
- Industrial and commercial use as a processing aid in pesticide, fertilizer and other agricultural chemical manufacturing
- Industrial and commercial use as a processing aid in catalyst regeneration in petrochemical manufacturing
- Industrial and commercial use in cleaning and furniture care products in wipe cleaning
- Industrial and commercial use in cleaning and furniture care products in other spot cleaning and spot removers, including carpet cleaning
- Industrial and commercial use in cleaning and furniture care products for mold release
- Industrial and commercial use in cleaning and furniture care products in dry cleaning and spot cleaning post-2006 dry cleaning
- Industrial and commercial use in cleaning and furniture care products in dry cleaning and spot cleaning $4^{th}/5^{th}$ gen only dry cleaning
- Industrial and commercial use in cleaning and furniture care products in automotive care products (*e.g.*, engine degreaser and brake cleaner)
- Industrial and commercial use in cleaning and furniture care products in non-aerosol cleaner
- Industrial and commercial use in metal (*e.g.*, stainless steel) and stone polishes
- Industrial and commercial use in laboratory chemicals
- Industrial and commercial use in welding
- Industrial and commercial use in other textile processing
- Industrial and commercial use in wood furniture manufacturing

- Industrial and commercial use in foundry applications
- Industrial and commercial use in specialty Department of Defense uses (oil analysis and water pipe repair)
- Commercial use in inks and ink removal products (based on printing)
- Commercial use in inks and ink removal products (based on photocopying)
- Commercial use for photographic film
- Commercial use in mold cleaning, release and protectant products

Consumer Uses that Present an Unreasonable Risk

- Consumer use in cleaning and furniture care products in cleaners and degreasers (other)
- Consumer use in cleaning and furniture care products in dry cleaning solvent
- Consumer use in cleaning and furniture care products in automotive care products (brake cleaner)
- Consumer use in cleaning and furniture care products in automotive care products (parts cleaner)
- Consumer use in cleaning and furniture care products in aerosol cleaner (vandalism mark and stain remover)
- Consumer use in cleaning and furniture care products in non-aerosol cleaner (*e.g.*, marble and stone polish)
- Consumer use in lubricants and greases (cutting oils)
- Consumer use in lubricants and greases (lubricants and penetrating oils)
- Consumer use in adhesives for arts and crafts (including industrial adhesive, arts and crafts adhesive, gun ammunition sealant)
- Consumer use in adhesives for arts and crafts (livestock grooming adhesive)
- Consumer use in adhesives for arts and crafts (column adhesive, caulk and sealant)
- Consumer use in paints and coatings as solvent-based paints and coatings (outdoor water shield (liquid))
- Consumer use in paints and coatings as solvent-based paints and coatings (coatings and primers (aerosol))
- Consumer use in paints and coatings as solvent-based paints and coatings (rust primer and sealant (liquid))
- Consumer use in paints and coatings as solvent-based paints and coatings (metallic overglaze)
- Consumer use in metal (*e.g.*, stainless steel) and stone polishes
- Consumer use in inks and ink removal products
- Consumer use in welding
- Consumer use in mold cleaning, release and protectant products

Disposal that Presents an Unreasonable Risk

- Disposal

1 INTRODUCTION

This document represents the final Risk Evaluation for PCE under the Frank R. Lautenberg Chemical Safety for the 21st Century Act. The Frank R. Lautenberg Chemical Safety for the 21st Century Act amended the Toxic Substances Control Act, the Nation's primary chemicals management law, in June 2016.

The Environmental Protection Agency (EPA) published the Scope of the Risk Evaluation for PCE in June 2017 (U.S. EPA, 2017h), and the Problem Formulation in June 2018 (U.S. EPA, 2018d), which represented the analytical phase of risk evaluation in which "the purpose for the assessment is articulated, the problem is defined, and a plan for analyzing and characterizing risk is determined" as described in Section 2.2 of the Framework for Human Health Risk Assessment to Inform Decision Making (U.S. EPA, 2014c). The Problem Formulation identified conditions of use and presented three conceptual models and an analysis plan. Based on EPA's analysis of the conditions of use, physical-chemical and fate properties, environmental releases, and exposure pathways, the Problem Formulation preliminarily concluded that further analysis was necessary for exposure pathways to aquatic receptors exposed via surface water, workers, and consumers. EPA received comments on the published Problem Formulation for PCE and has considered the comments specific to PCE, as well as more general comments regarding EPA's chemical risk evaluation approach for the first 10 chemicals EPA is evaluating. EPA subsequently published the draft Risk Evaluation for PCE in April 2020 and has taken public and peer review comments. The conclusions, findings, and determinations in this final Risk Evaluation are for the purpose of identifying whether the chemical substance presents unreasonable risk or no unreasonable risk under the conditions of use, in accordance with TSCA Section 6, and are not intended to represent any findings under TSCA Section 7.

In this risk evaluation, Section 1 presents the basic physical-chemical characteristics of PCE, as well as a background on regulatory history, conditions of use, and conceptual models, with particular emphasis on any changes since the publication of the Problem Formulation and draft Risk Evaluation. This section also includes a discussion of the systematic review process utilized in this risk evaluation. Section 2 provides a discussion and analysis of the exposures, both human and environmental, that can be expected based on the conditions of use for PCE. Section 3 discusses human health and environmental hazards of PCE. Section 4 presents the risk characterization, where EPA integrates and assesses reasonably available information on human health and environmental hazards and exposures, as required by TSCA (15 U.S.C. 2605(b)(4)(F)). This section also includes a discussion of any uncertainties and how they impact the risk evaluation. Section 5 presents EPA's determination of whether the chemical presents an unreasonable risk under the conditions of use, as required under TSCA (15 U.S.C. 2605(b)(4)).

As per EPA's final rule, (U.S. EPA, 2017c), this risk evaluation was subject to both public comment and peer review, which are distinct but related processes. EPA provided 60 days for public comment on all aspects of this risk evaluation. This satisfies TSCA (15 U.S.C. 2605(b)(4)(H)), which requires EPA to provide public notice and an opportunity for comment on a draft Risk Evaluation prior to publishing a final Risk Evaluation.

Peer review was conducted in accordance with EPA's regulatory procedures for chemical risk evaluations, including using the EPA Peer Review Handbook (U.S. EPA, 2015a) and other methods consistent with section 26 of TSCA (*See* 40 CFR 702.45). As explained in the Risk Evaluation Rule

(U.S. EPA, 2017c), the purpose of peer review is for the independent review of the science underlying the risk assessment. As such, peer review addressed aspects of the underlying science as outlined in the charge to the peer review panel such as hazard assessment, assessment of dose-response, exposure assessment, and risk characterization.

As EPA explained in the Risk Evaluation Rule (U.S. EPA, 2017c), it is important for peer reviewers to consider how the underlying risk evaluation analyses fit together to produce an integrated risk characterization, which forms the basis of an unreasonable risk determination. EPA believes peer reviewers will be most effective in this role if they receive the benefit of public comments on draft Risk Evaluations prior to peer review. For this reason, the public comment period opened prior to peer review. The final Risk Evaluation changed in response to public comments received on the draft Risk Evaluation and/or in response to peer review, which itself may be informed by public comments. EPA responded to public and peer review comments received on the draft Risk Evaluation and explained changes made in response to those comments in this final Risk Evaluation and the associated response to comments document.

EPA also solicited input on the first 10 chemicals as it developed use documents, scope documents, Problem Formulations, and draft Risk Evaluations. At each step, EPA has received information and comments specific to individual chemicals and of a more general nature relating to various aspects of the risk evaluation process, technical issues, and the regulatory and statutory requirements. EPA has considered comments and information received at each step in the process and factored in the information and comments as the Agency deemed appropriate and relevant including comments on the draft Risk Evaluation of PCE.

1.1 Physical and Chemical Properties

Physical-chemical properties influence the environmental behavior and the toxic properties of a chemical, thereby informing the potential conditions of use, exposure pathways, routes, and hazards being evaluated. A summary of the physical-chemical properties of PCE is set forth in Table 1-1.

Table 1-1. Physical and Chemical Properties of PCE

Property	Value[a]	References	Data Quality Rating
Molecular formula	C_2Cl_4		
Molecular weight	165.833		
Physical form	Colorless liquid; chloroform-like odor	Lewis (2007); NIOSH (2005); U.S. Coast Guard (1984)	High
Melting point	-22.3°C	Lide (2007)	High
Boiling point	121.3°C	Lide (2007)	High
Density	1.623 g/cm^3 at 20°C	Lide (2007)	High
Vapor pressure	18.5 mmHg at 25°C	Riddick et al. (1985)	High
Vapor density	5.83 (relative to air)	(Lewis, 1992)	High
Water solubility	206 mg/L at 20°C	Horvath (1982)	High
Octanol:water partition coefficient (log K_{OW})	3.40	Hansch et al. (1995)	High
Octanol:air partition coefficient (log K_{OA})	3.48	(U.S. EPA, 2012a)	High
Henry's Law constant	0.0177 atm-m^3/mole at 25°C (equivalent to 0.724 dimensionless)	Gossett (1987)	High
Flash point	Not applicable	Nfpa (2010)	High
Autoflammability	Not readily available		
Viscosity	0.839 cP at 25°C	Hickman (2000)	High
Refractive index	1.4775	Lide (2007)	High
Dielectric constant	2.30 at 25°C	(Lange and Dean, 1985)	High

[a] Measured unless otherwise noted.

1.2 Uses and Production Volume

The uses of PCE include the production of fluorinated compounds, dry cleaning and vapor degreasing, as well as a number of less produced uses. Nearly 65% of the production volume of PCE is used as an intermediate in industrial gas manufacturing, producing fluorinated compounds, such as hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) (NTP, 2014) (Icis, 2011). HFCs 134a and 125 are alternatives to chlorofluorocarbons (CFCs) and HCFCs, which are ozone depleting substances (ODSs), and the subject of a phase-out (https://www.epa.gov/ods-phaseout). HCFCs are transitional substances in the phase-out of ODSs (Icis, 2011), (Fay, 2017). Previously, PCE was widely used to manufacture CFCs (especially trichlorotrifluoroethane (CFC-113)) until production and importation of CFCs for most uses were phased out in the United States under the Montreal Protocol (40

CFR part 82). A relatively small amount of CFC-113 is still produced for exempted uses (EPA teleconference with Honeywell, 2017; summary is available in the docket: EPA-HQ-OPPT-2016-0732).

The second largest use of PCE (~15%) is as a solvent in dry cleaning facilities (NTP, 2014). PCE is non-flammable and effectively dissolves fats, greases, waxes and oils, without harming natural or human-made fibers. These properties enabled it to replace traditional petroleum solvents (ATSDR, 2014; Dow Chemical Co, 2008; Tirsell, 2000). The demand for PCE dry cleaning solvents has steadily declined as a result of the improved efficiency of dry cleaning equipment, increased chemical recycling and the popularity of wash-and-wear fabrics that eliminate the need for dry cleaning (ATSDR, 2019). PCE is also used in dry cleaning detergent and dry cleaning sizing.

Approximately 60% of dry cleaning machines in the United States use PCE as a solvent (DLI/NCA, 2017). However, there appears to have be a trend towards alternatives to PCE in dry cleaning. In 1991, EPA had estimated that 83% of all dry cleaning facilities used PCE as solvent (U.S. EPA, 1991b). In 2008, the Halogenated Solvents Industry Association (HSIA) estimated that 70% of dry cleaners used PCE (Graul, 2017) and a 2011 King County, WA profile of the dry cleaning industry found that 69% of respondents (105 of the 152 respondents) used PCE (Whittaker and Johanson, 2011). According to the dry cleaning industry, a majority of new PCE dry cleaning machines are sold in locations where "local fire codes preclude the use of Class III combustible alternative solvents or [where] the nature of the operation demands the use of PCE" (DLI/NCA, 2017).

The third largest use of PCE (~10%) is as a vapor degreasing solvent (NTP, 2014). PCE can be used to dissolve many organic compounds, select inorganic compounds and high-melting pitches and waxes making it useful for cleaning contaminated metal parts and other fabricated materials (ATSDR, 2019). It is a very good solvent for greases, fats, waxes, oils, bitumen, tar and many natural and synthetic resins for use in chemical cleaning systems, degreasing light and heavy metals, degreasing pelts and leather (tanning), extraction of animal and vegetable fats and oils and textile dyeing (solvent for dye baths) (Stoye, 2000). PCE is also used in cold cleaning, which is similar to vapor degreasing, except that cold cleaning does not require the solvent to be heated to its boiling point in order to clean a given component. Vapor degreasing and cold cleaning scenarios may include a range of open-top or closed systems, conveyorized/enclosed/inline systems, spray wands, dip containers and wipes.

PCE has many other uses, which collectively constitute ~10% of the production volume. EPA's search of safety data sheets, government databases and other sources found over 375 products containing PCE. These uses include (but are not limited to):

- Adhesives
- Aerosol degreasing
- Brake cleaner
- Laboratories
- Lubricants
- Mold cleaners, releases and protectants
- Oil refining
- Sealants
- Stainless steel polish
- Tire buffers and cleaners
- Vandal mark removers

Many of these uses include consumer products, such as adhesives (arts and crafts, as well as light repairs), aerosol degreasing, brake cleaners, aerosol lubricants, sealants, sealants for gun ammunition, stone polish, stainless steel polish and wipe cleaners. The uses of PCE in consumer adhesives and brake cleaners are especially prevalent; EPA has found 16 consumer adhesive products and 14 consumer brake cleaners containing PCE (see (U.S. EPA, 2017e)).

The Chemical Data Reporting (CDR) Rule under TSCA requires U.S. manufacturers and importers to provide EPA with information on the chemicals they manufacture or import into the United States. For the 2016 CDR cycle, data collected per chemical include the company name, volume of each chemical manufactured/imported, the number of workers at each site, and information on whether the chemical is used in the commercial, industrial, and/or consumer sector. However, only companies that manufactured or imported 25,000 pounds or more at each of their sites during the 2015 calendar year were required to report information under the CDR rule (U.S. EPA, 2016d).

The 2016 CDR (reporting period from 2012 to 2015) data for PCE are provided in Table 1-2 from EPA's CDR database (U.S. EPA, 2016c).

Table 1-2. Production Volume of PCE in CDR Reporting Period (2012 to 2015) [a]

Reporting Year	2012	2013	2014	2015
Total Aggregate Production Volume (lbs)	387,623,401	391,403,540	355,305,850	324,240,744

[a] The CDR data for the 2016 reporting period is available via ChemView (https://chemview.epa.gov/chemview) (ChemView, 2019). The CDR data presented in the risk evaluation is more specific than currently available in ChemView.

1.3 Regulatory and Assessment History

EPA conducted a search of existing domestic and international laws, regulations and assessments pertaining to PCE. EPA compiled this summary from data available from federal, state, international and other government sources, as cited in Appendix A.

Federal Laws and Regulations

PCE is subject to federal statutes or regulations, other than TSCA, that are implemented by other offices within EPA and/or other federal agencies/departments. A summary of federal laws, regulations and implementing authorities is provided in Appendix A.

State Laws and Regulations

PCE is subject to state statutes or regulations implemented by state agencies or departments. A summary of state laws, regulations and implementing authorities is provided in Appendix A.

Laws and Regulations in Other Countries and International Treaties or Agreements

PCE is subject to statutes or regulations in countries other than the United States. A summary of these laws and regulations is provided in Appendix A.

1.3.1 Assessment History

EPA identified numerous previous assessments conducted by Agency programs and other organizations (see Table 1-3). Depending on the source, these assessments may include information on conditions of use, hazards, exposures and potentially exposed or susceptible subpopulations. EPA found no additional assessments beyond those listed in the Problem Formulation document.

Table 1-3. Assessment History of PCE

Authoring Organization	Assessment
EPA Assessments	
Integrated Risk Information System (IRIS)	Toxicological Review of Tetrachloroethylene (Perchloroethylene) (CAS No. 127-18-4) (U.S. EPA, 2012d)
Office of Air Quality Planning and Standards (OAQPS)	Perchloroethylene Dry Cleaners Refined Human Health Risk Characterization (U.S. EPA, 2005c)
National Center for Environmental Assessment (NCEA)	Sources, Emission and Exposure for Trichloroethylene (TCE) and Related Chemicals (U.S. EPA, 2001)
Office of Air Toxics	Tetrachloroethylene (PCE, Perchloroethylene); 127-18-4 (U.S. EPA, 2000)
Office of Pesticides and Toxic Substances (now, Office of Chemical Safety and Pollution Prevention [OCSPP])	Occupational Exposure and Environmental Release Assessment of Tetrachloroethylene (U.S. EPA, 1985b)
Office of Health and Environmental Assessment	Final Health Effects Criteria Document for Tetrachloroethylene (U.S. EPA, 1985a)
Office of Water (OW)	Update of Human Health Ambient Water Quality Criteria: Tetrachloroethylene (Perchloroethylene) 127-18-4 (U.S. EPA, 2015b)
Office of Water (OW)	Ambient Water Quality Criteria for Tetrachloroethylene (U.S. EPA, 1980)
Other U.S.-Based Organizations	
California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (OEHHA), Air Toxics Hot Spots Program	Perchloroethylene Inhalation Cancer Unit Risk Factor (OEHHA, 2016)
Agency for Toxic Substances and Disease Registry (ATSDR)	Toxicological Profile for Tetrachloroethylene (PERC) (ATSDR, 2019)
National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances (NAC/AEGL Committee)	Tetrachloroethylene (NAC/AEGL, 2009)
California Environmental Protection Agency, OEHHA, Pesticide and Environmental Toxicology Section	Public Health Goal for Tetrachloroethylene in Drinking Water (OEHHA, 2001)
National Toxicology Program (NTP)	Toxicology and Carcinogenesis Studies of Tetrachloroethylene (Perchloroethylene); (CAS No. 127-18-4) in F344/N Rats and B6C3F1 Mice (NTP, 1986a)

Authoring Organization	Assessment
National Institute for Occupational Safety and Health (NIOSH)	Criteria for a recommended standard occupational exposure to tetrachloroethylene (perchloroethylene) (NIOSH, 1976)
International	
International Agency for Research on Cancer (IARC)	IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Tetrachloroethylene (IARC, 2014)
European Union (EU), Scientific Committee on Health and Environmental Risks (SCHER)	SCHER, Scientific Opinion on the Risk Assessment Report on Tetrachloroethylene, Human Health Part, CAS No.: 127-18-4, 12 (Scher, 2008)
World Health Organization (WHO)	Concise International Chemical Assessment Document 68; Tetrachloroethylene (WHO, 2006a)
EU, European Chemicals Bureau (ECB)	EU Risk Assessment Report; Tetrachloroethylene, Part 1 - environment (ECB, 2005)
National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Australia	Tetrachloroethylene; Priority Existing Chemical Assessment Report No. 15 (NICNAS, 2001)

1.4 Scope of the Evaluation

1.4.1 Conditions of Use Included in the Risk Evaluation

TSCA § 3(4) defines the conditions of use (COUs) as ‘‘the circumstances, as determined by the Administrator, under which a chemical substance is intended, known, or reasonably foreseen to be manufactured, processed, distributed in commerce, used, or disposed of.” The COUs for PCE are described below in Table 1-4. After publication of the Problem Formulation document (U.S. EPA, 2018d), EPA further analyzed the “Processing – Incorporated into Articles” category and determined that PCE is not incorporated into articles but is used as a degreaser to clean parts used in articles; therefore, this category of use was removed from the risk evaluation. EPA also added Department of Defense (DoD) uses to the “Other Industrial Uses” category. These uses were assessed in the draft Risk Evaluation but were not mapped to any of the existing categories of conditions of use. After further evaluation, EPA determined that these uses best fit into the “Other Industrial Uses” category. These changes are reflected in Table 1-4 and the life cycle diagram in Figure 1-1. EPA has not exercised its authority in TSCA section 6(b)(4)(D) to exclude any PCE conditions of use from the scope of the PCE risk evaluation. Figure 1-2 shows a breakdown of the production volume by uses according to HSIA (2008).

To help characterize the life cycle of PCE, EPA developed a national mass balance to evaluate how much of the volume of PCE can be accounted for from cradle-to-grave. The inputs into the mass balance included data from the 2016 CDR, 2017 National Emissions Inventory (NEI), 2017 Toxics Release Inventory (TRI), and available market data. The result of the mass balance is provided in Figure 1-3. The total mass accounted for at the end-of-life stage, which includes wastes from manufacturing, processing, use, waste treatment and disposal facilities, is approximately 89% of the 2015 production volume. The unaccounted-for volume is likely due to a combination of the following:

- Limitations in reporting requirements for NEI and TRI causing wastes and emissions from certain sites to go unreported.
- Uncertainty in the total accounted for volume due to combining data from different years.
- Uncertainty arising from the potential to double count TRI volumes reported as transferred off-site for energy recovery, treatment, and recycling that are then received by another TRI site that reports this volume in its on-site waste management activities.
- Undercounting the true export volume due to seven sites claiming their export volume as Confidential Business Information (CBI) in the 2016 CDR.

Additional details on the development of the mass balance can be found in Appendix C.

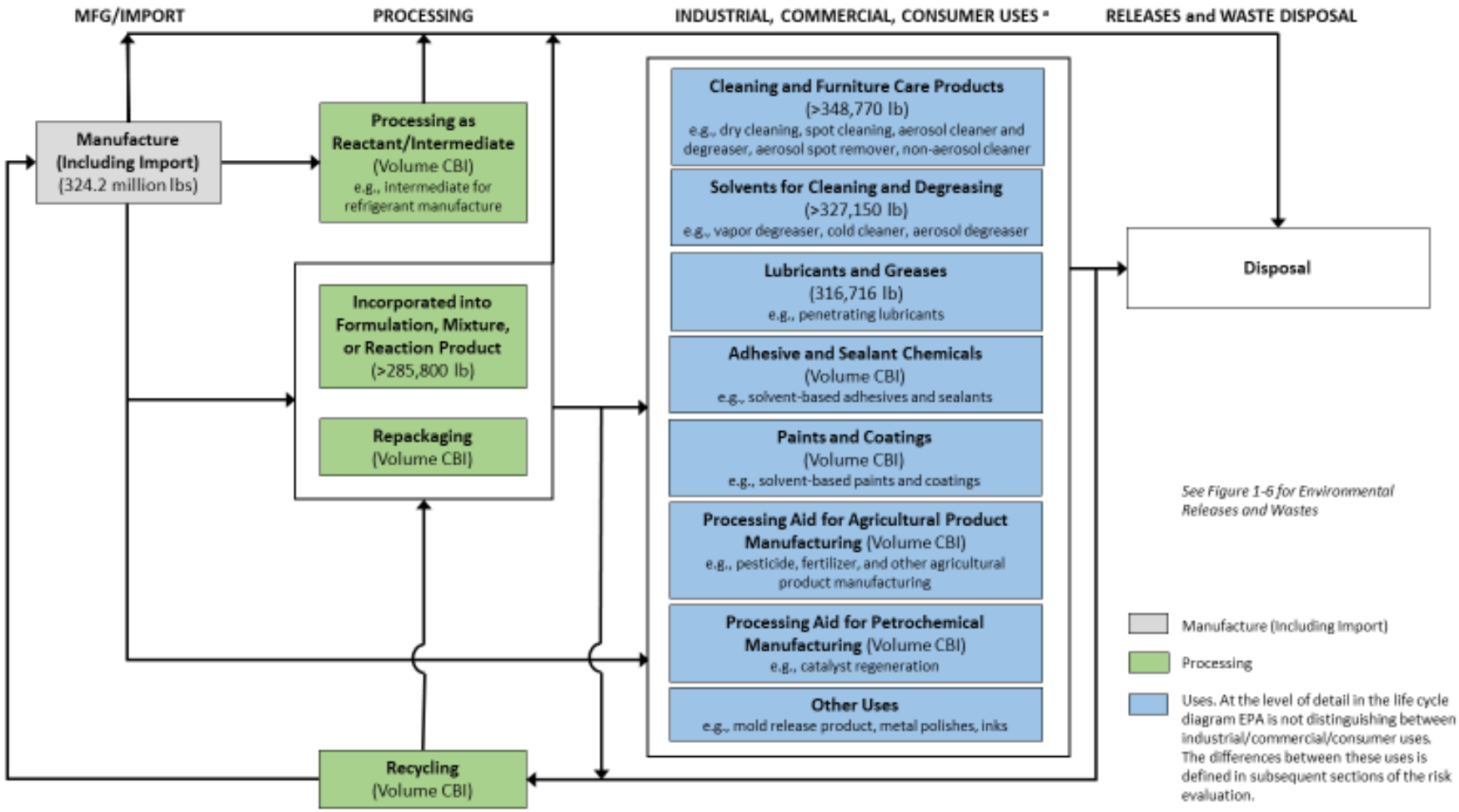


Figure 1-1. PCE Life Cycle Diagram

The life cycle diagram depicts the conditions of use that are within the scope of the risk evaluation during various life cycle stages including manufacturing, processing, use (industrial, commercial, or consumer) and disposal. The production volumes shown are for reporting year 2015 from the 2016 CDR reporting period (Table 1-2) (U.S. EPA, 2016c). Activities related to distribution (*e.g.*, loading, unloading) will be considered throughout the PCE life cycle, rather than using a single distribution scenario.

[a] See Table 1-4 for additional uses not mentioned specifically in this diagram.

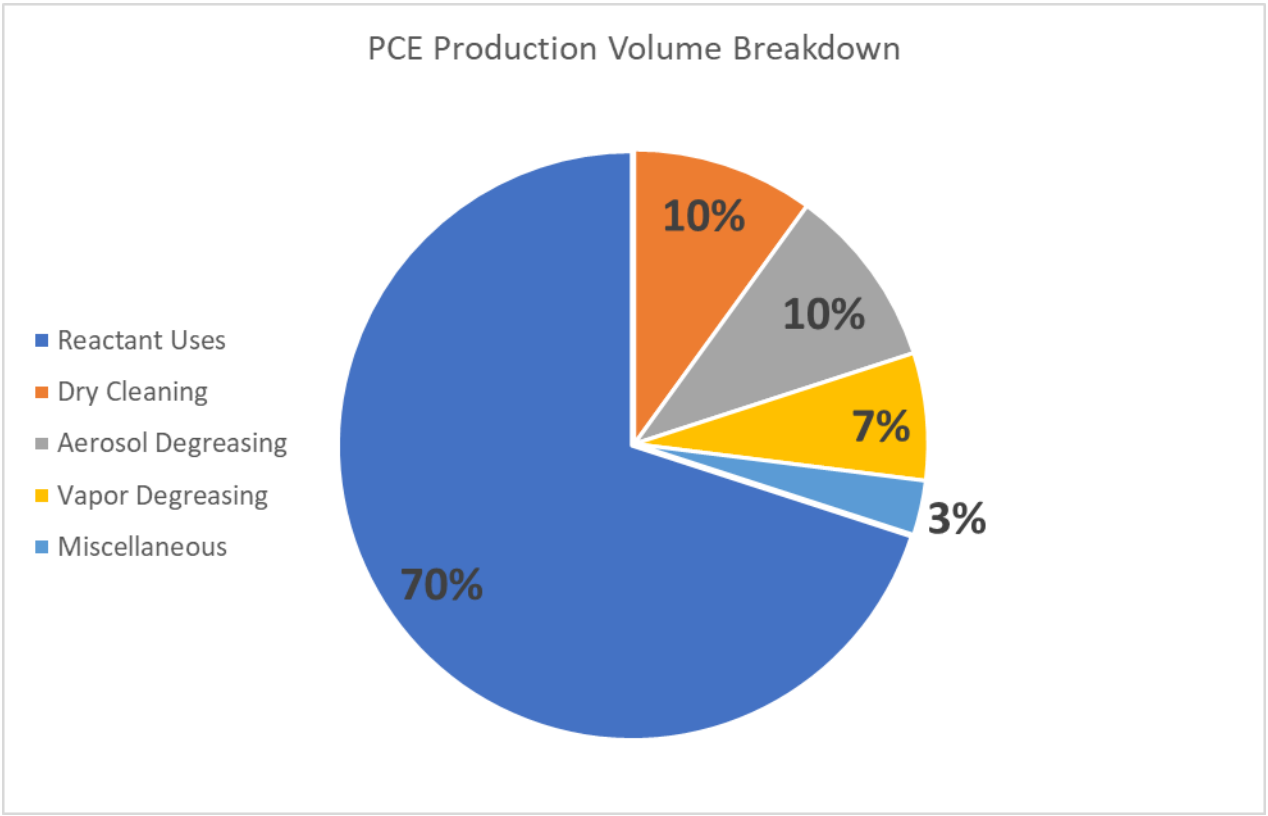


Figure 1-2. Breakdown of Perchloroethylene Production Volume by Uses According to HSIA (2008)

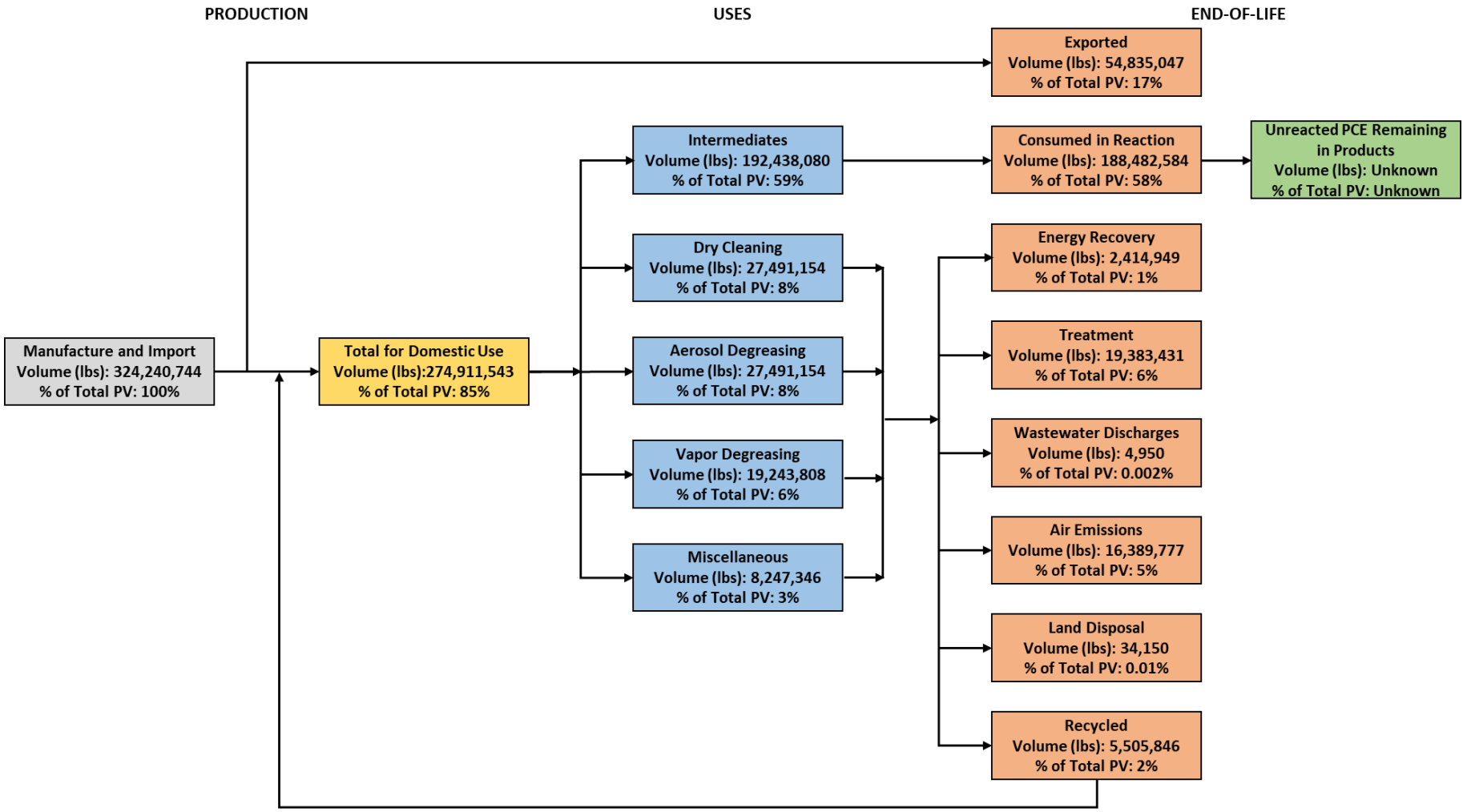


Figure 1-3. Mass Balance for Perchloroethylene

Table 1-4. Categories and Subcategories of Conditions of Use Included in the Scope of the Risk Evaluation[4]

Life Cycle Stage	Category [a]	Subcategory [b]	References
Manufacture	Domestic manufacture	Domestic manufacture	(U.S. EPA, 2016c)
	Import	Import	(U.S. EPA, 2016c)
Processing	Processing as a reactant or intermediate	Intermediate in industrial gas manufacturing	(U.S. EPA, 2016c); (U.S. EPA, 2017e); (Krock, 2017a); (Krock, 2017b); (Cooper, 2017); (Fay, 2017)
		Intermediate in basic organic chemical manufacturing	(U.S. EPA, 2016b), (U.S. EPA, 2017e);
		Intermediate in petroleum refineries	(U.S. EPA, 2016b); (U.S. EPA, 2017e);(Cooper, 2017)
		Reactant use	(Krock, 2017a); (Krock, 2017b);
	Incorporated into formulation, mixture or reaction product	Cleaning and degreasing products	(U.S. EPA, 2016b); (Rudnick, 2017a), (Rudnick, 2017b)
		Adhesive and sealant products	(U.S. EPA, 2016b)
		Paint and coating products	(U.S. EPA, 2016b)
		Other chemical products and preparations	(U.S. EPA, 2016b)
	Repackaging	Solvent for cleaning or degreasing	(U.S. EPA, 2016b)
		Intermediate	(U.S. EPA, 2016b)
	Recycling	Recycling	(U.S. EPA, 2016b)
Distribution in commerce	Distribution	Distribution	(U.S. EPA, 2017e)
Industrial use	Solvents (for cleaning or degreasing)	Solvents and/or degreasers (cold, aerosol spray or vapor degreaser; not specified in comment)	(U.S. EPA, 2017e); (Holmes, 2017); (Tatman, 2017)
		Batch vapor degreaser (*e.g.*, open-top, closed-loop)	(U.S. EPA, 1985b); (Riegle, 2017); (HSIA, 2018b)
		In-line vapor degreaser (*e.g.*, conveyorized, web cleaner)	(U.S. EPA, 1985b); (Dowell, 2017)

[4] Although EPA has identified both industrial and commercial uses here for purposes of distinguishing scenarios in this document, the Agency interprets the authority over "any manner or method of commercial use" under TSCA section 6(a)(5) to reach both.

Life Cycle Stage	Category [a]	Subcategory [b]	References
	Solvents (for cleaning or degreasing)	Cold cleaner	(U.S. EPA, 2017e); (Rudnick, 2017a), (Rudnick, 2017b)
		Aerosol spray degreaser/cleaner	(U.S. EPA, 2017e); (U.S. EPA, 2017e); (Sass, 2017); (Rudnick, 2017a), (Rudnick, 2017b)
		Dry cleaning solvent	(U.S. EPA, 2017e); (U.S. EPA, 2006b)
		Spot cleaner	(U.S. EPA, 2017e); (Sass, 2017)
	Lubricants and greases	Lubricants and greases - aerosol lubricants	(U.S. EPA, 2016b); (U.S. EPA, 2017e); (HSIA, 2018b); (Tatman, 2017); (HSIA, 2018b); (Tatman, 2017)
		Lubricants and greases - penetrating lubricants, cutting tool coolants	
	Adhesive and sealant chemicals	Solvent-based adhesives and sealants	(U.S. EPA, 2016b); (U.S. EPA, 2017e); (U.S. EPA, 2017e); (Sass, 2017); (Riegle, 2017); (Holmes, 2017); (HSIA, 2018b)
	Paints and coatings including paint and coating removers	Solvent-based paints and coatings, including for chemical milling	(U.S. EPA, 2016b); (U.S. EPA, 2017e); (Sass, 2017); (Riegle, 2017); (Davis, 2017); (HSIA, 2018b); (U.S. DOD, 2017)
	Processing aids, not otherwise listed	Pesticide, fertilizer and other agricultural chemical manufacturing	(U.S. EPA, 2016b)
	Processing aids, specific to petroleum production	Catalyst regeneration in petrochemical manufacturing	(U.S. EPA, 2016b); (U.S. EPA, 2017e); (Dow Chem, 2008); (Cooper, 2017); (HSIA, 2018b)
	Other uses	Textile processing	(U.S. EPA, 2017e)
		Wood furniture manufacturing	(U.S. EPA, 2017e)
		Laboratory chemicals	(U.S. EPA, 2017e); (Riegle, 2017)
		Foundry applications	(U.S. EPA, 2017e)
		Other DOD uses	(U.S. DOD and Environmental Health Readiness System - Industrial, 2018)

Life Cycle Stage	Category [a]	Subcategory [b]	References
Commercial/ consumer use	Cleaning and furniture care products	Cleaners and degreasers (other)	(U.S. EPA, 2017e); (Sass, 2017); (Rudnick, 2017a), (Rudnick, 2017b); (Holmes, 2017); (McCormick, 2017); (HSIA, 2018b); (Tatman, 2017)
		Dry cleaning solvent	(U.S. EPA, 2017e);(U.S. EPA, 2006b); (DLI/NCA, 2017); (Sass, 2017)
		Spot cleaner	(U.S. EPA, 2017e); (U.S. EPA, 2006b); (Sass, 2017)
		Automotive care products (*e.g.*, engine degreaser and brake cleaner)	U.S. EPA (2016d), (U.S. EPA, 2017e); (Rudnick, 2017a), (Rudnick, 2017b); (HSIA, 2018b)
		Aerosol cleaner	(U.S. EPA, 2017e); (Sass, 2017)
		Non-aerosol cleaner	(U.S. EPA, 2017e); (Sass, 2017)
	Lubricants and greases	Lubricants and greases (*e.g.*, penetrating lubricants, cutting tool coolants, aerosol lubricants)	(U.S. EPA, 2016b); (U.S. EPA, 2017e); (HSIA, 2018b); (Tatman, 2017)
	Adhesives and sealant chemicals	Adhesives for arts and crafts	(U.S. EPA, 2016b); (U.S. EPA, 2017e); (Sass, 2017)
		Light repair adhesives	(U.S. EPA, 2016b); (U.S. EPA, 2017e)
	Paints and coatings	Solvent-based paints and coatings	(U.S. EPA, 2016b); (U.S. EPA, 2017e); (Sass, 2017); (Davis, 2017); (HSIA, 2018b)
	Other uses	Carpet cleaning	(U.S. EPA, 2017e); (Sass, 2017)
		Laboratory chemicals	(U.S. EPA, 2017e)
		Metal (*e.g.*, stainless steel) and stone polishes	(U.S. EPA, 2017e)
		Inks and ink removal products	(U.S. EPA, 2017e)
		Welding	(U.S. EPA, 2017e)
		Photographic film	(U.S. EPA, 2017e)
		Mold cleaning, release and protectant products	(U.S. EPA, 2017e); (Rudnick, 2017a), (Rudnick, 2017b)
Disposal	Disposal	Industrial pre-treatment	(U.S. EPA, 2017e)
		Industrial wastewater treatment	

Life Cycle Stage	Category [a]	Subcategory [b]	References
		Publicly owned treatment works (POTW)	
		Underground injection	
		Municipal solid waste landfill	
		Hazardous waste landfill	
		Other land disposal	
		Municipal waste incinerator	
		Hazardous waste incinerator	
		Off-site waste transfer	
		Off-site waste transfer	

[a] These categories of conditions of use appear in the life cycle diagram, reflect CDR codes and broadly represent conditions of use for PCE in consumer, industrial, and/or commercial settings.
[b] These subcategories reflect more specific uses of PCE.

1.4.2 Exposure Pathways and Risks Addressed by Other EPA-Administered Statutes[5]

In its TSCA section 6(b) risk evaluations, EPA is coordinating action on certain exposure pathways and risks falling under the jurisdiction of other EPA-administered statutes or regulatory programs. More specifically, EPA is exercising its TSCA authorities to tailor the scope of its risk evaluations, rather than focusing on environmental exposure pathways addressed under other EPA-administered statutes or regulatory programs or risks that could be eliminated or reduced to a sufficient extent by actions taken under other EPA-administered laws. EPA considers this approach to be a reasonable exercise of the Agency's TSCA authorities, which include:

- TSCA section 6(b)(4)(D): "The Administrator shall, not later than 6 months after the initiation of a risk evaluation, publish the scope of the risk evaluation to be conducted, including the hazards, exposures, conditions of use, and the potentially exposed or susceptible subpopulations the Administrator expects to consider…"
- TSCA section 9(b)(1): "The Administrator shall coordinate actions taken under this chapter with actions taken under other Federal laws administered in whole or in part by the Administrator. If the Administrator determines that a risk to health or the environment associated with a chemical substance or mixture could be eliminated or reduced to a sufficient extent by actions taken under the authorities contained in such other Federal laws, the Administrator shall use such authorities to protect against such risk unless the Administrator determines, in the Administrator's discretion, that it is in the public interest to protect against such risk by actions taken under this chapter."
- TSCA section 9(e): "…[I]f the Administrator obtains information related to exposures or releases of a chemical substance or mixture that may be prevented or reduced under another Federal law, including a law not administered by the Administrator, the Administrator shall make such information available to the relevant Federal agency or office of the Environmental Protection Agency."

[5] The statutory interpretations and approach described in this subsection will apply to all TSCA risk evaluations and are not limited in application to this final risk evaluation for PCE.

- TSCA section 2(c): "It is the intent of Congress that the Administrator shall carry out this chapter in a reasonable and prudent manner, and that the Administrator shall consider the environmental, economic, and social impact of any action the Administrator takes or proposes as provided under this chapter."
- TSCA section 18(d)(1): "Nothing in this chapter, nor any amendment made by the Frank R. Lautenberg Chemical Safety for the 21st Century Act, nor any rule, standard of performance, risk evaluation, or scientific assessment implemented pursuant to this chapter, shall affect the right of a State or a political subdivision of a State to adopt or enforce any rule, standard of performance, risk evaluation, scientific assessment, or any other protection for public health or the environment that— (i) is adopted or authorized under the authority of any other Federal law or adopted to satisfy or obtain authorization or approval under any other Federal law…"

TSCA authorities supporting tailored risk evaluations and intra-agency referrals

TSCA section 6(b)(4)(D)

TSCA Section 6(b)(4)(D) requires EPA, in developing the scope of a risk evaluation, to identify the hazards, exposures, conditions of use, and potentially exposed or susceptible subpopulations the Agency "expects to consider" in a risk evaluation. This language suggests that EPA is not required to consider all conditions of use, hazards, or exposure pathways in risk evaluations. In the Problem Formulation documents for many of the first 10 chemicals undergoing risk evaluation, EPA applied this authority and rationale to certain exposure pathways, explaining that "EPA is planning to exercise its discretion under TSCA 6(b)(4)(D) to focus its analytical efforts on exposures that are likely to present the greatest concern and consequently merit a risk evaluation under TSCA, by excluding, on a case-by-case basis, certain exposure pathways that fall under the jurisdiction of other EPA-administered statutes." This approach is informed by the legislative history of the amended TSCA, which supports the Agency's exercise of discretion to focus the risk evaluation on areas that raise the greatest potential for risk. See June 7, 2016 Cong. Rec., S3519-S3520. Consistent with the approach articulated in the Problem Formulation documents, and as described in more detail below, EPA is exercising its authority under TSCA to tailor the scope of exposures evaluated in TSCA risk evaluations, rather than focusing on environmental exposure pathways addressed under other EPA-administered, media-specific statutes and regulatory programs.

TSCA section 9(b)(1)

In addition to TSCA Section 6(b)(4)(D), the Agency also has discretionary authority under the first sentence of TSCA Section 9(b)(1) to "coordinate actions taken under [TSCA] with actions taken under other Federal laws administered in whole or in part by the Administrator." This broad, freestanding authority provides for intra-agency coordination and cooperation on a range of "actions." In EPA's view, the phrase "actions taken under [TSCA]" in the first sentence of Section 9(b)(1) is reasonably read to encompass more than just risk management actions, and to include actions taken during risk evaluation as well. More specifically, the authority to coordinate intra-agency actions exists regardless of whether the Administrator has first made a definitive finding of risk, formally determined that such risk could be eliminated or reduced to a sufficient extent by actions taken under authorities in other EPA-administered Federal laws, and/or made any associated finding as to whether it is in the public interest to protect against such risk by actions taken under TSCA. TSCA Section 9(b)(1) therefore provides EPA authority to coordinate actions with other EPA offices without ever making a risk finding or following an identification of risk. This includes coordination on tailoring the scope of TSCA risk evaluations to focus on areas of greatest concern rather than exposure pathways addressed by other EPA-administered statutes and regulatory programs, which does not involve a risk determination or public interest finding under TSCA Section 9(b)(2).

In a narrower application of the broad authority provided by the first sentence of TSCA Section 9(b)(1), the remaining provisions of Section 9(b)(1) provide EPA authority to identify risks and refer certain of those risks for action by other EPA offices. Under the second sentence of Section 9(b)(1), "[i]f the Administrator determines that a risk to health or the environment associated with a chemical substance or mixture could be eliminated or reduced to a sufficient extent by actions taken under the authorities contained in such other Federal laws, the Administrator shall use such authorities to protect against such risk unless the Administrator determines, in the Administrator's discretion, that it is in the public interest to protect against such risk by actions taken under [TSCA]." Coordination of intra-agency action on risks under TSCA Section 9(b)(1) therefore entails both an identification of risk, and a referral of any risk that could be eliminated or reduced to a sufficient extent under other EPA-administered laws to the EPA office(s) responsible for implementing those laws (absent a finding that it is in the public interest to protect against the risk by actions taken under TSCA).

Risk may be identified by OPPT or another EPA office, and the form of the identification may vary. For instance, OPPT may find that one or more conditions of use for a chemical substance present(s) a risk to human or ecological receptors through specific exposure routes and/or pathways. This could involve a quantitative or qualitative assessment of risk based on reasonably available information (which might include, *e.g.,* findings or statements by other EPA offices or other federal agencies). Alternatively, risk could be identified by another EPA office. For example, another EPA office administering non-TSCA authorities may have sufficient monitoring or modeling data to indicate that a particular condition of use presents risk to certain human or ecological receptors, based on expected hazards and exposures. This risk finding could be informed by information made available to the relevant office under TSCA Section 9(e), which supports cooperative actions through coordinated information-sharing.

Following an identification of risk, EPA would determine if that risk could be eliminated or reduced to a sufficient extent by actions taken under authorities in other EPA-administered laws. If so, TSCA requires EPA to "use such authorities to protect against such risk," unless EPA determines that it is in the public interest to protect against that risk by actions taken under TSCA. In some instances, EPA may find that a risk could be sufficiently reduced or eliminated by future action taken under non-TSCA authority. This might include, *e.g.,* action taken under the authority of the Safe Drinking Water Act to address risk to the general population from a chemical substance in drinking water. This sort of risk finding and referral could occur during the risk evaluation process, thereby enabling EPA to use a more relevant and appropriate authority administered by another EPA office to protect against hazards or exposures to affected receptors.

Legislative history on TSCA Section 9(b)(1) supports both broad coordination on current intra-agency actions, and narrower coordination when risk is identified and referred to another EPA office for action. A Conference Report from the time of TSCA's passage explained that Section 9 is intended "to assure that overlapping or duplicative regulation is avoided while attempting to provide for the greatest possible measure of protection to health and the environment." S. Rep. No. 94-1302 at 84. See also H. Rep. No. 114-176 at 28 (stating that the 2016 TSCA amendments "reinforce TSCA's original purpose of filling gaps in Federal law," and citing new language in Section 9(b)(2) intended "to focus the Administrator's exercise of discretion regarding which statute to apply and to encourage decisions that avoid confusion, complication, and duplication"). Exercising TSCA Section 9(b)(1) authority to coordinate on tailoring TSCA risk evaluations is consistent with this expression of Congressional intent.

Legislative history also supports a reading of Section 9(b)(1) under which EPA coordinates intra-agency action, including information-sharing under TSCA Section 9(e), and the appropriately positioned EPA office is responsible for the identification of risk and actions to protect against such risks. See, *e.g.,*

Senate Report 114-67, 2016 Cong. Rec. S3522 (under TSCA Section 9, "if the Administrator finds that disposal of a chemical substance may pose risks that could be prevented or reduced under the Solid Waste Disposal Act, the Administrator should ensure that the relevant office of the EPA receives that information"); H. Rep. No. 114-176 at 28, 2016 Cong. Rec. S3522 (under Section 9, "if the Administrator determines that a risk to health or the environment associated with disposal of a chemical substance could be eliminated or reduced to a sufficient extent under the Solid Waste Disposal Act, the Administrator should use those authorities to protect against the risk"). Legislative history on Section 9(b)(1) therefore supports coordination with and referral of action to other EPA offices, especially when statutes and associated regulatory programs administered by those offices could address exposure pathways or risks associated with conditions of use, hazards, and/or exposure pathways that may otherwise be within the scope of TSCA risk evaluations.

TSCA sections 2(c) & 18(d)(1)
Finally, TSCA Sections 2(c) and 18(d) support coordinated action on exposure pathways and risks addressed by other EPA-administered statutes and regulatory programs. Section 2(c) directs EPA to carry out TSCA in a "reasonable and prudent manner" and to consider "the environmental, economic, and social impact" of its actions under TSCA. Legislative history from around the time of TSCA's passage indicates that Congress intended EPA to consider the context and take into account the impacts of each action under TSCA. S. Rep. No. 94-698 at 14 ("the intent of Congress as stated in this subsection should guide each action the Administrator takes under other sections of the bill").

Section 18(d)(1) specifies that state actions adopted or authorized under any Federal law are not preempted by an order of no unreasonable risk issued pursuant to TSCA Section 6(i)(1) or a rule to address unreasonable risk issued under TSCA Section 6(a). Thus, even if a risk evaluation were to address exposures or risks that are otherwise addressed by other federal laws and, for example, implemented by states, the state laws implementing those federal requirements would not be preempted. In such a case, both the other federal and state laws, as well as any TSCA Section 6(i)(1) order or TSCA Section 6(a) rule, would apply to the same issue area. See also TSCA Section 18(d)(1)(A)(iii). In legislative history on amended TSCA pertaining to Section 18(d), Congress opined that "[t]his approach is appropriate for the considerable body of law regulating chemical releases to the environment, such as air and water quality, where the states have traditionally had a significant regulatory role and often have a uniquely local concern." Sen. Rep. 114-67 at 26.

EPA's careful consideration of whether other EPA-administered authorities are available and more appropriate for addressing certain exposures and risks is consistent with Congress' intent to maintain existing federal requirements and the state actions adopted to locally and more specifically implement those federal requirements, and to carry out TSCA in a reasonable and prudent manner. EPA believes it is both reasonable and prudent to tailor TSCA risk evaluations in a manner reflective of expertise and experience exercised by other EPA and State offices to address specific environmental media, rather than attempt to evaluate and regulate potential exposures and risks from those media under TSCA. This approach furthers Congressional direction and EPA aims to efficiently use Agency resources, avoid duplicating efforts taken pursuant to other Agency and State programs, and meet the statutory deadline for completing risk evaluations.

<u>EPA-administered statutes and regulatory programs that address specific exposure pathways and/or risks</u>
During the course of the risk evaluation process for PCE, OPPT worked closely with the offices within EPA that administer and implement regulatory programs under the Clean Air Act (CAA), the Safe Drinking Water Act (SDWA), the Clean Water Act (CWA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Resource Conservation and Recovery

Act (RCRA). Through intra-agency coordination, EPA determined that specific exposure pathways are well-regulated by the EPA statutes and regulations described in the following paragraphs.

Ambient Air Pathway
The CAA contains a list of hazardous air pollutants (HAP) and provides EPA with the authority to add to that list pollutants that present, or may present, a threat of adverse human health effects or adverse environmental effects. For stationary source categories emitting HAP, the CAA requires issuance of technology-based standards and, if necessary, additions or revisions to address developments in practices, processes, and control technologies, and to ensure the standards adequately protect public health and the environment. The CAA thereby provides EPA with comprehensive authority to regulate emissions to ambient air of any hazardous air pollutant.

PCE is a HAP. See 42 U.S.C. 7412. EPA has issued a number of technology-based standards for source categories that emit PCE to ambient air and, as appropriate, has reviewed, or is in the process of reviewing remaining risks. See 40 CFR part 63; Appendix A. Because stationary source releases of PCE to ambient air are addressed under the CAA, EPA is not evaluating emissions to ambient air from commercial and industrial stationary sources or associated inhalation exposure of the general population or terrestrial species in this TSCA risk evaluation.

Drinking Water Pathway
EPA has regular analytical processes to identify and evaluate drinking water contaminants of potential regulatory concern for public water systems under the Safe Drinking Water Act (SDWA). Under SDWA, EPA must also review existing national primary drinking water regulations every 6 years, and subsequently revise them as appropriate.

EPA has promulgated National Primary Drinking Water Regulations (NPDWRs) for PCE under SDWA. See 40 CFR part 141; Appendix A. EPA has set an enforceable Maximum Contaminant Level (MCL) as close as feasible to a health based, non-enforceable Maximum Contaminant Level Goal (MCLG). Feasibility refers to both the ability to treat water to meet the MCL and the ability to monitor water quality at the MCL. Public water systems are required to monitor for the regulated chemical based on a standardized monitoring schedule to ensure compliance with the maximum contaminant level (MCL).

Hence, because the drinking water exposure pathway for PCE is currently addressed in the NPDWR, EPA is not evaluating exposures to the general population from the drinking water exposure pathway in the risk evaluation for PCE under TSCA.

Ambient Water Pathway
EPA develops recommended water quality criteria under Section 304(a) of the CWA for pollutants in surface water that are protective of aquatic life or human health designated uses. EPA develops and publishes water quality criteria based on priorities of states and others that reflect the latest scientific knowledge. A subset of these chemicals is identified as “priority pollutants” (103 human health and 27 aquatic life). The CWA requires states adopt numeric criteria for priority pollutants for which EPA has published recommended criteria under Section 304(a), the discharge or presence of which in the affected waters could reasonably be expected to interfere with designated uses adopted by the state. When states adopt criteria that EPA approves as part of state’s regulatory water quality standards, exposure is considered when state permit writers determine if permit limits are needed and at what level for a specific discharger of a pollutant to ensure protection of the designated uses of the receiving water. Once states adopt criteria as water quality standards, the CWA requires that National Pollutant Discharge Elimination System (NPDES) discharge permits include effluent limits as stringent as necessary to meet

standards. CWA Section 301(b)(1)(C). This is the process used under the CWA to address risk to human health and aquatic life from exposure to a pollutant in ambient waters.

EPA has identified PCE as a priority pollutant and has developed recommended water quality criteria for protection of human health for PCE which are available for adoption into state water quality standards for the protection of human health and are available for use by NPDES permitting authorities in deriving effluent limits to meet state criteria.[6] See, *e.g.,* 40 CFR part 423, Appendix A; 40 CFR 131.11(b)(1); 40 CFR 122.44(d)(1)(vi). As such, EPA is not evaluating exposures to the general population from the surface water exposure pathway in the risk evaluation under TSCA.

Biosolids to General Population Pathway
As wastewater undergoes treatment, some wastewater treatment facilities such as publicly owned treatment works (POTWs) use the remaining biosolids for land application. These biosolids could have residual PCE. PCE in biosolids that are land applied could be transported via runoff from rainwater to surface waters. Residual concentrations of PCE in surface waters not used for drinking water are covered by the CWA Ambient Water Quality Criteria for human health consumption of water and organisms (10 ug/L). CWA 304(a)(1). States and tribal governments may adopt the EPA Clean Water Act Section 304(a) recommended criteria or may adopt their own criteria that differ from EPA's recommendations, subject to EPA's approval, using scientifically defensible methods. States are required to adopt and implement EPA-approved criteria as part of their regulatory water quality standards, and compliance with these criteria is considered by states in permits and water quality assessment decisions. Thus, general population exposure via the biosolid pathway is not evaluated in the final Risk Evaluation.

Onsite Releases to Land Pathway
The Comprehensive Environmental Response, Compensation, and Liability Act, otherwise known as CERCLA or Superfund, provides EPA with broad authority to address uncontrolled or abandoned hazardous-waste sites as well as accidents, spills, and other releases of hazardous substances, pollutants and contaminants into the environment. Through CERCLA, EPA is provided authority to conduct a response action and seek reimbursement of cleanup costs from potentially responsible parties, or in certain circumstances, order a potentially responsible party to conduct a cleanup.

CERCLA Section 101(14) defines "hazardous substance" by referencing other environmental statutes, including toxic pollutants listed under CWA Section 307(a); hazardous substances designated pursuant to CWA Section 311(b)(2)(A); hazardous air pollutants listed under CAA Section 112; imminently hazardous substances with respect to which EPA has taken action pursuant to TSCA Section 7; and hazardous wastes having characteristics identified under or listed pursuant to RCRA Section 3001. See 40 CFR 302.4. CERCLA Section 102(a) also authorizes EPA to promulgate regulations designating as hazardous substances those substances which, when released into the environment, may present substantial danger to the public health or welfare or the environment. EPA must also promulgate regulations establishing the quantity of any hazardous substance the release of which must be reported under Section 103. Section 103 requires persons in charge of vessels or facilities to report to the National Response Center if they have knowledge of a release of a hazardous substance above the reportable quantity threshold.

PCE is a hazardous substance under CERCLA. Releases of PCE in excess of 100 pounds within a 24-hour period must be reported (40 CFR 302.4, 302.6). The scope of this EPA TSCA risk evaluation does

[6] See https://www.regulations.gov/document?D=EPA-HQ-OW-2014-0135-0189.

not include on-site releases to the environment of PCE at Superfund sites and subsequent exposure of the general population or non-human species.

Disposal Pathways
PCE is included on the list of hazardous wastes pursuant to RCRA Section 3001 (40 CFR Sections 261.31, 261.33) as a listed waste on the F and U lists (F001, F002, and U210). The general standard in RCRA Section 3004(a) for the technical criteria that govern the management (treatment, storage, and disposal) of hazardous waste are those "necessary to protect human health and the environment," RCRA 3004(a). The regulatory criteria for identifying “characteristic” hazardous wastes and for “listing” a waste as hazardous also relate solely to the potential risks to human health or the environment. 40 C.F.R. §§ 261.11, 261.21-261.24. RCRA statutory criteria for identifying hazardous wastes require EPA to “tak[e] into account toxicity, persistence, and degradability in nature, potential for accumulation in tissue, and other related factors such as flammability, corrosiveness, and other hazardous characteristics.” Subtitle C controls cover not only hazardous wastes that are landfilled, but also hazardous wastes that are incinerated (subject to joint control under RCRA Subtitle C and the CAA hazardous waste combustion MACT) or injected into UIC Class I hazardous waste wells (subject to joint control under Subtitle C and SDWA).

EPA is not evaluating emissions to ambient air from municipal and industrial waste incineration and energy recovery units or associated exposures to the general population or terrestrial species in the risk evaluation, as these emissions are regulated under Section 129 of the Clean Air Act. CAA Section 129 requires EPA to review and, if necessary, add provisions to ensure the standards adequately protect public health and the environment. Thus, combustion by-products from incineration treatment of PCE wastes would be subject to these regulations, as would PCE burned for energy recovery. See 40 CFR part 60.

EPA is not evaluating on-site releases to land that go to underground injection or associated exposures to the general population or terrestrial species in its risk evaluation. Environmental disposal of PCE injected into Class I hazardous well types are covered under the jurisdiction of RCRA and SDWA and disposal of PCE via underground injection is not likely to result in environmental and general population exposures. See 40 CFR part 144.

EPA is not evaluating on-site releases to land from RCRA Subtitle C hazardous waste landfills or exposures of the general population or terrestrial species from such releases in the TSCA evaluation. Design standards for Subtitle C landfills require double liner, double leachate collection and removal systems, leak detection system, run on, runoff, and wind dispersal controls, and a construction quality assurance program. They are also subject to closure and post-closure care requirements including installing and maintaining a final cover, continuing operation of the leachate collection and removal system until leachate is no longer detected, maintaining and monitoring the leak detection and groundwater monitoring system. Bulk liquids may not be disposed in Subtitle C landfills. Subtitle C landfill operators are required to implement an analysis and testing program to ensure adequate knowledge of waste being managed, and to train personnel on routine and emergency operations at the facility. Hazardous waste being disposed in Subtitle C landfills, including PCE (listed as a hazardous waste in 40 CFR 261.31, 261.33), must also meet RCRA waste treatment standards before disposal. See 40 CFR part 264; Appendix A.

EPA is not evaluating on-site releases to land from RCRA Subtitle D municipal solid waste (MSW) landfills or exposures of the general population or terrestrial species from such releases in the TSCA evaluation. While permitted and managed by the individual states, municipal solid waste landfills are

required by federal regulations to implement some of the same requirements as Subtitle C landfills. MSW landfills generally must have a liner system with leachate collection and conduct groundwater monitoring and corrective action when releases are detected. MSW landfills are also subject to closure and post-closure care requirements and must have financial assurance for funding of any needed corrective actions. MSW landfills have also been designed to allow for the small amounts of hazardous waste generated by households and very small quantity waste generators (less than 220 lbs per month). Bulk liquids, such as free solvent, may not be disposed of at MSW landfills. See 40 CFR part 258.

EPA is not evaluating on-site releases to land from industrial non-hazardous waste and construction/demolition waste landfills or associated exposures to the general population or terrestrial species in the PCE risk evaluation. Industrial non-hazardous and construction/demolition waste landfills are primarily regulated under authorized state regulatory programs. States must also implement limited federal regulatory requirements for siting, groundwater monitoring and corrective action and a prohibition on open dumping and disposal of bulk liquids. States may also establish additional requirements such as for liners, post-closure and financial assurance, but are not required to do so. See, *e.g.*, RCRA Section 3004(c), 4007; 40 CFR part 257.

1.4.3 Conceptual Models

The conceptual models for this risk evaluation are shown in Figure 1-4, Figure 1-5, and Figure 1-6. EPA considered the potential for hazards to human health and the environment resulting from exposure pathways outlined in the conceptual models of the PCE Scope document (U.S. EPA, 2017h). These conceptual models considered potential exposures resulting from industrial and commercial activities, consumer activities and uses and environmental releases and wastes. The Problem Formulation documents refined the initial conceptual models and analysis plans that were provided in the PCE Scope document (U.S. EPA, 2017h) and Problem Formulation (U.S. EPA, 2018d).

For the purpose of this evaluation, EPA considered workers and ONUs, which includes men and women of reproductive age (Figure 1-4). Consumer exposure was assessed for various pathways for users age 11 and older along with bystanders of all ages (Figure 1-5).

The potential pathways that were determined to be included in the risk evaluation and further analyzed include:

- Exposure to aquatic species (*e.g.*, aquatic plants) via contaminated surface water.
- Inhalation and dermal exposures to workers and consumer users, and inhalation exposures to ONUs and consumer bystanders, from industrial/commercial activities and consumer activities.
- Inhalation and dermal exposures to workers and inhalation exposures to ONUs from waste handling, treatment and disposal.

Review and evaluation of reasonably available information on PCE confirmed the preliminary conclusions in the Problem Formulation (U.S. EPA, 2018d). The conceptual models for this risk evaluation are shown in Figure 1-4, Figure 1-5, and Figure 1-6.

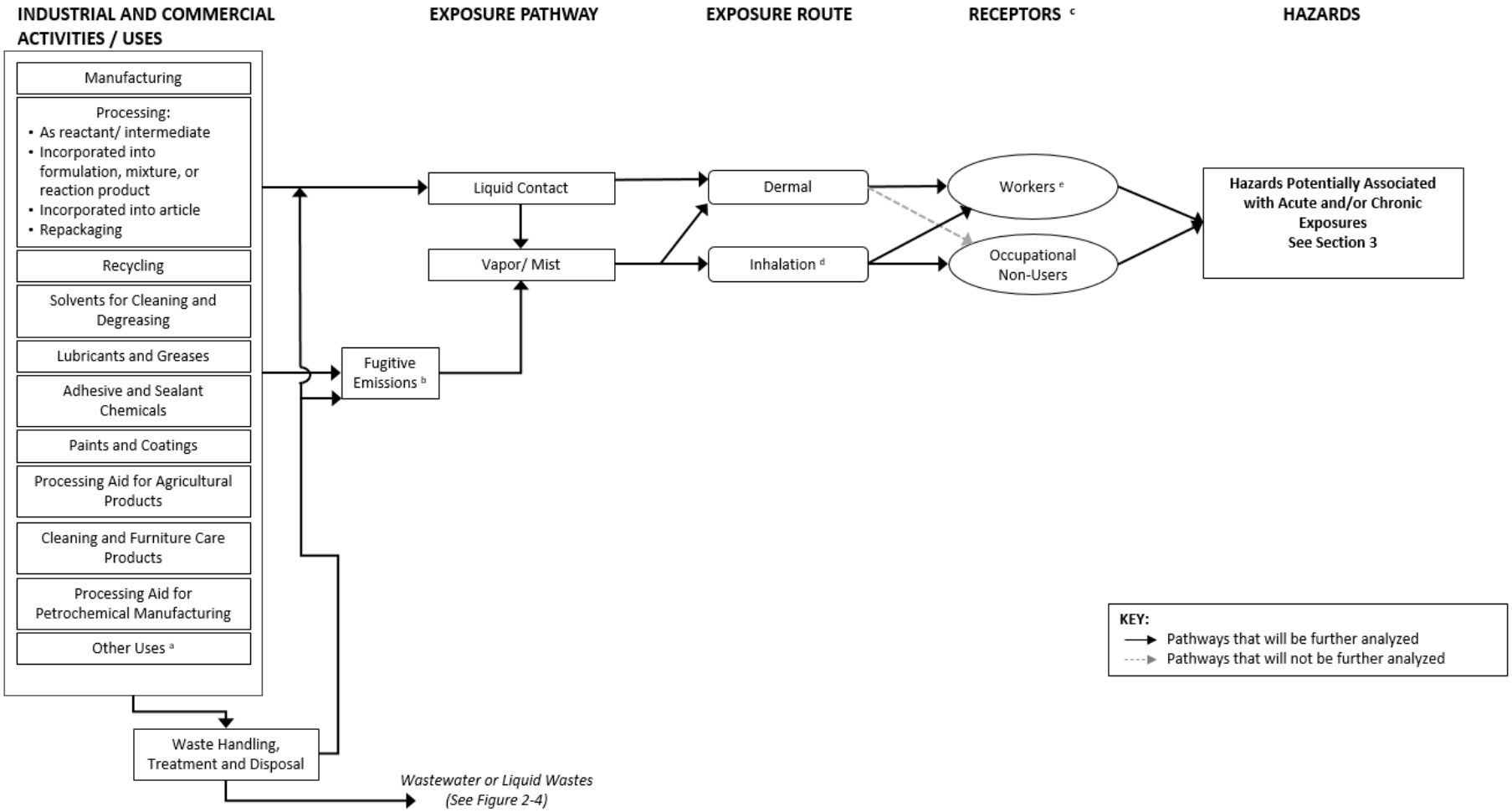


Figure 1-4. PCE Conceptual Model for Industrial and Commercial Activities and Uses: Potential Exposures and Hazards

The conceptual model presents the exposure pathways, exposure routes and hazards to human receptors from industrial and commercial activities and uses of PCE.

[a] Some products are used in both commercial and consumer applications such adhesives and sealants. Additional uses of PCE are included in Table 1-4.

[b] Fugitive air emissions are those that are not stack emissions and include fugitive equipment leaks from valves, pump seals, flanges, compressors, sampling connections and open-ended lines; evaporative losses from surface impoundment and spills; and releases from building ventilation systems.

[c] Receptors include potentially exposed or susceptible subpopulations.

[d] Oral exposure may occur through mists that deposit in the upper respiratory tract however, based on physical chemical properties, mists of PCE will likely be rapidly absorbed in the respiratory tract or evaporate and will be considered as an inhalation exposure.

[e] EPA also considers the effect that engineering controls and/or personal protective equipment have on occupational exposure levels.

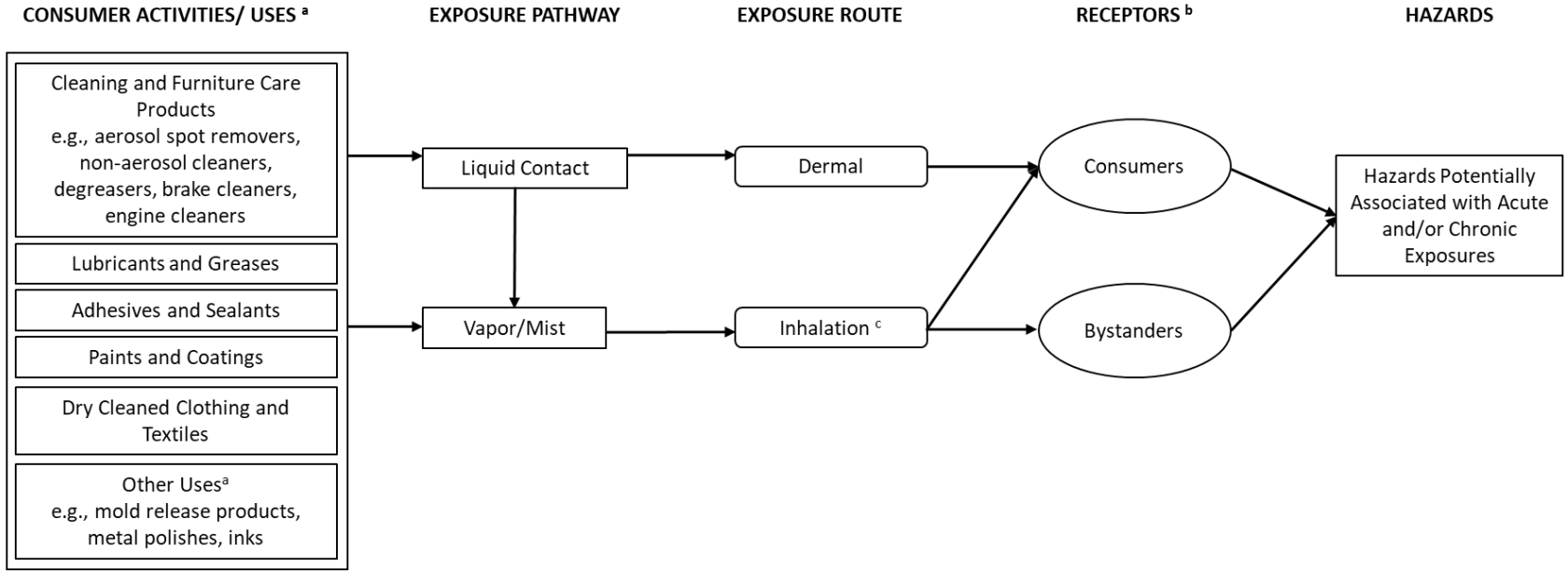


Figure 1-5. PCE Conceptual Model for Consumer Activities and Uses: Potential Exposures and Hazards

The conceptual model presents the exposure pathways, exposure routes and hazards to human receptors from consumer activities and uses of PCE.

[a] Some products are used in both commercial and consumer applications. Additional uses of PCE are included in Table 1-2.

[b] Receptors include potentially exposed or susceptible subpopulations.

[c] Consumers oral exposure may occur through mists that deposit in the upper respiratory tract however, based on physical chemical properties, mists of PCE will likely be rapidly absorbed in the respiratory tract or evaporate and will be considered as an inhalation exposure.

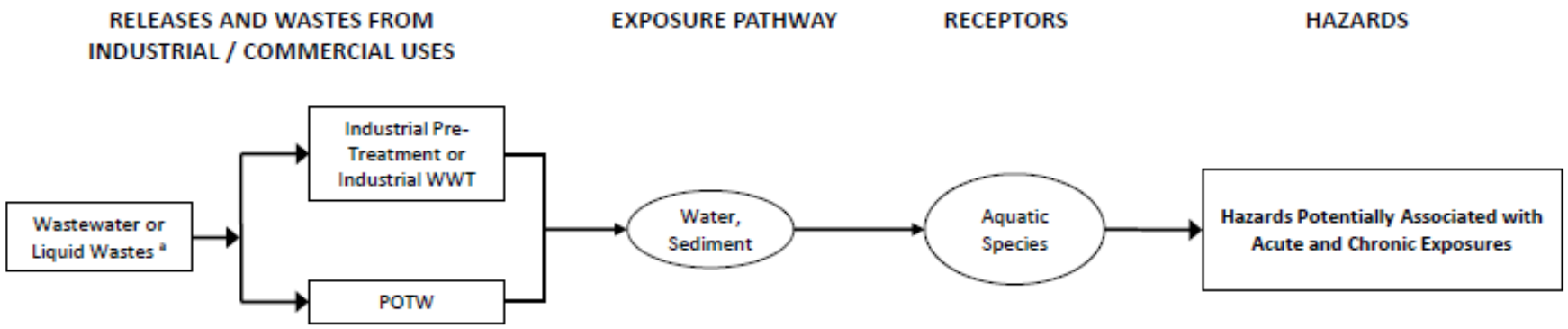


Figure 1-6. PCE Conceptual Model for Environmental Releases and Wastes: Potential Ecological Exposures and Hazards

The conceptual model presents the exposure pathways, exposure routes and hazards to environmental receptors from environmental releases and wastes of PCE.

[a] Industrial wastewater or liquid wastes may be treated on-site and then released to surface water (direct discharge) or pre-treated and released to POTW (indirect discharge).

1.5 Systematic Review

TSCA requires EPA to use scientific information, technical procedures, measures, methods, protocols, methodologies and models consistent with the best available science when making science-based decisions under section 6 on the weight of the scientific evidence. Within the TSCA risk evaluation context, the weight of the scientific evidence is defined as *"a systematic review method, applied in a manner suited to the nature of the evidence or decision, that uses a pre-established protocol to comprehensively, objectively, transparently, and consistently identify and evaluate each stream of evidence, including strengths, limitations, and relevance of each study and to integrate evidence as necessary and appropriate based upon strengths, limitations, and relevance"* (40 CFR 702.33).

To meet the TSCA section 26(h) science standards, EPA used the TSCA systematic review process described in the *Application of Systematic Review in TSCA Risk Evaluations* document (U.S. EPA, 2018c). The process complements the risk evaluation process in that the data collection, data evaluation and data integration stages of the systematic review process are used to develop the exposure and hazard assessments based on reasonably available information. EPA defines "reasonably available information" to mean information that EPA possesses, or can reasonably obtain and synthesize for use in risk evaluations, considering the deadlines for completing the evaluation (40 CFR 702.33).

EPA is implementing systematic review methods and approaches within the regulatory context of the amended TSCA. Although EPA adopted as many best practices as practicable from the systematic review community, EPA modified the process to ensure that the identification, screening, evaluation and integration of data and information can support timely regulatory decision making under the timelines of the statute.

1.5.1 Data and Information Collection

EPA planned and conducted a comprehensive literature search based on key words related to the different discipline-specific evidence supporting the risk evaluation (*e.g.,* environmental fate and transport; environmental releases and occupational exposure; exposure to general population, consumers and environmental exposure; and human health and environmental hazards). EPA then developed and applied inclusion and exclusion criteria during the title/abstract screening to identify information potentially relevant for the risk evaluation process. The literature and screening strategy as specifically applied to PCE is described in *Strategy for Conducting Literature Searches for Perchloroethylene (PCE) Supplemental File to the TSCA Scope Document* (U.S. EPA, 2017i) and the results of the title and abstract screening process were published in *PCE (CASRN 127-18-4) Bibliography: Supplemental File for the TSCA Scope Document;* (U.S. EPA, 2017d).

For studies determined to be on-topic (or relevant) after title and abstract screening, EPA conducted a full text screening to further exclude references that were not relevant to the risk evaluation. Screening decisions were made based on eligibility criteria documented in the form of the populations, exposures, comparators, and outcomes (PECO) framework or a modified

framework[7]. Data sources that met the criteria were carried forward to the data evaluation stage. The inclusion and exclusion criteria for full text screening for PCE are available in in Appendix F of the *Problem Formulation of the Risk Evaluation for PCE* (U.S. EPA, 2018d).

Although EPA conducted a comprehensive search and screening process as described above, EPA made the decision to leverage the literature published in previous assessments[8] to identify key and supporting data[9] and information for developing the PCE risk evaluation. This is discussed *Strategy for Conducting Literature Searches for Perchloroethylene (PCE) Supplemental File to the TSCA Scope Document* (U.S. EPA, 2017i). In general, many of the key and supporting data sources were identified in the comprehensive *Perchloroethylene (CASRN 127-18-4) Bibliography: Supplemental File for the TSCA Scope Document;* (U.S. EPA, 2017d). However, there was an instance during the releases and occupational exposure data search for which EPA missed relevant references that were not captured in the initial categorization of the on-topic references. EPA found additional relevant data and information using backward reference searching, which was a technique that will be included in future search strategies. This issue is discussed in Section 4 of *Application of Systematic Review for TSCA Risk Evaluations* (U.S. EPA, 2018c). Other relevant key and supporting references were identified through targeted supplemental searches to support the analytical approaches and methods in the PCE risk evaluation (*e.g.*, to locate specific information for exposure modeling).

EPA used previous chemical assessments to quickly identify relevant key and supporting information as a pragmatic approach to expedite the quality evaluation of the data sources, but many of those data sources were already captured in the comprehensive literature as explained above. EPA also considered newer information not taken into account by previous chemical assessments as described in *Strategy for Conducting Literature Searches for Perchloroethylene (PCE) Supplemental File to the TSCA Scope Document* (U.S. EPA, 2017i). EPA then evaluated the confidence of the key and supporting data sources as well as newer information instead of evaluating the confidence of all the underlying evidence ever published on a chemical substance's fate and transport, environmental releases, environmental and human exposure and hazards. Such comprehensive evaluation of all of the data and information ever published for a chemical substance would be extremely labor intensive and could not be achieved under the TSCA statutory deadlines for most chemical substances especially those that have a data-rich database. Furthermore, EPA considered how evaluation of newer information in addition to the key and supporting data and information would change the conclusions presented in previous assessments.

[7] A PESO statement was used during the full text screening of environmental fate and transport data sources. PESO stands for Pathways and Processes, Exposure, Setting or Scenario, and Outcomes. A RESO statement was used during the full text screening of the engineering and occupational exposure literature. RESO stands for Receptors, Exposure, Setting or Scenario, and Outcomes.

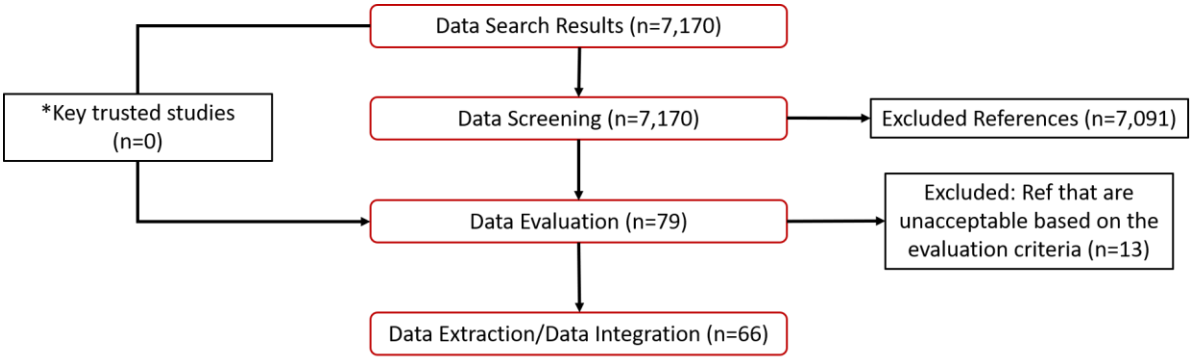
[8] Examples of existing assessments are EPA's chemical assessments (e.g., previous work plan risk assessments, Problem Formulation documents), ATSDR's Toxicological Profiles and EPA's IRIS assessments. This is described in more detail in *Strategy for Conducting Literature Searches for PCE (PCE) Supplemental File to the TSCA Scope Document* (U.S. EPA, 2017i).

[9] Key and supporting data and information are those that support key analyses, arguments, and/or conclusions in the risk evaluation.

This pragmatic approach allowed EPA to maximize the scientific and analytical efforts of other regulatory and non-regulatory agencies by accepting for the most part the relevant scientific knowledge gathered and analyzed by others except for influential information sources that may have an impact on the weight of the scientific evidence and ultimately the risk findings. The influential information (*i.e.*, key/supporting) came from a smaller pool of sources subject to the rigor of the TSCA systematic review process to ensure that the risk evaluation uses the best available science and the weight of the scientific evidence.

The figures below depict literature flow diagrams illustrating the results of this process for each scientific discipline-specific evidence supporting the risk evaluation (Figure 1-7, Figure 1-8, Figure 1-9, Figure 1-10 and Figure 1-11). Each diagram provides the total number of references at the start of each systematic review stage (*i.e.*, data search, data screening, data evaluation, data extraction/data integration) and those excluded based on criteria guiding the screening and data quality evaluation decisions.

EPA made the decision to bypass the data screening step for data sources that were highly relevant to the risk evaluation as described above. These data sources are depicted as "key/supporting data sources" in the literature flow diagrams. Note that the number of "key/supporting data sources" were excluded from the total count during the data screening stage and added, for the most part, to the data evaluation stage depending on the discipline-specific evidence. The exception was the environmental releases and occupational exposure data sources that were subject to a combined data extraction and evaluation step (Figure 1-8).



*Any relevant studies from prior assessments that were identified as potentially relevant for TSCA assessment needs bypassed the data screening step and moved directly to the data evaluation step (e.g. key supporting studies from IRIS assessments, ATSDR assessments, ECHA dossiers, etc.).

Figure 1-7. Literature Flow Diagram for Environmental Fate Information

Note: Literature search results for the environmental fate and transport of PCE yielded 7,170 studies. During Problem Formulation, following data screening, most environmental exposure pathways were removed from the conceptual models. As a result, 7,091 studies were deemed off-topic and excluded. The remaining 79 studies related to environmental exposure pathways retained in the conceptual models entered data evaluation, where 13 studies were deemed unacceptable and 66 moved into data extraction and integration. Note: Data sources identified relevant to physical-chemical properties were not included in this literature flow diagram. The data quality evaluation of physical-chemical properties studies can be found in the supplemental document, (U.S. EPA, 2020o) and the extracted data are presented in Table 1-1.

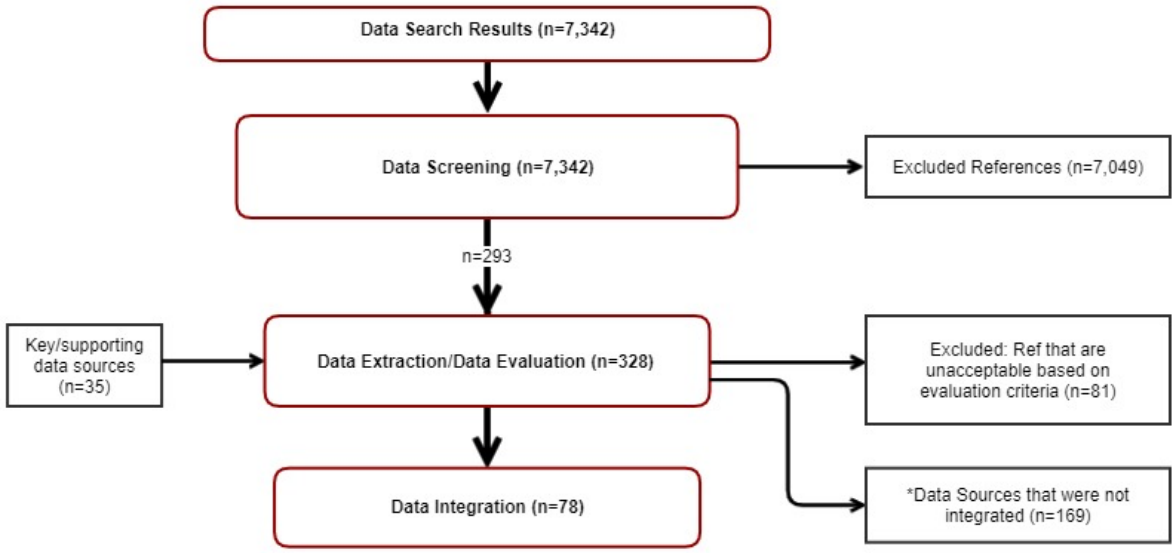
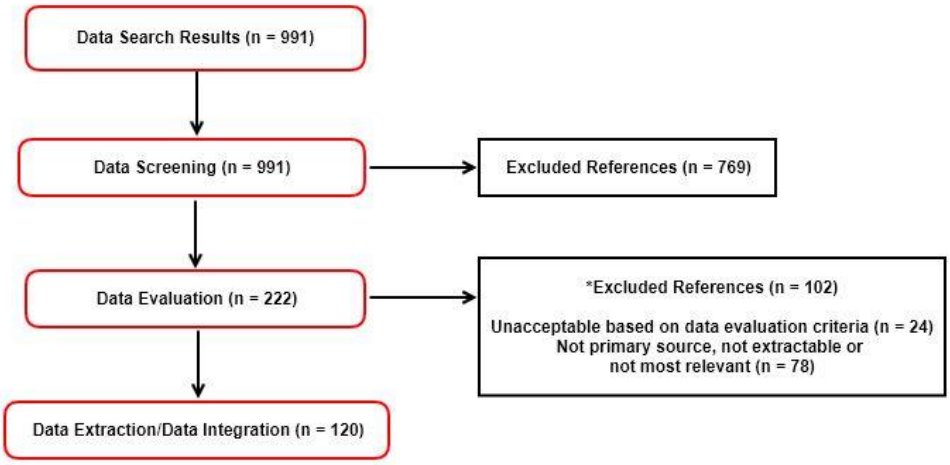


Figure 1-8. Literature Flow Diagram for Environmental Releases and Occupational Exposure

*The quality of data in these sources (n=169) were acceptable for risk assessment purposes, but they were ultimately excluded from further consideration based on EPA's integration approach for environmental release and occupational exposure data/information. EPA's approach uses a hierarchy of preferences that guide decisions about what types of data/information are included for further analysis, synthesis and integration into the environmental release and occupational exposure assessments. EPA prefers using data with the highest rated quality among those in the higher level of the hierarchy of preferences (*i.e.*, data > modeling > occupational exposure limits or release limits). If warranted, EPA may use data/information of lower rated quality as supportive evidence in the environmental release and occupational exposure assessments.

Note: Literature search results for environmental release and occupational exposure yielded 7,342 data sources. Of these data sources, 293 were determined to be relevant for the risk evaluation through the data screening process. These relevant data sources were entered into the data extraction/evaluation phase. After data extraction/evaluation, EPA identified several data gaps and performed a supplemental, targeted search to fill these gaps (*e.g.*, to locate information needed for exposure modeling). The supplemental search yielded 35 relevant data sources that bypassed the data screening step and were evaluated and extracted in accordance with *Appendix D: Data Quality Criteria for Occupational Exposure and Release Data of the Application of Systematic Review for TSCA Risk Evaluations* document (U.S. EPA, 2018c). Of the 328 sources from which data were extracted and evaluated, 81 sources only contained data that were rated as unacceptable based on serious flaws detected during the evaluation (See the *Systematic Review Supplemental File: Data Quality Evaluation of Environmental Releases and Occupational Exposure* for the data evaluation results for each source). Of the 247 sources forwarded for data integration, data from 78 sources were integrated, and 169 sources contained data that were not integrated (*e.g.*, lower quality data that were not utilized due to the existence of higher quality data, data for release media that were removed from scope after data collection).



*The quality of data in these sources were acceptable for risk assessment purposes and considered for integration. The sources; however, were not extracted for a variety of reasons, such as they contained only secondary source data, duplicate data, or non-extractable data (i.e., charts or figures). Additionally, some data sources were not as relevant to the PECO as other data sources which were extracted.

Figure 1-9. Literature Flow Diagram for Consumer and Environmental Exposure Data Sources

Note: EPA conducted a literature search to determine relevant data sources for assessing exposures for perchloroethylene within the scope of the risk evaluation. This search identified 991 data sources including relevant supplemental documents. Of these, 769 were excluded during the screening of the title, abstract, and/or full text and 222 data sources were recommended for data evaluation across up to five major study types in accordance with *Appendix E:Data Quality Criteria for Studies on Consumer, General Population and Environmental Exposure of the Application of Systematic Review for TSCA Risk Evaluations* document (U.S. EPA, 2018b). Following the evaluation process, 120 references were forwarded for further extraction and data integration. EPA has not developed data quality criteria for all types of exposure information, some of which may be relevant when estimating consumer exposures. This is the case for absorption and permeability data and some product-specific data such as density and weight fraction often reported in Safety Data Sheets. As appropriate, EPA evaluated and summarized these data to determine their utility with supporting the risk evaluation.

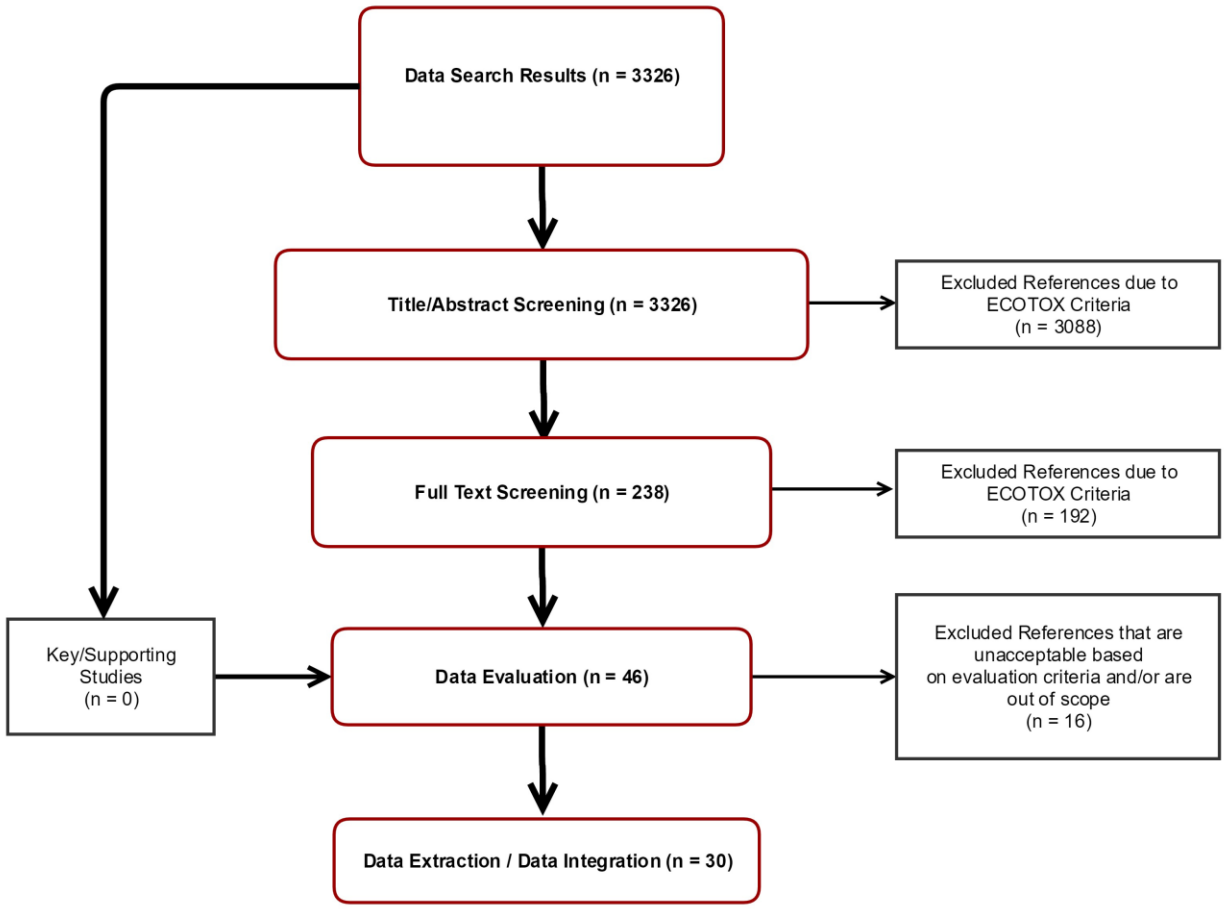


Figure 1-10. Literature Flow Diagram for Environmental Hazard Data Sources

Note: The environmental hazard data sources were identified through literature searches and screening strategies using the ECOTOX Standing Operating Procedures. Additional details about the process can be found in the Strategy for Conducting Literature Searches for *PCE: Supplemental File for the TSCA Scope Document* (U.S. EPA, 2017h). During Problem Formulation, EPA made refinements to the conceptual models resulting in the elimination of the terrestrial exposure pathway. Thus, environmental hazard data sources on terrestrial organisms were considered out of scope and excluded from data quality evaluation.

The literature search process for environmental hazard data found 3326 citations for PCE. At the title and abstract screening phase, 3088 citations were excluded as off-topic using ECOTOXicology knowledgebase criteria. The remaining 238 citations underwent a more thorough full text screening using the same criteria to determine which citations should undergo data evaluation. For data evaluation, EPA developed data quality evaluation (DQE) criteria to evaluate the data under TSCA, based on a combination of EPA's ECOTOXicology knowledgebase (ECOTOX) criteria and the Criteria for Reporting and Evaluating ecotoxicity Data (CRED). There were 46 citations that went to data evaluation for PCE. EPA analyzed each of these studies using the DQE results to determine overall study quality. Thirty studies were considered acceptable and were rated high, medium, or low quality during this analysis. The extracted data from these 30 studies were used during data integration for PCE.

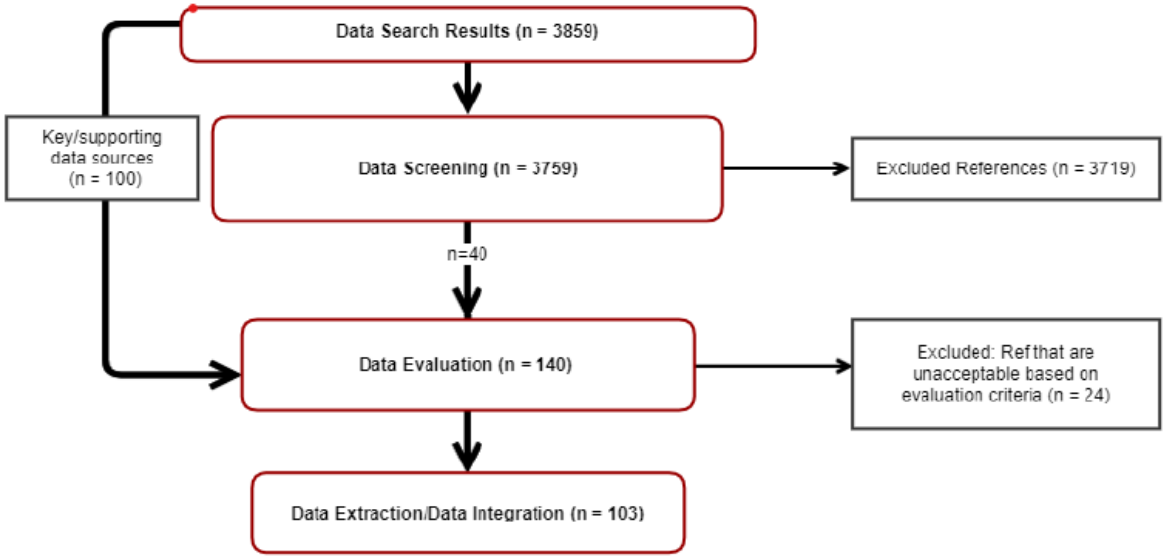


Figure 1-11. Literature Flow Diagram for Human Health Hazard Data Sources
Note: The literature search results for human health hazard of PCE yielded 3859 studies. This included 100 key and supporting studies identified from previous EPA assessments. Of the 3759 new studies screened for relevance, 3719 were excluded as off topic. The remaining 40 new studies together with the 40 key and supporting studies entered data evaluation. Thirteen studies were deemed unacceptable based on the evaluation criteria for human health hazard data sources and the remaining 103 studies were carried forward to data extraction/data integration. Additional details can be found in the *PCE Bibliography: Supplemental File for the TSCA Scope Document*, (U.S. EPA, 2017d).

1.5.2 Data Evaluation

During the data evaluation stage, the EPA assesses the quality of the methods and reporting of results of the individual studies identified during Problem Formulation using the evaluation strategies described in *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018b). The EPA evaluated the quality of the on-topic PCE study reports identified in *Perchloroethylene (CASRN 127-18-4) Bibliography: Supplemental File for the TSCA Scope Document;* (U.S. EPA, 2017d), and gave all studies an overall high, medium, low or unacceptable confidence rating during data evaluation.

The results of the data quality evaluations for key studies are summarized in Section 2.1 (Fate and Transport), Section 2.2 (Releases to the Environment), Section 2.3 (Environmental Exposures), Section 2.4 (Human Exposures), Section 3 (Environmental Hazards) and Section 3.2 (Human Health Hazards). Supplemental files (Appendix B) also provide details of the data evaluations including individual metric scores and the overall study score for each data source.

1.5.3 Data Integration

Data integration includes analysis, synthesis and integration of information for the risk evaluation. During data integration, the EPA considers quality, consistency, relevancy, coherence and biological plausibility to make final conclusions regarding the weight of the scientific evidence. As stated in *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018b), data integration involves transparently discussing the significant issues, strengths, and limitations as well as the uncertainties of the reasonably available information and

the major points of interpretation (U.S. EPA, 2018f). EPA defines "reasonably available information" to mean information that EPA possesses, or can reasonably obtain and synthesize for use in risk evaluations, considering the deadlines for completing the evaluation (U.S. EPA, 2017g).

EPA used previous assessments (see Table 1-3) to identify key and supporting information and then analyzed and synthesized available evidence regarding PCE's chemical properties, environmental fate and transport properties and its potential for exposure and hazard. EPA's analysis also considered recent data sources that were not considered in the previous assessments (1.5.1) as well as reasonably available information on potentially exposed or susceptible subpopulations.

The exposures and hazards sections describe EPA's analysis of the influential information (*i.e.*, key and supporting data) that were found acceptable based on the data quality reviews as well as discussion of other scientific knowledge using the approach described in Section 1.5.1. The exposure section also describes whether aggregate or sentinel exposures to a chemical substance were considered under the conditions of use within the scope of the risk evaluation, and the basis for that consideration.

2 EXPOSURES

2.1 Fate and Transport

Environmental fate includes both transport and transformation processes. Environmental transport is the movement of the chemical within and between environmental media. Transformation occurs through the degradation or reaction of the chemical with other species in the environment. Hence, knowledge of the environmental fate of the chemical informs the determination of the specific exposure pathways and potential human and environmental receptors EPA has considered during risk evaluation.

2.1.1 Fate and Transport Approach and Methodology

EPA gathered and evaluated environmental fate information according to the process described in the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018b). Table 2-1 provides environmental fate data and physical chemical properties that EPA considered while assessing the fate of PCE, including biotic and abiotic degradation rates, removal during wastewater treatment, volatilization from lakes and rivers, and the organic carbon:water partition coefficient (log K_{OC}). This data was updated after Problem Formulation with information identified through systematic review. Additional study summaries are available in the supplemental document, *Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Extraction Tables for Environmental Fate and Transport Studies* (U.S. EPA, 2020h), and complete information on data quality evaluations for all identified fate data are available in the supplemental document, *Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation for Environmental Fate and Transport Studies* (U.S. EPA, 2020j). Environmental fate properties not adequately reported in the literature were estimated using Estimation Programs Interface (EPI) Suite™ models, as described in Appendix C.

Table 2-1. Environmental Fate Characteristics and Select Physical and Chemical Properties of PCE

Property or Endpoint	Value [a]	References	Data Quality Rating
Aerobic Biodegradation	86-87% in 28 days	(Tabak et al., 1981)	High
	74% in batch-fed reactor	(Long et al., 1993)	High
	0% in continuous-flow system	(Bouwer and McCarty, 1982)	High
	0% in 175 days	(Bouwer et al., 1981)	Low
	Loss of PCE in some studies may be due to volatilization	(Namkung and Rittmann, 1987; Wakeham et al., 1983)	Medium, Medium
Anaerobic Biodegradation	100% in 37 days	(Cabirol et al., 1996)	High
	Approx. 38% in 30 days	(Wood et al., 1981)	High
	44%-68% in 112 days	(Bouwer et al., 1981)	High

Property or Endpoint	Value [a]	References	Data Quality Rating
Bioconcentration factor (BCF)	25.8-77.1 (fish)	(Kawasaki, 1980)	High
	49 (fish)	(Barrows et al., 1980)	High
	39.7 (fish)	(Dow Chem, 1973)	High
	312 and 118 (marine algae)	(Wang et al., 1996)	High
Bioaccumulation factor (BAF)	46 (estimated)[b]	(ECB, 2005); (U.S. EPA, 2012a)	High
Organic carbon:water partition coefficient (log K_{OC})	2.4	(U.S. EPA, 2012f)	High
	2.95 (estimated by regression from log K_{OW})[b] 1.98 (estimated by molecular connectivity index method)[b]	(U.S. EPA, 2012a)	High
Vapor pressure	18.5 mmHg at 25°C	(Riddick et al. (1985))	High
Vapor density	5.83 (relative to air)	(Lewis, 1992)	High
Water solubility	206 mg/L at 20°C	(Horvath (1982))	High
Octanol:water partition coefficient (K_{OW})	3.40	(Hansch et al. (1995))	High
Henry's Law constant	0.0177 atm-m3/mole at 25°C (equivalent to 0.724 dimensionless)	(Gossett (1987))	High

[a] Measured unless otherwise noted.
[b] Information was estimated using EPI Suite™ (U.S. EPA, 2012a)

2.1.2 Summary of Fate and Transport

The EPI Suite™ model that estimates chemical removal in sewage treatment plants ("STP" module) was run using default settings to evaluate the potential for PCE to be removed from wastewater. The STP module estimates that a total of 88% of PCE in wastewater will be removed, 82% by volatilization and 6% by sorption to sludge organic matter. Based on the mixed aerobic biodegradation data reported for PCE (ranging from rapid to negligible biodegradation in aerobic environments; see Table 2-1) the overall removal of PCE in wastewater treatment plants is expected to range from 88% to complete. PCE has moderate potential to sorb to sludge organic matter and thus is expected to be present in biosolids (processed sludge). Due to its Henry's Law constant (0.0177 atm-m^3/mole) and vapor pressure (18.5 mmHg at 25°C) PCE in land-applied biosolids will volatilize from solid and liquid phases during and after spraying, although some PCE may partition from biosolids into soil and groundwater.

In soil and aquifers, PCE has moderate potential to sorb to soil or sediment organic matter and may be transported to ground water. Because it has moderate mobility through soil and sediment, PCE may be transported between groundwater and surface water where local hydrologic

conditions permit. Anaerobic biodegradation, which is reported to be rapid to very slow depending on local conditions and microbial populations (WHO, 2006a; ECB, 2005), may be a significant degradation mechanism in soil and groundwater. In anaerobic environments, PCE biodegradation products include potentially hazardous substances including trichloroethylene, cis-1,2 dichloroethene and vinyl chloride (de Bruin et al., 1992).

Based on its Henry's Law constant (0.0177 atm-m^3/mole) and vapor pressure (18.5 mmHg at 25°C), PCE can be expected to volatilize from surface water to air and from soil to air. The EPI Suite™ model that predicts volatilization for surface water ("Volatilization" module) estimated the PCE volatilization half-life from a model river to be 1.4 hours, and the volatilization half-life from a model lake to be 123 hours (5.1 days). In the vapor phase, PCE can be slowly transformed by reaction with hydroxyl and other radicals with half-lives of months or greater, and long-range transport may occur. In the atmosphere, PCE is expected to slowly degrade via indirect photolysis (half-life ≥ 80 days). Given its slow photodegradation, PCE is expected to undergo long-range atmospheric transport.

With measured bioconcentration factors of 312 or lower and estimated bioaccumulation factor of 46, PCE has limited bioaccumulation potential.

Overall, PCE may be persistent or very persistent in the environment. It has moderate potential to accumulate in wastewater biosolids, soil, and sediment, and has low potential to bioaccumulate. In the environment, PCE is expected to largely volatilize to the atmosphere where it may undergo long-range transport and slowly degrade via indirect photolysis. The fate of PCE in the environment is summarized in Figure 2-1.

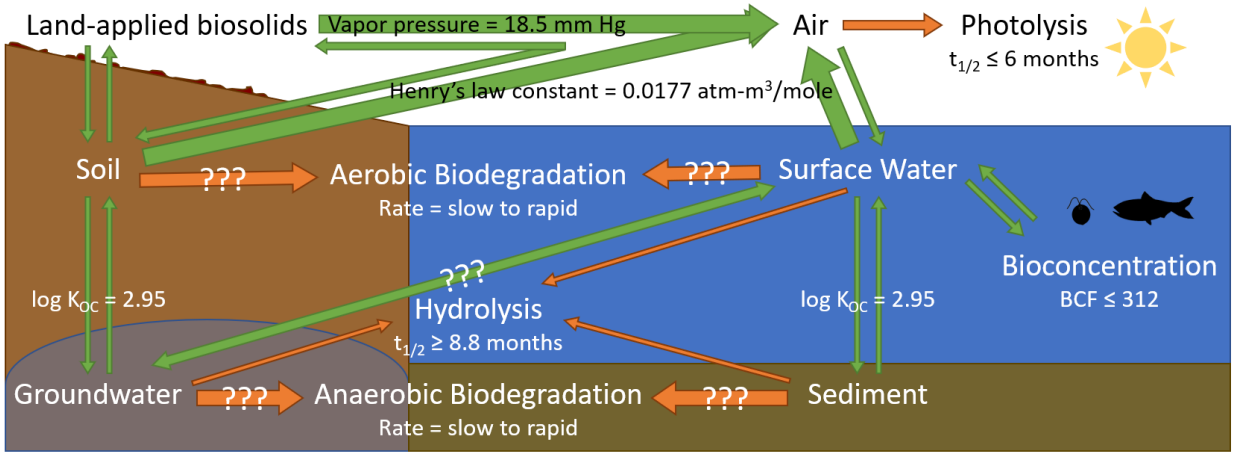


Figure 2-1. Diagram demonstrating the transport, partitioning, and degradation of PCE in the environment

In Figure 2-1, transport and partitioning are indicated by green arrows and degradation is indicated by orange arrows. The width of the arrow is a qualitative indication of the likelihood that the indicated partitioning will occur or the rate at which the indicated degradation will occur (*i.e.*, wider arrows indicate more likely partitioning or more rapid degradation). Because transport and partitioning processes (green arrows) can occur in both directions across an interface, the transport and partitioning pathways are illustrated with arrows pointing in both

directions. For interfaces where one direction of transport and partitioning is expected to prevail based on release rates and partition coefficients, the primary direction of transport is indicated by a wider arrow. However, the direction of transport in a given locality depends on the site-specific properties of environmental media, weather conditions, PCE release rates, degradation and transformation rates, and PCE concentrations within environmental compartments. Question marks over arrows indicate uncertainty regarding how quickly PCE will transport or degrade because they rely on processes which vary greatly based on local conditions. Figure 2-1 considers only transport, partitioning, and degradation within and among environmental media; sources to the environment such as discharge and disposal are not illustrated.

2.1.3 Key Sources of Uncertainty in Fate and Transport Assessment

The experimentally determined PCE biodegradation rates in aerobic and anaerobic environments ranged from slow to rapid (see Table 2-1). For comparison, the EPI Suite™ module that predicts biodegradation rates ("BIOWIN" module) was run using default settings to estimate biodegradation rates of PCE. The BIOWIN models for aerobic environments (BIOWIN 1-6) estimate that PCE will not rapidly biodegrade in aerobic environments. The BIOWIN model of anaerobic biodegradation (BIOWIN 7) predicts that PCE will biodegrade under anaerobic conditions. Overall, PCE biodegradation rates in the environment may vary based on factors including level of oxygenation, microorganisms present, and microorganisms' previous exposure and adaptation to PCE. This uncertainty in biodegradation rates was considered in the assessment of persistence in aerobic and anaerobic environments and estimates of removal from wastewater. The full range of reported biodegradation rates was used in qualitative assessments (*e.g.,* sediment assessment, Section 4.1.3). The most conservative ends of the data distributions (*i.e.,* longer half-lives) were used in quantitative assessments, including estimated removal in wastewater treatment (Section 2.3.1.1.3).

Although PCE has limited potential to bioconcentrate, some bioconcentration has been observed in algae (measured BCF values < 320). This implies the potential for trophic transfer and, if the predator species does not efficiently metabolize PCE, trophic magnification. However, systematic review of fate information on PCE did not yield measured data on PCE trophic transfer or trophic magnification.

2.2 Releases to the Environment

2.2.1 Environmental Discharges of Wastewater

EPA categorized the conditions of use (COUs) listed in Table 1-4 into 22 Occupational Exposure Scenarios (OES). For each OES, a daily wastewater discharge was estimated based on annual releases, release days, and the number of facilities (Figure 2-2). In this section, EPA describes its approach and methodology for estimating daily wastewater discharges, and for each OES, provides a summary of release days, number of facilities, and daily wastewater discharges. For detailed facility level results, see the "Water Release Assessment" section for each OES in the supplemental information file *Environmental Releases and Occupational Exposure Assessment* (U.S. EPA, 2020d).

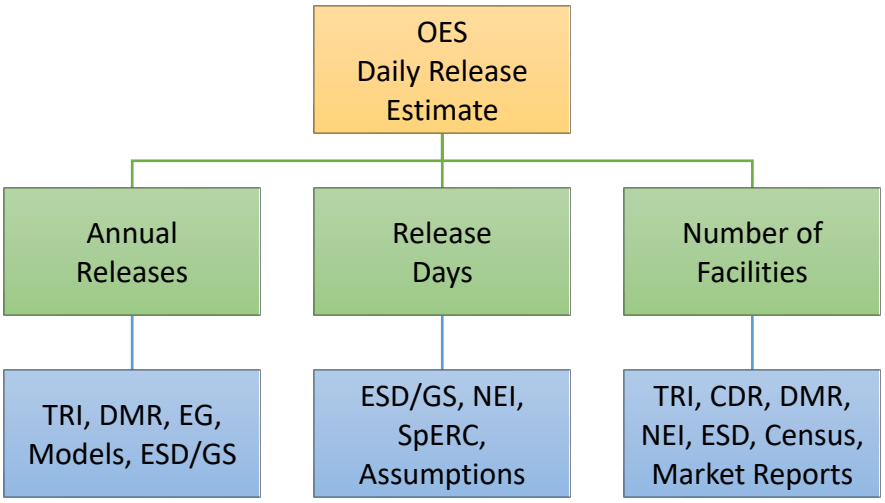


Figure 2-2. An overview of EPA's Approach to Estimate Daily Wastewater Discharges[10].

2.2.1.1 Results for Daily Wastewater Discharge Estimates

EPA combined its estimates for annual releases, release days, and number of facilities to estimate a range for daily wastewater discharges for each OES. A summary of these ranges across facilities is presented in Table 2-2 Results in the table are for total annual releases from a facility and may include discharges from multiple outfalls at the same facility. The basis for the overall confidence levels referenced in the tables are described in Table 2-7 in Section 2.2.1.3. Surface water discharges reported in DMR are based on required monitoring as part of a facility's National Pollutant Discharge Elimination System (NPDES) permit. For some OES, EPA was not able to estimate or did not expect water releases. For example:

- **OES Aerosol Degreasing and Aerosol Lubricants:** Wastewater discharges containing PCE were not expected due to its volatility; releases from this OES are expected to be to air.
- **OES Wipe Cleaning and Metal/Stone Polishes:** Wastewater discharges containing PCE were not expected due to its volatility and the nature of the wipe cleaning and polishing process; releases from this OES are expected to be to air (volatilization) or with shop rags to landfill/incineration.
- **OES Other Spot Cleaning/Spot Removers (Including Carpet Cleaning):** EPA did not identify data to estimate wastewater discharges for this OES.
- **OES Laboratory Chemicals:** EPA did not identify data to estimate wastewater discharges for this OES.

[10] TRI = Toxics Release Inventory; DMR = Discharge Monitoring Report; NEI = National Emissions Inventory; CDR = Chemical Data Reporting; EG = Effluent Guidelines; ESD = Emission Scenario Document; GS = Generic Scenarios; SpERC = Specific Environmental Release Category

Table 2-2. Summary of EPA's Daily Wastewater Discharge Estimates for Each OES

Occupational Exposure Scenario (OES)	Release Media/ Treatment Facility Type[a]	Number of Sites with Wastewater Discharges[b]	Estimated Daily Release Range Across Sites (kg/site-day)[c]		Overall Confidence	Corresponding Section in the Supplemental Engineering Report (U.S. EPA, 2019a)
			Minimum[d]	Maximum		
Manufacturing	Surface Water	1	1.7E-03		M	Section 2.1.4
	Non-POTW WWT	1	4.1E-02		M	
	Surface Water or POTW[e]	4	8.9E-05	0.2	M	
Repackaging	Surface Water	3	9.1E-05	4.8E-03	M	Section 2.2.4
	Non-POTW WWT	1	1.1		M	
Processing as a Reactant	Surface Water	18	1.2E-05	1.3	M	Section 2.3.4
	POTW	1	0.1		M	
Incorporation into Formulation, Mixture, or Reaction Product	Surface Water	1	1.7E-03		M	Section 2.4.4
	POTW	1	1.5E-03		M	
	Non-POTW WWT	1	5.3		M	
Batch Open-Top Vapor Degreasing[f]	Surface Water	16	9.0E-07	7.1E-02	M	Section 2.5.4
	POTW	1	3.5E-04		M	
	POTW or non-POTW WWT	275-4,819	1.6E-3	1.6E-2	M	Section 2.5.4
Batch Closed-Loop Vapor Degreasing	POTW or non-POTW WWT	13,789-25,423	1.6E-3	1.6E-2	M	Section 2.6.4
Conveyorized Vapor Degreasing	POTW or non-POTW WWT	272-445	1.6E-3	1.6E-2	M	Section 2.7.4
Web Vapor Degreasing	POTW or non-POTW WWT	272-445	1.6E-3	1.6E-2	M	Section 2.8.4
Cold Cleaning	Included with release estimates for Batch Open Top Vapor Degreasing[f].					Section 2.9.4

Occupational Exposure Scenario (OES)	Release Media/ Treatment Facility Type[a]	Number of Sites with Wastewater Discharges[b]	Estimated Daily Release Range Across Sites (kg/site-day)[c]		Overall Confidence	Corresponding Section in the Supplemental Engineering Report (U.S. EPA, 2019a)
			Minimum[d]	Maximum		
Aerosol Degreasing and Aerosol Lubricants	EPA does not expect wastewater discharges containing PCE from these sites.				H	Section 2.10.4
Dry Cleaning and Spot Cleaning (commercial)	POTW	12,822	5.6E-04	1.7E-03	M	Section 2.11.4
Dry Cleaning and Spot Cleaning (industrial)	Surface Water	2	4.5E-05	2.1E-04	M	Section 2.11.4
Adhesives, Sealants, Paints, and Coatings	POTW	Unknown	0.4	1.8	L	Section 2.12.4
Maskant For Chemical Milling	Surface Water	3	5.9E-06	8.6E-04	M	Section 2.13.4
	POTW	2	2.6E-03	1.1E-02	M	
Industrial Processing Aid	Surface Water	12	3.0E-04	8.6E-02	M	Section 2.14.4
	POTW	2[g]	8.8E-02	0.4	M	
Metalworking Fluids	Included with release estimates for Batch Open Top Vapor Degreasing[f].					Section 2.15.4
Wipe Cleaning and Metal/Stone Polishes	EPA does not expect wastewater discharges containing PCE from these sites.				H	Section 2.16.4
Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	EPA did not identify data to estimate wastewater discharges for this OES.					Section 2.17.4
Other Industrial Uses	Surface Water	7	1.1E-06	0.3	M	Section 2.18.4

Occupational Exposure Scenario (OES)	Release Media/ Treatment Facility Type[a]	Number of Sites with Wastewater Discharges[b]	Estimated Daily Release Range Across Sites (kg/site-day)[c]		Overall Confidence	Corresponding Section in the Supplemental Engineering Report (U.S. EPA, 2019a)
			Minimum[d]	Maximum		
Other Commercial Uses	Surface Water	7	1.3E-05	2.9E-03	M	Section 2.19.4
Laboratory Chemicals	EPA did not identify data to estimate wastewater discharges for this OES.					Section 2.20.4
Waste Handling, Disposal, Treatment, and Recycling	Surface Water	5	5.9E-05	3.8E-03	M	Section 2.21.4
	POTW	4	3.6E-07	0.3	M	
	Non-POTW WWT	4	5.4E-03	1.4	M	

[a] The daily discharge estimates presented in this table represent both direct discharges to surface water and indirect discharges to POTW and non-POTW WWT. Removal efficiencies at POTWs and non-POTW WWT are taking into account in the environmental exposure assessment.
[b] For most conditions of use, only a subset of the facilities are expected to discharge wastewater containing PCE. Other sites may dispose of PCE-containing wastes through other means such as via landfill or incineration.
[c] Except for commercial dry cleaning estimates; the minimum and maximum daily discharge estimates are based on site-specific discharges (*i.e.*, the minimum corresponds to the site with the lowest discharge and the maximum corresponds to the site with the highest discharge). Minimum daily discharge at any given site may be higher than the minimum presented, and the maximum daily discharge may be lower than the value presented.
[d] The minimum presented represents the minimum of the sites that have wastewater discharges, it does not include sites that dispose of PCE through other media which would result in a minimum of zero for most OES.
[e] Discharges from these sites may be to either surface water or POTW but not both for a given site.
[f] EPA does not have enough information to distinguish whether sites from TRI and DMR use PCE in OTVDs, closed-loop degreasers, conveyorized degreasers, web degreasers, cold cleaners, or metalworking fluids. Therefore, the daily release estimates may include sites that perform any of these activities.
[g] These two sites reported both direct and indirect discharges.

2.2.1.2 Approach and Methodology

2.2.1.2.1 Wastewater Discharge Estimates

EPA performed a literature search to identify process operations that could potentially result in direct or indirect discharges to water for each condition of use. Where available, EPA used 2016 Toxics Release Inventory (TRI) (U.S. EPA, 2017j) and 2016 Discharge Monitoring Report (DMR) (U.S. EPA, 2016a) data to provide a basis for estimating releases. Facilities are only required to report to TRI if the facility has 10 or more full-time employees, is included in an applicable NAICS code, and manufactures, processes, or uses the chemical in quantities greater than a certain threshold within a calendar year (25,000 pounds per year for manufacturers and processors of PCE and 10,000 pounds per year for users of PCE). Due to these limitations, some sites that manufacture, process, or use PCE may not report to TRI and are therefore not included in these datasets.

For the 2016 DMR, EPA used the Water Pollutant Loading Tool within EPA's Enforcement and Compliance History Online (ECHO) to query all PCE point source water discharges in 2016. DMR data are submitted by National Pollutant Discharge Elimination System (NPDES) permit holders to states or directly to the EPA according to the monitoring requirements of the facility's permit. States are only required to load major discharger data into DMR and may or may not load minor discharger data. The definition of major vs. minor discharger is set by each state and could be based on discharge volume or facility size. Due to these limitations, some sites that discharge PCE may not be included in the DMR dataset.

Facilities reporting discharges in TRI and DMR also report associated NAICS and Standard Industrial Classification (SIC) industry codes, respectively. Where possible, EPA reviewed the NAICS and SIC descriptions for each reported discharge and mapped each facility to a potential condition of use associated with occupational exposure scenarios (OES, see Table 2-14). For facilities that did not report a NAICS or SIC code, EPA performed a supplemental internet search of the specific facility to determine the mapping. Facilities that could not be mapped were grouped together into an "Other" category.

EPA's preference was to use TRI or DMR data to assess wastewater discharges; however, due to the reporting requirements for each dataset (described above in this section), these data may not be available for all conditions of use or for all sites within a condition of use. In such cases, EPA estimated wastewater discharges using release data from literature, relevant emission scenario documents (ESD) or generic scenarios (GS), existing EPA/OPPT models, and/or relevant Effluent Guidelines (EG). EG are national regulatory standards set forth by EPA for wastewater discharges to surface water and municipal sewage treatment plants.

When possible for each OES covering conditions of use, EPA estimated annual releases, average daily releases, and number of release days/yr. Where TRI and/or DMR were available, EPA used the reported annual releases for each site and estimated the daily release by averaging the annual release over the estimated release days/yr. Where ESDs, GSs, existing models, or EGs were used EPA estimated a daily release and calculated the annual release by multiplying the daily release by the number of release days per year.

2.2.1.2.2 Estimates of Number of Facilities

Where available, EPA used 2016 CDR (U.S. EPA, 2016d), 2016 TRI (U.S. EPA, 2017j), 2016 Discharge Monitoring Report (DMR) (U.S. EPA, 2016a) and 2014 National Emissions Inventory (NEI) (U.S. EPA, 2018a) data to provide a basis to estimate the number of sites using PCE within a condition of use. Generally, information for reporting sites in CDR and NEI was sufficient to accurately characterize each reporting sites condition of use. However, information for determining the condition of use for reporting sites in TRI and DMR is typically more limited.

In TRI, sites submitting a Form R indicate whether they perform a variety of activities related to the chemical including, but not limited to: produce the chemical; import the chemical; use the chemical as a reactant; use the chemical as a chemical processing aid; and ancillary or other use. In TRI, sites submitting Form A are not required to designate an activity. For both Form R and Form A, TRI sites are also required to report the primary North American Industry Classification System (NAICS) code for their site. For each TRI site, EPA used the reported primary NAICS code and activity indicators to determine the condition of use at the site. For instances where EPA could not definitively determine the condition of use because: 1) the reported NAICS codes could include multiple conditions of use; 2) the site reported multiple activities; and/or 3) the site did not report activities due to submitting a Form A, EPA had to make an assumption on the condition of use to avoid double counting the site. For these sites, EPA supplemented the NAICS code and activity information with the following information to determine a "most likely" or "primary" condition of use:

- Information on known uses of the chemical and market data identifying the most prevalent conditions of use of the chemical.
- Information obtained from public comments and/or industry meetings with EPA that provided specific information on the site.

In DMR, the only information reported on condition of use is each site's Standard Industrial Classification (SIC) code. EPA could not determine each reporting site's condition of use based on SIC code alone; therefore, EPA supplemented the SIC code information with the same supplementary information used for the TRI sites (market data, public comments, and industry meetings).

Where the number of sites could not be determined using CDR/TRI/DMR/NEI or where CDR/TRI/DMR/NEI data were determined to not capture the entirety of sites within a condition of use, EPA supplemented the available data with U.S. economic data using the following method:

1. Identify the NAICS codes for the industry sectors associated with these uses.
2. Estimate total number of sites using the U.S. Census' Statistics of US Businesses (SUSB) (SUSB Data) data on total establishments by 6-digit NAICS.
3. Use market penetration data to estimate the percentage of establishments likely to be using PCE instead of other chemicals.
4. Combine the data generated in Steps 1 through 3 to produce an estimate of the number of sites using PCE in each 6-digit NAICS code, and sum across all applicable NAICS codes for the condition of use to arrive at a total estimate of the number of sites within the condition of use.

Table 2-3 summarizes the number of facilities estimates for each OES. Based on reasonably available data, EPA does not expect all sites within a condition of use will have wastewater discharges containing PCE; therefore, the number of facilities estimates in Table 2-3 may be greater than the number of sites presented in release summary in Table 2-2.

Table 2-3. Summary of EPA's Estimates for the Number of Facilities for Each OES

Occupational Exposure Scenario (OES)	Number of Facilities	Notes
Manufacturing	8	Based on CDR reporting
Repackaging	51	Based on TRI and DMR reporting
Processing as a Reactant	117	Based on TRI and DMR reporting
Incorporation into Formulation, Mixture, or Reaction Product	39	Based on TRI and DMR reporting
Batch Open-Top Vapor Degreasing	398 to 4,942	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Batch Closed-Loop Vapor Degreasing	13,912 to 25,546	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Conveyorized Vapor Degreasing	395 to 568	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Web Degreasing	395 to 568	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Cold Cleaning	17	Based on NEI reporting
Aerosol Degreasing and Aerosol Lubricants	75,938	Based on Census data and a market penetration of 29.6% based on California Air Resources Board (CARB) survey of automotive maintenance and repair facilities
Dry Cleaning and Spot Cleaning	12,822 (commercial) 12 (industrial)	Commercial estimate based on Census data and a market penetration of 60% based on information from the Dry Cleaning and Laundry Institute and the National Cleaners Association Industrial estimate based on U.S. EPA (2006c) economics report
Adhesives, Sealants, Paints, and Coatings	60	Based on NEI reporting
Maskant for Chemical Milling	71	Based on stakeholder information from AC Products (2017)
Industrial Processing Aid	98	Based on TRI and DMR reporting
Metalworking Fluids	-	No information identified to estimate number of facilities
Wipe Cleaning and Metal/Stone Polishes	-	No information identified to estimate number of facilities
Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	-	No information identified to estimate number of facilities
Other Industrial Uses	130	Based on TRI and DMR reporting
Other Commercial Uses	-	No information identified to estimate number of facilities

Occupational Exposure Scenario (OES)	Number of Facilities	Notes
Laboratory Chemicals	-	No information identified to estimate number of facilities
Waste Handling, Disposal, Treatment, and Recycling	94	Based on TRI and DMR reporting

2.2.1.2.3 Estimates of Release Days

EPA referenced ESDs, NEI data, SpERCs, or needed to make assumptions when estimating release days for each OES. A summary along with a brief explanation is presented in Table 2-4 below.

Table 2-4. Summary of EPA's Estimates for Release Days for Each OES

Occupational Exposure Scenario (OES)	Release Days	Notes
Manufacturing	350	Assumes operation seven days/week and 50 weeks/yr with two weeks down for shutdown activities
Repackaging	250	Assumed 5 days per week and 50 weeks per year
Processing as a Reactant	350	Assumes operation seven days/week and 50 weeks/yr with two weeks down for shutdown activities
Incorporation into Formulation, Mixture, or Reaction Product	300	SpERC for the formulation and (re)packing of substances and mixtures (European Solvents Industry, 2019)
Batch Open-Top Vapor Degreasing	260	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Batch Closed-Loop Vapor Degreasing	260	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Conveyorized Vapor Degreasing	260	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Web Degreasing	260	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Cold Cleaning	260	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)
Aerosol Degreasing and Aerosol Lubricants	-	Wastewater discharges not expected from this OES
Dry Cleaning and Spot Cleaning	250 to 312	Assumes facilities may operate five days/week and 50 weeks/yr at the low-end up to six days/week and 52 weeks/yr at the high-end
Adhesives, Sealants, Paints, and Coatings	250	Assumed 5 days per week and 50 weeks per year
Maskant for Chemical Milling	172 to 208	Based on NEI reporting
Industrial Processing Aid	300	SpERC for the manufacture of a substance (which includes use as a process chemical or extraction agent) (European Solvents Industry, 2012)
Metalworking Fluids	260	2017 Draft ESD on the Use of Vapor Degreasers (OECD, 2017a)

Occupational Exposure Scenario (OES)	Release Days	Notes
Wipe Cleaning and Metal/Stone Polishes	-	Wastewater discharges not expected from this OES
Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	-	No information identified to estimate wastewater discharges from this OES
Other Industrial Uses	250	Assumed 5 days per week and 50 weeks per year
Other Commercial Uses	250	Assumed 5 days per week and 50 weeks per year
Laboratory Chemicals	-	No information identified to estimate wastewater discharges from this OES
Waste Handling, Disposal, Treatment, and Recycling	250	Assumed 5 days per week and 50 weeks per year

2.2.1.3 Assumptions, Key Sources of Uncertainty, and Overall Confidence for Environmental Releases

2.2.1.3.1 Release Trends

A key source of uncertainty in the assessment of environmental releases is the use of reporting year 2016 data from TRI and DMR and whether such data is a representative "snapshot" of releases from other years. To determine if 2016 data was representative of a typical reporting year, specifically with respect to reports of indirect and direct wastewater discharges, EPA used linear regression analyses and the interquartile rule for outliers on data from both reporting programs for reporting years 2012 to 2018. 2012 was chosen as the first year in the analysis as it corresponds to the earliest year production volume data was available in the 2016 Chemical Data Reporting (CDR) (the latest CDR reporting cycle). 2018 was selected as the final year in the analysis as it was the latest reporting year available for TRI at the time the analysis was initiated (DMR data was available through 2019).

Linear Regression Analysis

The linear regression analysis determines if there is significant evidence that changes in the data are increasing or decreasing from year-to-year. To perform this analysis, EPA used the Microsoft Excel Analysis Toolpak. This tool calculated both p-values and coefficients of determination (R^2) to help evaluate the presence of any linear trends in the data from year to year. In linear regression analyses, the p-value is the probability of finding an observed value of a particular statistic when the null hypothesis (*i.e.,* there is no trend between releases in year 1, year 2, etc.) is true. Simply, p-values range from zero to one with lower p-values indicating the null hypothesis is false (*i.e.,* there is a linear trend between years) and higher p-values indicating the null hypothesis is true. EPA used the standard p-value of 0.05 as the cutoff for determining statistical significance (*i.e.,* p-values<0.05 indicate a statistical trend, and p-values ≥0.05 indicate no statistical trend).

R^2 measures how well the independent variable (the year in this analysis) explains the change in the dependent variable (the release in this analysis). R^2 values range from zero to one with values closer to zero meaning the independent variable poorly predicts the dependent variable and

values closer to one meaning the independent variable does predict the dependent variable well. Unlike the p-value, there is no standard cutoff value for R^2 used in statistics to determine if the trend is a "good fit." Rather, R^2 values are discussed qualitatively to provide context to the trends.

Interquartile Rule for Outliers

The interquartile range (IQR) is the difference between the third quartile (*i.e.*, 75th percentile) and first quartile (*i.e.*, 25th percentile) of a dataset. The interquartile rule for outliers states that if the distance between a data point and the first or third quartile is greater than 1.5 times the IQR, the data point is an outlier (*i.e.*, values <25th percentile -1.5IQR or values >75th percentile + 1.5IQR). EPA used this logic to determine if any year in the TRI or DMR data were outliers.

Trends in TRI

Figure 2-3 shows the PCE TRI data for total production related wastes reported in TRI from 2012 to 2018 divided into the following categories: recycling (includes both on- and off-site recycling), energy recovery, treatment, and releases. Figure 2-4 shows PCE releases reported in TRI divided into air emissions, surface water discharges, land disposal, and "other" (note: these values include one-time non-production related releases). Figure 2-5 shows the PCE TRI data for direct discharges to surface water and indirect discharges to POTW and non-POTW wastewater treatment (WWT).

Linear regression analyses did not find any statistically significant trends in total reported releases, indirect discharges to POTW, indirect discharges to non-POTW WWT, or direct discharges to surface water in TRI. The p-value and R^2 values from each regression analysis are provided in Table 2-5.

EPA did not identify any outlier years for total releases or indirect discharges to non-POTW WWT; however, 2014 was an outlier for both surface water discharges and indirect discharges to POTW. The surface water outlier can be attributed to a single site that reported 17,640 lbs of PCE discharged to surface water, which was the only on-site surface water discharge of PCE reported by the site for any year since 2012 with most or all of the release being attributed to a one-time non-production related release. Similarly, the POTW outlier can be attributed to a single site that reported 2,632 lb discharged to POTWs in 2014 which was the only transfer to POTW reported by the site since 2012 except 5 lbs reported in 2013.

Due to the lack of a trend from year-to-year, it is difficult to say whether 2016 is a typical year since a "typical" year cannot be statistically defined. However, the analyses performed by EPA did not provide any rationale to indicate that data from 2016 were not a representative snapshot of PCE wastewater discharges in TRI. The total releases for 2016 were the lowest of the years analyzed but the wastewater discharges were within the range of expected values for the years analyzed.

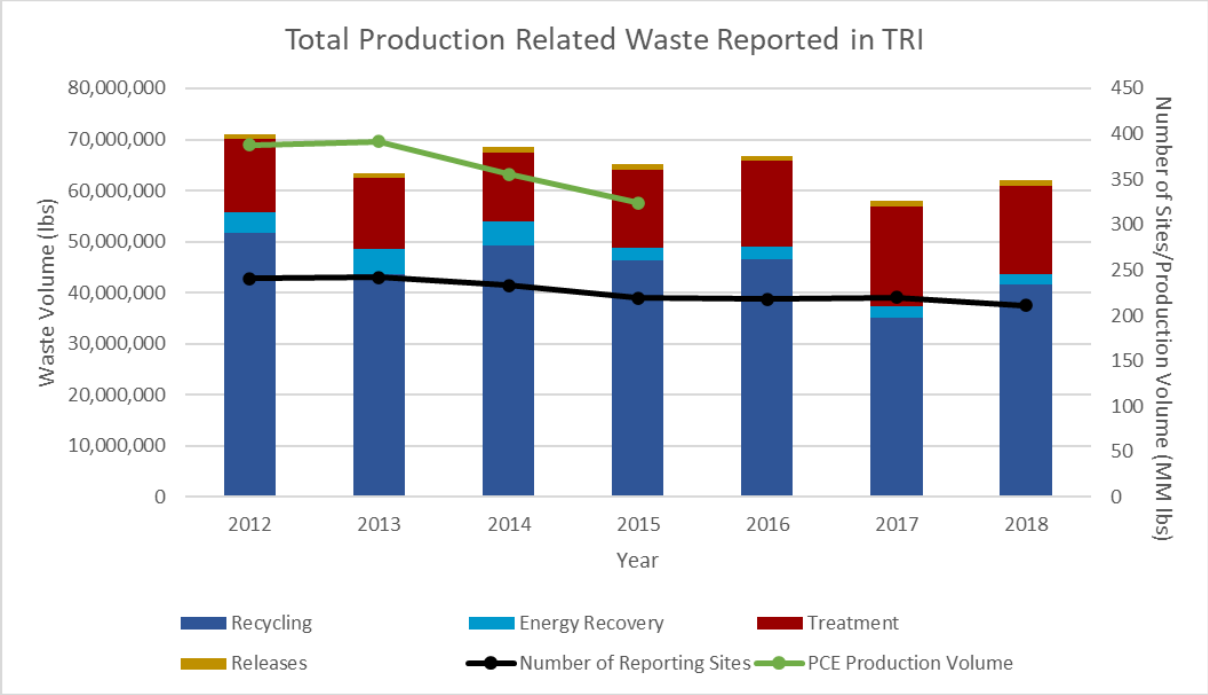


Figure 2-3. Total Production Related Waste Reported in TRI

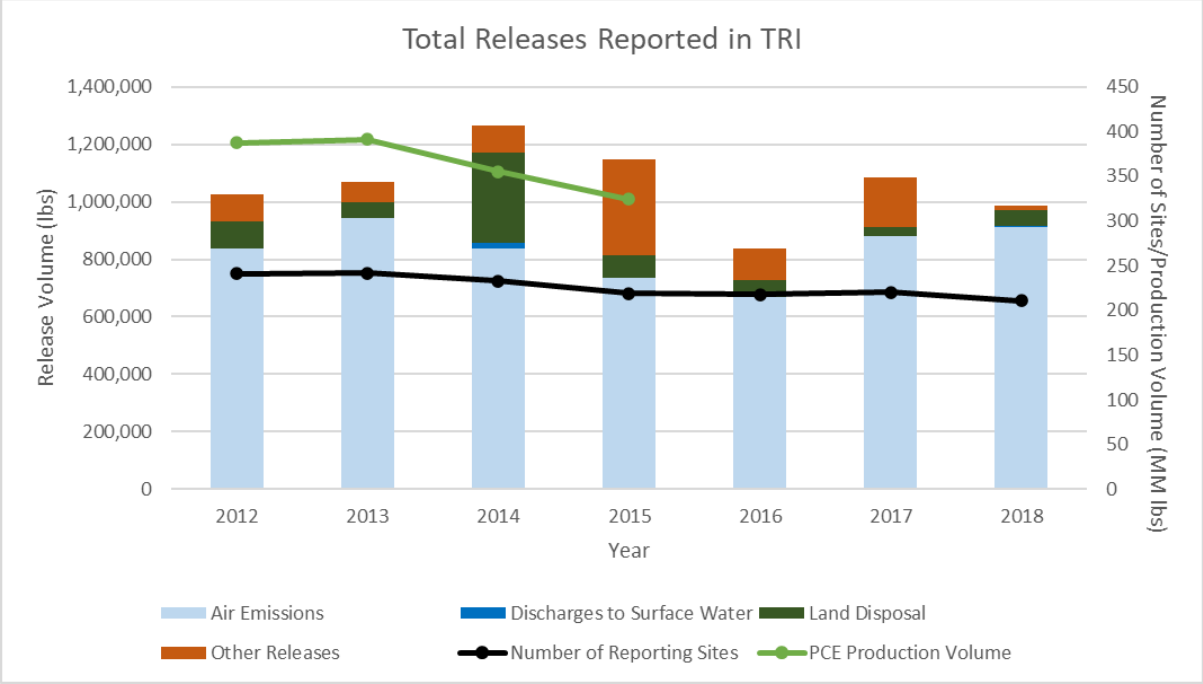


Figure 2-4. Total Releases Reported in TRI[11]

[11] These release quantities include releases due to one-time events not associated with production such as remedial actions or earthquakes

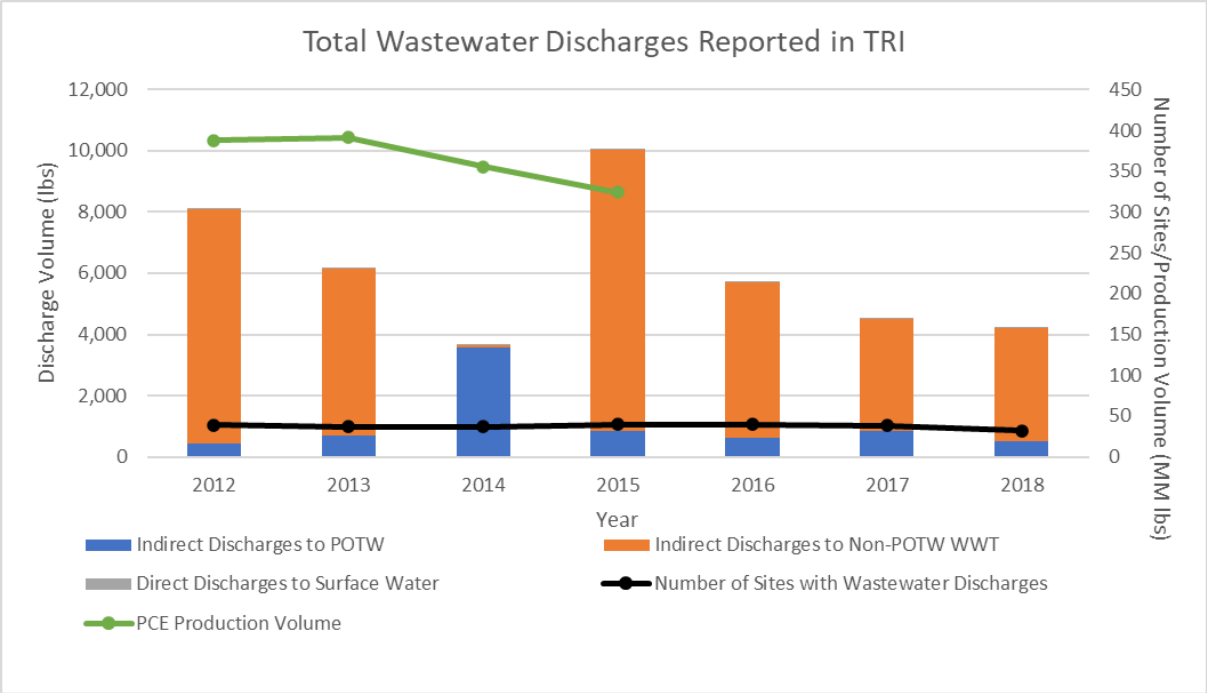


Figure 2-5. Total Wastewater Discharges Reported in TRI

Table 2-5. Results from Linear Regression Analysis of TRI Data

Data	p-Value	R^2
Total Releases	0.513	0.090
Indirect Discharges to POTW	0.715	0.029
Indirect Discharges to non- POTW WWT	0.554	0.074
Direct Discharges to Surface Water	0.663	0.041

Trends in DMR

Figure 2-6 shows the PCE DMR data for surface water discharges. Discharges were divided among discharges from POTW (including federal facilities), industrial and commercial sites, and remediation sites. DMR includes specific designations for POTWs and federal facilities; therefore, discharges from these sites were readily obtainable from the database. However, all other discharges are categorized into "non-POTW", which may include discharges from industrial and commercial sites as well as sites performing remediation activities. Since remediation activities are not in scope of the risk evaluation, EPA attempted to separate out these sites using the following logic:

- Any site determined to be a remediation site in the 2016 DMR was assumed to be a remediation site any year it reported to DMR. These sites were identified during a detailed analysis to determine the condition of use for each site in the 2016 DMR for use in the risk evaluation and included reviewing reported SIC codes and facility names and websites. EPA leveraged this information to determine remediation sites in other reporting years.

- Any facility name that contained the following terms was marked as a remediation site: “groundwater”, “GW treatment”, “remediation”, “superfund”, “former”, “restoration”, “well”, “GWCU”, “reclamation.”
- Any site that reported the following SIC codes were marked as remediation: 1794–Excavation Work and 4959–Sanitary Services, Not Elsewhere Classified.

Figure 2-7 shows the same data; however, on a different scale (Figure 2-7 is a “zoom-in” of Figure 2-6 cut-off at 10,000 lbs for discharges). Due to the large difference between 2014 and other reporting years, it is difficult to compare reporting years using only Figure 2-6. Therefore, EPA presented both figures to better illustrate the data.

Similar to the TRI analysis, the linear regression analyses did not find any statistically significant trends in total reported discharges, or discharges from industrial and commercial sites in DMR. The p-value and R^2 values from each regression analysis are provided in Table 2-6.

EPA did not identify any outlier years for discharges from industrial and commercial sites; however, similar to TRI, 2014 was an outlier for total reported discharges in DMR. This outlier year can be attributed to a single remediation site that reported 608,310 lbs of PCE discharged to surface water in 2014 but did not report more than 3,005 lbs for any other year since 2012.

Due to the lack of a trend from year-to-year it is difficult to say whether 2016 is typical year since a “typical” year cannot be statistically defined. However, the analyses performed by EPA did not provide any rationale to indicate that data from 2016 were not a representative snapshot of PCE surface water discharges in DMR. The total discharges for 2016 were within the range of expected values for the years analyzed.

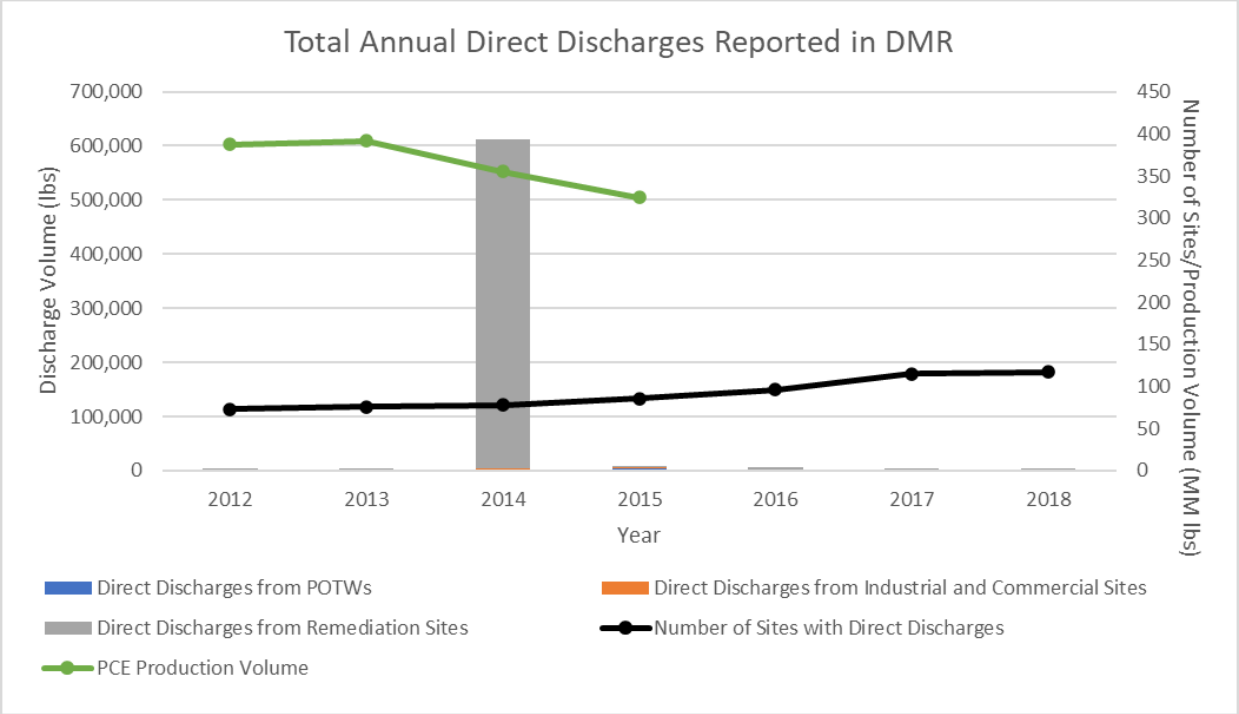
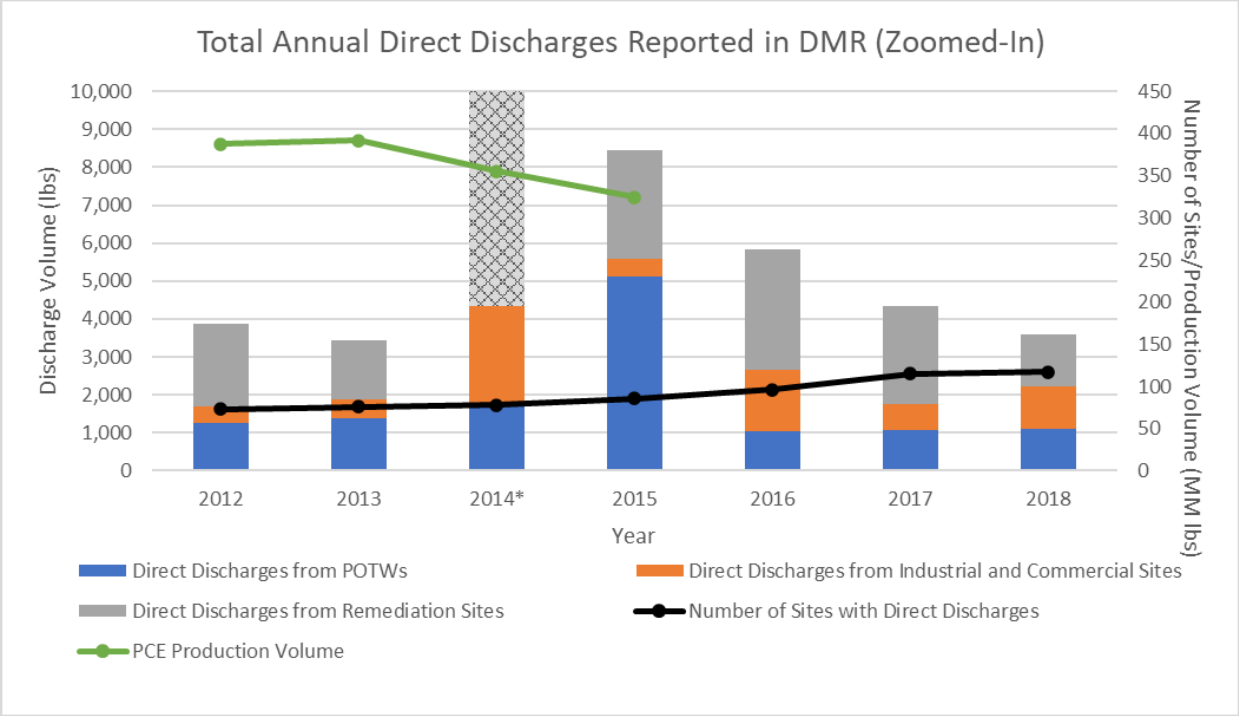


Figure 2-6. Total Annual Direct Discharges Reported in DMR



*Discharges from remediation sites in 2014 exceed the maximum value presented on the scale of this figure.

Figure 2-7. Zoom-in of Total Annual Direct Discharges Reported in DMR

Table 2-6. Results from Linear Regression Analysis of DMR Data

Data	p-Value	R^2
Direct Discharges from All Sites	0.662	0.041
Direct Discharges from Industrial and Commercial Sites	0.764	0.020

Effect on Overall Confidence in the Environmental Release Assessment

Although no statistical trends were identified in the release data, the trend analysis also did not provide any information to indicate that 2016 data were not a reasonable representation of wastewater discharges from 2012-2018. Therefore, this analysis improves EPA's overall confidence in the wastewater discharge assessment and the use of 2016 data for evaluating risks from wastewater discharges.

2.2.1.3.2 OES-Specific Assumptions, Uncertainties, and Overall Confidence for the Environmental Release Assessment

Table 2-7 provides a summary of the assumptions, key sources of uncertainty, and EPA's overall confidence in its release estimates for each of the OES assessed.

Table 2-7. Summary of Assumptions, Uncertainty, and Overall Confidence in Release Estimates by OES

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
Manufacturing	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI for four sites. TRI data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of "medium." The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in the Daily Discharge Estimates:*** EPA assumed 350 days/yr of operation (7 days/week, 50 weeks/yr with two weeks for turnaround) and averaged the annual discharges over the operating days. There is some uncertainty that all sites manufacturing PCE will operate for this duration as some sites may operate less than 7 days/wk or may have turnarounds greater than or less than the assumed 2 weeks/yr. Therefore, the average daily discharges may be higher if sites operate for fewer than 350 days/yr or lower if they operate for greater than 350 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day due to changes in process conditions (*e.g.*, total wastewater flow) such

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Strengths in Discharges Assessed Using Effluent Guidelines:*** The discharges estimated using the EG are within an order of magnitude of the discharges reported by sites in TRI. The exception to this is the Solvents & Chemicals site which had a much lower production volume than the averaged assessed at all other sites. ***Uncertainties in Discharges Assessed Using Effluent Guidelines:*** Water discharges from the remaining four sites were estimated using the maximum daily and monthly discharge limits in the OCPSF (Organic Chemicals, Plastics and Synthetic Fibers) EG and the estimated volume of wastewater produced per pound of PCE production from the SpERC developed by the European Solvent Industry Group for the manufacture of a substance. The estimates assume the sites operate at the limits set by the EG; actual releases may be lower for sites operating below the limits or higher for sites not in compliance with the OCPSF EG. Furthermore, the production volumes used to estimate discharges for two of the four sites are based on the average production volume. Each site may manufacture volumes greater than or less than the average resulting in higher or lower discharge volumes, respectively. ***Uncertainties in the Number of Sites Estimate:*** Information to determine the activity at two of the assessed sites as manufacture or import was not publicly available. It is possible these two sites are importers and not manufacturers; thus, eliminating the wastewater discharges from manufacturing at these sites (note: the sites may have other wastewater discharges of PCE depending on the conditions of use at the site). ***Overall Confidence Rating:*** Based on the data quality score and the uncertainties in the daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates for the four sites in the 2016 TRI. Based on the uncertainties in using effluent guidelines and the number of sites, EPA has a medium confidence in the wastewater discharge estimates for the four sites assessed using the OCPSF EG.
Repackaging	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in Number of Sites Estimate:*** Due to reporting requirements for TRI and DMR, the number of sites in this OES may be underestimated.

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	It is uncertain the extent that sites not captured in these databases discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. Additionally, information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are performing repackaging activities rather than a different condition of use. If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA assumed 250 days/yr of operation and averaged the annual discharges over the operating days. There is some uncertainty that all sites repackaging PCE will repackage PCE for this duration as some sites may not repackage PCE every day while others may operate more than 5 days/week and 50 weeks/yr. Therefore, the average daily discharges may be higher if sites repackage for fewer than 250 days/yr or lower if they repackage for greater than 250 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Processing as a Reactant	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in Number of Sites Estimate:*** Due to reporting requirements for TRI and DMR, the number of sites in this OES may be underestimated. It is uncertain the extent that sites not captured in these databases discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. Additionally, information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are processing PCE as a reactant rather than a different condition of use. If the sites were categorized under a different OES, the

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA assumed 350 days/yr of operation (7 days/week, 50 weeks/yr with two weeks for turnaround) and averaged the annual discharges over the operating days. There is some uncertainty that all sites processing PCE as a reactant will operate for this duration as some sites may operate less than 7 days/wk, have turnarounds greater than or less than the assumed 2 weeks/yr, or not manufacture products that use PCE as a reactant every day. Therefore, the average daily discharges may be higher if sites operate for fewer than 350 days/yr or lower if they operate for greater than 350 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Incorporation into Formulation, Mixture, or Reaction Product	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in Number of Sites Estimate:*** Due to reporting requirements for TRI and DMR, the number of sites in this OES may be underestimated. It is uncertain the extent that sites not captured in these databases discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. Additionally, information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are performing formulation activities rather than a different condition of use. If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA assumed 300 days/yr of operation and averaged the annual discharges over

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	the operating days. There is some uncertainty that all sites formulating PCE-based products will operate for this duration as some sites may not make products that contain PCE every day while others may operate more than 300 days/yr based on product demand and process needs. Therefore, the average daily discharges may be higher if sites operate for fewer than 300 days/yr or lower if they operate for greater than 300 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Batch Open-Top Vapor Degreasing	***Data Quality Ratings:*** For sites that meet the reporting requirements, wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Limitations to Release Data for Site Reporting to TRI/DMR:*** Due to reporting requirements for TRI and DMR, only 123 sites related to degreasing operations are captured in the databases. The remaining sites may not be captured in the data due to not meeting reporting thresholds in the case of TRI, or because they do not discharge PCE to surface water in the case of DMR (discharges to POTW and non-POTW WWT are not reported in DMR). Information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the TRI/DMR sites assessed in this section are using PCE in OTVD rather than a different condition of use (including other vapor degreasing and cold cleaning operations and use of PCE in metalworking fluids). If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA assumed 260 days/yr of operation and averaged the annual discharges over the operating days. There is some uncertainty that all sites using PCE in OTVDs will operate for this duration as some sites may use degreasing equipment more or less frequently than 260 days/yr depending on process

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	demands. Therefore, the average daily discharges may be higher if sites operate for fewer than 260 days/yr or lower if they operate for greater than 260 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Strengths of the Release Model for Sites not Reporting to TRI/DMR:*** Wastewater discharges from sites not reporting to TRI/DMR are assessed using the *EPA/OPPT Water Saturation Loss Model*, which assumes that water contacted with the chemical becomes saturated with the chemical and remains saturated at the time of disposal. The low end of the amount of water in contact with PCE is estimated to be 2 gals/day based on data from literature (U.S. EPA, 1977). ***Uncertainties in the Release Model for Sites not Reporting to TRI/DMR:*** The high-end of the amount of water in contact with PCE used in the *EPA/OPPT Water Saturation Loss Model* is 20 gal/day. This is an order of magnitude estimate from the data provided in literature (U.S. EPA, 1977). The U.S. EPA (1977) estimate of 2 gal/day does not account for steam stripping of still bottoms in distillation units or from regeneration of carbon beds used for emission controls (where such controls are present). To account for this additional water usage, EPA used an order of magnitude assumption and assessed no more than 20 gals/day of water will come into contact with PCE. However, the true amount produced is unknown and can be affected by the use patterns (*e.g.,* frequency of carbon bed regeneration) and size of degreasers used at a given site. There is also some uncertainty on how sites will dispose of water containing-PCE; however, EPA expects discharges to be either to POTW or non-POTW WWT to reduce concentrations of PCE below regulatory limits set forth in effluent guidelines prior to discharge to surface water. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates from sites reporting to TRI and DMR. Based on the strength and uncertainties of the model, EPA has a medium level of confidence in the wastewater discharges from sites not reporting to TRI/DMR.
Batch Closed-Loop Vapor Degreasing	Same as the Open-Top Vapor Degreasing (OTVD) OES.
Conveyorized Vapor Degreasing	Same as the Open-Top Vapor Degreasing (OTVD) OES.
Web Degreasing	Same as the Open-Top Vapor Degreasing (OTVD) OES.
Cold Cleaning	Same as the Open-Top Vapor Degreasing (OTVD) OES.
Aerosol Degreasing and Aerosol Lubricants	EPA assessed no wastewater discharges for this OES. There is some uncertainty as to whether and how much PCE may deposit on shop floors. However, due to the volatility of PCE, EPA expects PCE to evaporate from any such deposit prior to it being discharged; thus, limiting any potential discharges to surface water, POTW, or non-POTW WWT from this source.

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	Based on this information, EPA has a high confidence in the release assessment.
Dry Cleaning and Spot Cleaning	***Data Quality Ratings:*** Wastewater discharges from industrial launderers are assessed using reported discharges from the 2016 DMR. DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. The "low" scores are a result of the information available in DMR. For example, DMR does not include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Limitations to Release Data for Industrial Launderer:*** DMR does not contain data for 4 of the 12 industrial launderer sites. These four sites may not be in DMR because they may have no water discharges or because they discharge to sewer rather than surface water (sewer discharges not reported in DMR). ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to DMR only report annual discharges; to assess daily discharges, EPA assumed 250 to 312 annual days of operation and averaged the annual discharges over the operating days. There is some uncertainty that all industrial launderers using PCE will operate for this duration as site-specific demands may result in higher or lower operating days. Therefore, the average daily discharges may be higher if sites operate for fewer than the operating days or lower if they operate for greater than the operating days. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. Based on this information, EPA has a medium confidence in the wastewater discharge estimates at industrial launderers. ***Strengths of the Release Model for Small Commercial Dry Cleaners:*** Wastewater discharges from small commercial dry cleaners is assessed using the Solvent Release in Water Discharge from Dry Cleaning Machines Model. The model is based on the *EPA/OPPT Water Saturation Loss Model*, which assumes that water contacted with the chemical becomes saturated with the chemical and remains saturated at the time of disposal. The primary difference between this model and the *EPA/OPPT Water Saturation Model* is this model calculates the amount of produced wastewater using data (and distributions, where available) obtained from literature for the volume of water produced water per pound of clothes cleaned, load size, and loads per day. Using these parameters and distributions the model is able to capture variability in the amount of produced wastewater at dry cleaners. ***Uncertainties in the Release Model for Small Commercial Dry Cleaners:*** There is some uncertainty on how sites will dispose of water containing-PCE and some states may regulate the disposal; therefore, not all sites are expected to discharge wastewater to POTW.

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	Overall Confidence Rating: Based on the data quality score, the limitations to the release data, and the uncertainties in the daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates at industrial launderers. Based on the strengths and uncertainties of the model, EPA has a medium level of confidence in the wastewater discharge estimates at small commercial dry cleaners.
Adhesives, Sealants, Paints, and Coatings	***Uncertainties in the Release Model:*** Wastewater discharges from adhesive, sealant, coating, and paint applications are assessed using loss fractions from ESDs and the *EPA/OPPT Automobile OEM (Original Equipment Manufactuer) Coating Overspray Loss Model*. These approaches represent release estimates for the solids (*i.e.*, non-volatile) portions of the coatings or adhesives and do not account for potential evaporation of volatiles from the mist prior to entering wastewater. Therefore, these estimates likely overestimate actual wastewater discharges of PCE due to volatilization (PCE vapor pressure is 18.5 mmHg at 25°C). This evaporation is difficult to estimate and is not considered in this assessment. ***Uncertainties in Use Rate:*** EPA did not identify any sites in TRI that use PCE as an adhesive or coating. Therefore, EPA assumed the use-rate for any site not in TRI would be just below the TRI reporting threshold for "otherwise use" of 10,000 lb/yr. Therefore, EPA assessed the PCE use-rate to be 9,999 lb/yr. EPA did not have data to determine if this is representative of typical coating or adhesive application sites. For sites with use rates less than 9,999 lb/yr, wastewater discharges may be underestimated. ***Uncertainties in Application Methods:*** EPA estimated releases for roll coating and spray coating applications with water curtains. However, it is unknown how many sites use these application methods. For sites that use dip, syringe/bead, or spray coating applications with dry filters, there may be no wastewater discharges containing PCE. ***Uncertainties in the Media of Release:*** EPA assessed all the captured mists/splatter to be discharged to POTW; however, some sites may dispose of captured mists/splatter to incineration or landfill. EPA did not identify data to determine how many sites dispose to POTW versus other media/treatment methods. ***Uncertainties in Number of Sites Estimate:*** There is further uncertainty that the number of sites obtained from the 2014 NEI represent the total number of sites using adhesives or coatings containing PCE. NEI data only covers specific industries which may not capture the entirety of industries using these products. NEI also does not include operations that are classified as area sources because area sources are reported at the county level and do not include site-specific information. It is uncertain the extent that sites not captured in this assessment discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. ***Overall Confidence Rating:*** Based on the uncertainties described above, EPA has a low confidence in the wastewater discharge estimates.
Maskant for Chemical Milling	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in Number of Sites Estimate:*** The discharges in TRI and DMR do not include 44 of the expected 71 sites that use PCE-based maskants. It is uncertain the extent that sites not captured in these databases discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT; however, the sites may be required to comply with the Metal Finishing EG. Additionally, information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are performing maskant operations rather than a different condition of use. If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA used site-specific reported operating time from the 2014 NEI, where available, or assumed 172 days/yr of operation (based on the average operating time from the 2014 NEI) and averaged the annual discharges over the operating days. There is some uncertainty that all sites using PCE-based maskants will operate for this duration as, based on process needs, some sites may perform masking activities more or less frequently than the average days/yr from NEI or use other maskants not containing PCE for certain operations. Therefore, the average daily discharges may be higher if sites operate for fewer than the estimated operating days or lower if they operate for greater than the estimated operating days. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Industrial Processing Aid	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in Number of Sites Estimate:*** Due to reporting requirements for TRI and DMR, the number of sites in this OES may be underestimated. It is uncertain the extent that sites not captured in these databases discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. Additionally, information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are using PCE as a processing aid rather than a different condition of use. If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA assumed 300 days/yr of operation and averaged the annual discharges over the operating days. There is some uncertainty that all sites using PCE as a processing aid will operate for this duration as some sites may use PCE processing aids more or less frequently than 300 days/yr based on process needs. Therefore, the average daily discharges may be higher if sites operate for fewer than 300 days/yr or lower if they operate for greater than 300 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Metalworking Fluids	Same as the Open-Top Vapor Degreasing (OTVD) OES.
Wipe Cleaning and Metal/Stone Polishes	EPA assessed no wastewater discharges for this OES. There is some uncertainty as to whether and how much PCE may drip from the rag/cloth or the substrate surface onto shop floors or ground (for outdoor applications). However, due to the volatility of PCE, EPA expects PCE to evaporate from any such deposit prior to it being discharged; thus, limiting any potential discharges to surface water, POTW, or non-POTW WWT from this source. Based on this information, EPA has a high confidence in the release assessment.
Other Spot Cleaning/Spot	No information identified to estimate wastewater discharges from this OES.

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
Removers (Including Carpet Cleaning)	
Other Industrial Uses	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in Number of Sites Estimate:*** Due to reporting requirements for TRI and DMR, the number of sites in this OES may be underestimated. It is uncertain the extent that sites not captured in these databases discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. Additionally, information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are performing other industrial uses rather than a different condition of use. If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA assumed 250 days/yr of operation and averaged the annual discharges over the operating days. There is some uncertainty that all sites using PCE for other industrial uses will operate for this duration as some sites may use PCE more or less frequently than 250 days/yr based on process needs. Therefore, the average daily discharges may be higher if sites operate for fewer than 250 days/yr or lower if they operate for greater than 250 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Other Commercial Uses	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 DMR. DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	resulting in an overall quality of medium. The "low" scores are a result of the information available in DMR. For example, DMR does not include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates. ***Uncertainties in Number of Sites Estimate:*** Due to reporting requirements for DMR, these sites are not expected to capture the entirety of water releases from this OES. It is uncertain the extent that sites not captured in DMR discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. Additionally, information on the conditions of use of PCE at facilities in DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are performing other commercial uses rather than a different condition of use. If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to DMR only report annual discharges; to assess daily discharges, EPA assumed 250 days/yr of operation and averaged the annual discharges over the operating days. There is some uncertainty that all sites using PCE in other commercial uses will operate for this duration as some sites may use PCE more or less frequently than 250 days/yr based on process needs. Therefore, the average daily discharges may be higher if sites operate for fewer than 250 days/yr or lower if they operate for greater than 250 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Laboratory Chemicals	No information identified to estimate wastewater discharges from this OES.
Waste Handling, Disposal, Treatment, and Recycling	***Data Quality Ratings:*** Wastewater discharges are assessed using reported discharges from the 2016 TRI and the 2016 DMR. TRI and DMR data were determined to have a "medium" data quality rating through EPA's systematic review process. Specifically, the TRI and DMR data were scored high for representativeness of geographic scope, applicability, and temporal representativeness but scored low for methodology, accessibility/clarity, and variability/uncertainty resulting in an overall quality of medium. The "low" scores are a result of the information available in each data source. For example, neither TRI nor DMR include: data on how each reporter estimated their releases (methodology); metadata (*e.g.*, release frequency, process/unit operation that is the source of the release) other than the media of release (accessibility/clarity); or address variability/uncertainty in the reported estimates.

Occupational Exposure Scenario (OES)	Assumptions, Uncertainty, and Overall Confidence in Release Estimates
	Uncertainties in Number of Sites Estimate: Due to reporting requirements for TRI and DMR, the number of sites in this OES may be underestimated. It is uncertain the extent that sites not captured in these databases discharge wastewater containing PCE and whether any such discharges would be to surface water, POTW, or non-POTW WWT. Additionally, information on the conditions of use of PCE at facilities in TRI and DMR is limited; therefore, there is some uncertainty as to whether all of the sites assessed in this section are performing waste treatment, disposal, and recycling activities rather than a different condition of use. If the sites were categorized under a different OES, the annual wastewater discharges for each site would remain unchanged; however, average daily discharges may change depending on the number of operating days expected for the OES. ***Uncertainties in the Daily Discharge Estimates:*** Facilities reporting to TRI and DMR only report annual discharges; to assess daily discharges, EPA assumed 250 days/yr of operation and averaged the annual discharges over the operating days. There is some uncertainty that all sites disposing/treating/recycling wastes containing PCE will operate for this duration as some sites may receive/treat PCE-containing wastes more or less frequently than 250 days/yr based on customer demands. Therefore, the average daily discharges may be higher if sites operate for fewer than 250 days/yr or lower if they operate for greater than 250 days/yr. Furthermore, PCE concentrations in wastewater discharges at each site may vary from day-to-day such that on any given day the actual daily discharges may be higher or lower than the estimated average daily discharge. ***Overall Confidence Rating:*** Based on the data quality score, and the uncertainties in the number of sites and daily discharge estimates, EPA has a medium confidence in the wastewater discharge estimates.
Other Department of Defense Uses	No information identified to estimate wastewater discharges from this OES.

2.3 Environmental Exposures

The manufacturing, processing, use and disposal of PCE can result in releases to the environment. In this section, EPA presents what approach and methodology was used to evaluate PCE exposures to aquatic organisms via surface water. The environmental exposure characterization focuses on aquatic releases of PCE from facilities that use, manufacture, or process PCE under industrial and/or commercial conditions of use subject to TSCA regulations.

To characterize environmental exposure, EPA identified and reviewed national scale monitoring data. Measured surface water concentrations were obtained from EPA's Water Quality Exchange (WQX) using the online Water Quality Portal (WQP) tool, which is the nation's largest source of water quality monitoring data and includes results from EPA's STORage and RETrieval (STORET) Data Warehouse, the United States Geological Survey (USGS), National Water Information System (NWIS), and other federal, state, and tribal sources. A full systematic review of reasonably available surface water literature was also conducted to identify other peer-

reviewed or grey literature[12] sources of measured surface water concentrations in the US. Point estimate exposures were derived from both measured and predicted concentrations of PCE in surface water in the United States. Predicted surface water concentrations were modeled for facility releases in the EPA Lifecycle Release Analysis conducted for reporting year 2016, as determined from EPA's Toxics Release Inventory (TRI), Discharge Monitoring Reports (DMR; through EPA's Water Pollutant Loading Tool), and EPA's Chemical Data Reporting (CDR).

The aquatic modeling was conducted with EPA's Exposure and Fate Assessment Screening Tool, version 2014 (E-FAST 2014) (U.S. EPA, 2014b), using reported annual release/loading amounts (kg/yr) and estimates of the number of days per year that the annual load is released. As appropriate, two scenarios were modeled per release: release of the annual load over an estimated maximum number of operating days per year and over only 20 days per year. Twenty days of release was modeled as the low-end release frequency at which possible ecologic chronic risk could be determined. Additionally, the Probabilistic Dilution Model (PDM), a module of E-FAST 2014 was run to estimate the number of days a stream concentration will exceed the designated concentration of concern (COC) value.

The measured concentrations reflect localized ambient exposures at the monitoring sites, and the modeled concentrations reflect near-site estimates at the point of release. A geospatial analysis at the watershed level (HUC-8 and HUC-12; Hydrologic Unit Codes) was conducted to compare the measured and predicted surface water concentrations and investigate if the facility releases may be associated with the observed concentrations in surface water. Hydrologic Unit Codes (HUCs) are a geographically hierarchical tiered approach to organizing stream networks across the United States from regions to sub water sheds and part of the Watershed Boundary Dataset developed by U.S. Geological Survey and U.S. Department of Agriculture (USGS, 2013). HUC-8 and HUC-12 sized units were selected as they were expected to give a representative geographic size range over which predicted surface water concentrations would be relevant to measured concentrations.

2.3.1 Aquatic Exposure Modeling Approach

Surface water concentrations resulting from wastewater releases of PCE from facilities that use, manufacture, or process PCE related to TSCA conditions of use were modeled using EPA's Exposure and Fate Assessment Screening Tool, Version 2014 (U.S. EPA, 2014b). E-FAST 2014 is a model that estimates chemical concentrations in water to which aquatic life may be exposed using upper percentile and/or mean exposure parametric values, resulting in high-end exposure estimates. Other assumptions and uncertainties in the model, including ways it may be underestimating or overestimating exposure, are discussed in Section 2.3.4.3. Advantages to this model are that it requires minimal input parameters and it has undergone extensive peer review by experts outside of EPA. A brief description of the calculations performed within the tool, as well as a description of required inputs and the methodology to obtaining and using inputs specific to this assessment is described below. To obtain more detailed information on the E-

[12] Grey literature refers to sources of scientific information that are not formally published and distributed in peer reviewed journal articles. These references are still valuable and consulted in the TSCA risk evaluation process. Examples of grey literature are theses and dissertations, technical reports, guideline studies, conference proceedings, publicly-available industry reports, unpublished industry data, trade association resources, and government reports. (U.S. EPA, 2018c)

FAST 2014 tool from the user guide/background document (U.S. EPA, 2014b), as well as to download the tool, visit this web address: https://www.epa.gov/tsca-screening-tools/e-fast-exposure-and-fate-assessment-screening-tool-version-2014/. All model runs for this assessment were conducted between December 2018 and June 2019**.**

2.3.1.1 Exposure and Fate Assessment Screening (E-FAST) Tool 2014 Inputs

Individual model inputs and accompanying considerations for the surface water modeling for E-Fast 2014 (U.S. EPA, 2014b) are discussed in the following sections.

2.3.1.1.1 Chemical release to wastewater (WWR)

Annual wastewater loading estimates (kg/site/year or lb/site/year) were obtained from TRI, the Water Pollutant Loading Tool, or CDR in the year 2016, as discussed in the lifecycle assessment in Section 2.2.1.1**.** To model these releases within E-FAST 2014 (U.S. EPA, 2014b), the annual release is converted to a daily release using an estimated days of release per year. Below is an example calculation:

WWR (kg/day) = Annual loading (kg/site/year) / Days released per year (days/year) (Eq. 2-3)

In cases where the total annual release amount from one facility was discharged via multiple mechanisms (*i.e.*, direct to surface water and/or indirectly through one or more WWTPs), the annual release amount was divided accordingly based on reported information in TRI (Form R).

2.3.1.1.2 Release Days (days/year)

The number of days per year that the chemical is discharged is used to calculate a daily release amount from annual loading estimates (see above). Current regulations do not require facilities to report the number of days associated with reported releases. Therefore, two release scenarios were modeled for direct discharging facilities to provide upper and lower bounds for the range of surface water concentrations predicted by E-FAST 2014 (U.S. EPA, 2014b). The two scenarios modeled are a maximum release frequency (200 to 350 days) based on estimates specific to the facility's condition of use and a low-end release frequency of 20 days of release per year. The 20-day risk from chronic exposure criterion is derived from partial life cycle tests (*e.g.*, daphnid chronic and fish early life stage tests) that typically range from 21 to 28 days in duration. For indirect dischargers, only the maximum estimated days of release per year was modeled because it was assumed that the actual release to surface water would occur at receiving WWTPs which typically operate every day of the year.

2.3.1.1.3 Removal from wastewater treatment (WWT%)

The WWT% is the percentage of the chemical removed from wastewater during treatment before discharge to a body of water. As discussed in Section 2.1.2, Summary of Fate and Transport, the WWT% for PCE was estimated as 88% using the "STP" module within The EPI Suite™, which was run using default settings to evaluate the potential for PCE to volatilize to air or sorb to sludge during wastewater treatment. The WWT% of 88% was applied to releases from indirect discharging facilities because the releases are transferred off-site for treatment at a WWTP prior to discharge to surface water. A WWT% of zero was used for direct releasing facilities because the release reported in TRI and DMR already accounts for any wastewater treatment which may have occurred. In the absence of sufficient release information to determine if the release was direct or indirect, E-FAST 2014 (U.S. EPA, 2014b) was run with a WWT% of zero and 88%,

respectively. These releases are typically those identified through the OCSPF EGL data source and are from facilities that are not in DMR or TRI.

2.3.1.1.4 Facility or Industry Sector

The required site-specific stream flow or dilution factor information is contained in the E-FAST 2014 database (U.S. EPA, 2014b), which is accessed by querying a facility National Pollutant Discharge Elimination System (NPDES) number, name, or reach code. For facilities that directly discharge to surface water (*i.e.*, "direct dischargers"), the NPDES of the direct discharger was selected from the database. For facilities that indirectly discharge to surface water (*i.e.*, "indirect dischargers" because the release is sent to a waste-water treatment plant (WWTP) prior to discharge to surface water), the NPDES of the receiving WWTP was selected. The receiving facility name and location was obtained from the TRI database (Form R), if available. As TRI does not contain the NPDES of receiving facilities, the NPDES was obtained using EPA's Envirofacts search tool (https://www3.epa.gov/enviro/facts/multisystem.html, (U.S. EPA, 2019d)). If a facility NPDES was not available in the E-FAST-2014 database (U.S. EPA, 2014b), the release was modeled using water body data for a surrogate NPDES (preferred) or an industry sector, as described below.

Surrogate NPDES

In cases where the site-specific NPDES was not available in the E-FAST 2014 database (U.S. EPA, 2014b), the preferred alternative was to select the NPDES for a nearby facility that discharges to the same waterbody. Nearby facilities were identified using the Chemical Safety Mapper within IGEMS and/or search of the E-FAST 2014 database (U.S. EPA, 2014b) by reach code.

Industry Sector (SIC Code Option)

If the NPDES is unknown, no close analog could be identified, or the exact location of a chemical loading is unknown, surface water concentrations were modeled using the "SIC Code Option" within E-FAST 2014 (U.S. EPA, 2014b). This option uses the 10^{th} and 50^{th} percentile receiving 7Q10 stream flows for dischargers in a given industry sector, as defined by the Standard Industrial Classification (SIC) codes of the industry. The industrial sectors for each condition of use category can be found in Appendix E.

2.3.1.2 E-FAST 2014 Equations

2.3.1.2.1 Surface Water Concentrations

EPA used E-FAST 2014 (U.S. EPA, 2014b) estimate site-specific surface water concentrations for discharges to both free-flowing water bodies (*i.e.*, rivers and streams) and for still water bodies (*i.e.*, bays, lakes, and estuaries).

For free-flowing water body assessments, E-FAST 2014 (U.S. EPA, 2014b) calculates surface water concentrations for four stream flow conditions (7Q10, harmonic mean, 30Q5, and 1Q10 flows) using the following equation:

$$SWC = \frac{WWR \times CF1 \times \left(1 - \frac{WWT}{100}\right)}{SF \times CF2} \quad \text{(Eq. 2-1)}$$

where:

SWC	=	Surface water concentration (parts per billion (ppb) or µg/L)
WWR	=	Chemical release to wastewater (kg/day)
WWT	=	Removal from wastewater treatment (%)
SF	=	Estimated flow of the receiving stream (MLD, Million Liters per Day)
CF1	=	Conversion factor (10^9 µg/kg)
CF2	=	Conversion factor (10^6 L/day/MLD)

For still water body assessments, no simple stream flow value represents dilution in these types of water bodies. As such, E-FAST 2014 (U.S. EPA, 2014b) accounts for dilution by incorporating an acute or chronic dilution factor for the water body of interest instead of stream flows. Dilution factors in E-FAST 2014 (U.S. EPA, 2014b) are typically 1 (representing no dilution) to 200, based on NPDES permits or regulatory policy. The following equation is used to calculate surface water concentrations in still water bodies:

$$SWC = \frac{WWR \times CF1 \times \left(1 - \frac{WWT}{100}\right)}{PF \times CF2 \times DF} \quad \text{(Eq. 2-2)}$$

where:

SWC	=	Surface water concentration (ppb or µg/L)
WWR	=	Chemical release to wastewater (kg/day)
WWT	=	Removal from wastewater treatment (%)
PF	=	Effluent flow of the discharging facility (MLD)
DF	=	Acute or chronic dilution factor used for the water body (typically between 1 and 200)
CF1	=	Conversion factor (10^9 µg/kg)
CF2	=	Conversion factor (10^6 L/day/MLD)

2.3.1.2.2 Days of COC Exceedance

The PDM portion of E-FAST 2014 (U.S. EPA, 2014b) was also run for free-flowing water bodies, which predicts the number of days per year a chemical's concentration of concern (COC) in an ambient water body will be exceeded. The model is based on a simple mass balance approach presented by (Di Toro, 1984) that uses probability distributions as inputs to reflect that streams follow a highly variable seasonal flow pattern and there are numerous variables in a manufacturing process can affect the chemical concentration and flow rate of the effluent. PDM does not estimate exceedances for chemicals discharged to still waters, such as lakes, bays, or estuaries. For these water bodies, the days of exceedance is assumed be zero unless the predicted surface water concentration exceeds the COC. In these cases, the days of exceedance is set to the number of release days per year (see required inputs in Section 2.3.1.1).

2.3.1.3 E-FAST 2014 Outputs

There are two main results generated from E-FAST (U.S. EPA, 2014b) that EPA used in characterizing environmental exposures: surface water concentration estimates, and the number of days a certain surface water concentration was exceeded. Site-specific surface water concentration estimates for free-flowing water bodies are reported for both the 7Q10 and harmonic mean stream flows. The 7Q10 stream flow is the lowest consecutive 7-day average flow during any 10-year period. The harmonic mean stream flow, a less conservative value, is the inverse mean of reciprocal daily arithmetic mean flow values. Site-specific surface water concentration estimates for still water bodies are reported for calculations using the acute dilution factors. In cases where site-specific flow/dilution data were not available, the releases were modeled using stream flows of a representative industry sector, as calculated from all facilities assigned to the industry sector in the E-FAST database (U.S. EPA, 2014b) (discussed below). Estimates from this calculation method are reported for the 10^{th} percentile harmonic mean and 10^{th} percentile 7Q10 stream flows.

2.3.2 Surface Water Monitoring Data Gathering Approach

To characterize environmental exposure in ambient water for PCE, EPA used two approaches to obtain measured surface water concentrations. One approach was to conduct a search of published literature for surface water concentrations in peer reviewed journals and the second was to pull monitoring data on surface water concentrations from the WQP.

2.3.2.1 Method for Systematic Review of Surface Water Monitoring Data

EPA conducted a review of published literature to identify studies reporting concentrations of PCE in surface water associated with background levels of contamination or potential releases from facilities that manufacture, process, use and/or dispose of PCE in the United States. Studies clearly associated with releases from Superfund sites, improper disposal methods, and landfills were considered off-PECO and excluded from data evaluation and extraction. The systematic review process is described in detail in Section 1.5. A total of 26 surface water studies were extracted and the results are summarized in Section 2.3.4.2.3. A total of 3 U.S. surface water studies were extracted and the results are summarized in Section 2.3.4.2.3.

2.3.2.2 Method for Obtaining Surface Water Monitoring Data from WQX/WQP

The primary source for the occurrence of PCE in surface water is monitoring data retrieved from the Water Quality Portal (WQP), which integrates publicly available U.S. water quality data from multiple databases: 1) USGS NWIS, 2) STORET, and 3) the USDA ARS Sustaining The Earth's Watersheds - Agricultural Research Database System (STEWARDS). For PCE the data retrieved originated from the NWIS and STORET databases. NWIS is the Nation's principal repository of water resources data USGS collects from over 1.5 million sites, including sites from the National Water-Quality Assessment (NAWQA). STORET refers to an electronic data system originally created by EPA in the 1960s to compile water quality monitoring data. NWIS and STORET now use common web services, allowing data to be published through WQP tool. The WQP tool and User Guide is accessed from the following website: (http://www.waterqualitydata.us/portal.jsp, (Nwqmc, 2017))

2.3.2.2.1 Data Retrieval from WQP

Surface water data for PCE were downloaded from the WQP (Nwqmc, 2017) on October 3, 2018. The WQP can be searched through three different search options: Location Parameters, Site Parameters, and Sampling Parameters. The PCE data were queried through the Sampling Parameters search using the Characteristics parameter (selected "Tetrachloroethene (NWIS, STORET)") and Date Range parameter (selected "01-01-2008 to 12-31-2017"). Both the "Site data only" and "Sample results (physical/chemical metadata)" were selected for download in "MS Excel 2007+" format. The "Site data only" file contains monitoring site information (*i.e.*, location in hydrologic cycle, HUC and geographic coordinates); whereas the "Sample result" file contains the sample collection data and analytical results for individual samples. An example of WQP search option is shown below in Figure 2-8.

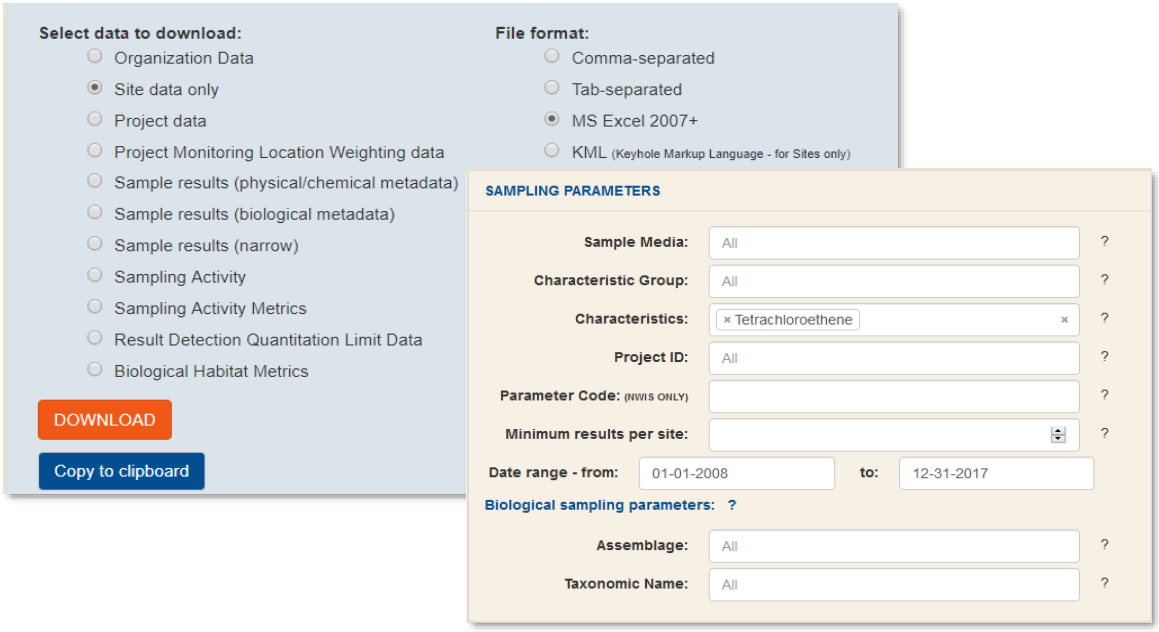


Figure 2-8. WQP Search Option. Surface water data were obtained from the WQP by querying the Sampling Parameters search option for the characteristic (STORET data), Parameter Code (NWIS data), and date range parameter.

2.3.2.2.2 Data Filtering and Cleansing

The "Site data only" and "Sample results (physical/chemical metadata)" files were linked together using the common field "Monitoring Location Identifier" and then filtered and cleansed to obtain surface water samples for years 2013 through 2017. Specifically, cleansing focused on obtaining samples were only for the media of interest (*i.e.*, surface water), were not quality control samples (*i.e.*, field blanks), were of high analytical quality (*i.e.*, no quality control issues, sample contamination, or estimated values), and were not associated with contaminated sites (*i.e.*, Superfund).

The following filtering to obtain the final dataset, the domains were examined to identify samples with non-detect concentrations. All non-detect samples were tagged and the concentrations were converted to ½ the reported detection limit for summary calculation

purposes. If a detection limit was not provided, calculations were performed using the average of the reported detection limits in all samples (calculated as 0.3 µg/L).

2.3.3 Geospatial Analysis Approach

Using 2016 data, the measured surface water concentrations from the WQP and predicted concentrations from the modeled facility releases were mapped in ArcGIS to conduct a watershed analysis at the HUC 8 and HUC 12 level. The purpose of the analysis was to identify if any the observed surface water concentrations could be attributable to the modeled facility releases. In addition, the analysis included a search for Superfund sites within 1 to 5 miles of the surface water monitoring stations to exclude these monitoring sites from the analysis. A U.S. scale map was developed to provide a spatial representation of the measured and predicted concentrations. HUCs with co-located monitoring stations and facility releases were identified and examined further. Maps were developed on a U.S. scale to provide a spatial display of the concentrations, as well as at the HUC scale to focus on co-located monitoring stations and facility releases.

2.3.3.1 Geographic Coordinates

The location of the monitoring stations was determined from the geographic coordinates (latitude and longitude) provided in WQP. Releases from facilities were located based on the geographic coordinates for the NPDES, TRI, and/or FRS of the mapped facility, as provided by FRS. For indirect dischargers, the location of the receiving facility was mapped if known. If not known, the location of the indirect discharger was mapped. Superfund sites in 2016 were identified and mapped using geographic coordinates, as reported in the Superfund Enterprise Management System (SEMS) database in Envirofacts (U.S. EPA, 2014d).

2.3.4 Environmental Exposure Results

In the section below, EPA summarizes what was identified in the evaluation of PCE in surface water. To determine what potential PCE occurrence there is in surface water, EPA evaluated both measured and modeled data using various approaches and methods. In the evaluation of PCE there are certain limitations that need to be accounted for when interpreting PCE exposure in the environment.

2.3.4.1 Aquatic Environmental Exposures

2.3.4.1.1 Predicted Surface Water Concentrations: E-FAST 2014 Modeling

A summary of the surface water concentration estimates modeled using E-FAST 2014 (U.S. EPA, 2014b), based on the lifecycle release analysis for the year 2016, is summarized by OES category in Table 2-8 through Table 2-10. For the maximum release scenario (200-350 days of release/year), surface water concentrations under 7Q10 flow conditions ranged from 5.80E-09 to 81.34 ppb (Table 2-8). For the 20 days of release/year scenario for direct dischargers, surface water concentrations under 7Q10 flow conditions ranged from 4.05E-06 to 397.25 ppb (Table 2-9). For comparison purposes, indirect releases to non-POTW WWTPs were also modeled for the 20 days of release/year scenario, resulting in surface water concentrations of 0.03 to 1220.57 ppb (Table 2-10). On a per facility basis, the 20-day release scenario yielded higher surface water concentrations than the maximum days of release scenario.

Reported loadings were used to model surface water concentrations with E-FAST 2014 (U.S. EPA, 2014b). E-FAST was run using no further removal for wastewater treatment, this is appropriate for direct release DMR data because DMRs are "submitted from facilities that have NPDES permitted outfalls (which in most cases are discharges to surface waters)" (https://echo.epa.gov/trends/loading-tool/resources/faq), and the top indirect dischargers were wastewater treatment facilities, reporting post-treatment release to surface water. TRI reporting facilities must identify the name of water body (or receiving POTW) into which the TRI chemical is being discharged (https://www.epa.gov/toxics-release-inventory-tri-program/descriptions-tri-data-terms-text-version (U.S. EPA, 2020m). Most releases were modeled using site-specific NPDES codes (50%); surrogate NPDES codes were used in only approximately 5% of the cases, with the remaining cases (45%) run using a representative industry sector SIC code. National Pollutant Discharge Elimination System (NPDES) permit codes were used to identify reach and flow characteristics for discharges. If a NPDES code was not identified, the most applicable SIC (Standard Industrial Classification) code was used. Surface water estimates were generated assuming an acute scenario of a single day release, and chronic scenarios of 20 and 250 days of release. Wastewater treatment plants and water pollution control plants were only assessed for chronic scenarios (20 and 250 days of release).

Table 2-8. Summary of Surface Water Concentrations by OES for Maximum Days of Release Scenario

OES	No. of Releases Modeled	Surface Water Concentration (7Q10) (ppb)	
		Min	Max
Manufacturing	n = 10	6.84E-06	18.48
Import/Repackaging	n = 4	3.24E-07	17.32
Processing as a Reactant	n = 18	4.15E-05	5.71
Incorporation into Formulation	n = 4	1.60E-04	81.34
OTVD	n = 17	1.00E-04	5.97
OTVD (not in TRI/DMR)	n = 1	0.25	0.25
Closed Loop Vapor Degreasers (not in TRI/DMR)	n = 1	0.25	0.25
Conveyorized Degreasers (not in TRI/DMR)	n = 1	0.25	0.25
Web Degreasers (not in TRI/DMR)	n = 1	0.25	0.25
Commercial Dry Cleaning Sites	n = 5	6.25E-03	5.51
Dry Cleaning (industrial only)	n = 2	2.69E-02	0.12
Adhesives, Paints, and Coatings	n = 2	21.59	27.76
Chemical Maskant	n = 5	5.34E-04	0.21
Industrial Processing Aid	n = 14	1.39E-05	11.39
Other Industrial Uses	n = 8	1.64E-03	31.75
Other Commercial Uses	n = 7	1.69E-03	0.37
Waste Handling, Disposal, Treatment, and Recycling	n = 13	5.80E-09	20.88
Grand Total	**n = 113**	**5.80E-09**	**81.34**

Maximum and central annual release amounts were available for four facilities/sites (Axiall Corporation, Greenchem, Solvents & Chemicals, and Univar USA Inc). This summary table only compiles the high-end release amount.

Table 2-9. Summary of Surface Water Concentrations by OES for 20 Days of Release Scenario for Direct Releaser Facilities

OES	No. of Releases Modeled	Surface Water Concentration (7Q10) (ppb)	
		Min	Max
Manufacturing	n = 5	1.19E-04	99.82
Import/Repackaging	n = 3	4.05E-06	2.18E-02
Processing as a Reactant	n = 17	7.25E-04	100
Incorporation into Formulation	n = 1	1.05E-02	1.05E-02
OTVD	n = 16	1.30E-03	77.64
Commercial Dry Cleaning Sites	n = 4	8.81E-02	79.55
Dry Cleaning (industrial only)	n = 2	0.39	1.69
Chemical Maskant	n = 3	4.60E-03	1.33
Industrial Processing Aid	n = 12	0.66	170.63
Other Industrial Uses	n = 8	2.05E-02	397.25
Other Commercial Uses	n = 7	2.11E-02	4.63
Waste Handling, Disposal, Treatment, and Recycling	n = 5	0.27	6.06
Grand Total	**n = 83**	**4.05E-06**	**397.25**

Table 2-10. Summary of Surface Water Concentrations by OES for 20 Days of Release Scenario for Indirect Releaser Facilities

OES	No. of Releases Modeled	Surface Water Concentration (7Q10) (ppb)	
		Min	Max
Manufacturing	n = 1	0.03	0.03
Import/Repackaging	n = 1	215.72	215.72
Incorporation into Formulation	n = 1	1220.57	1220.57
Waste Handling, Disposal, Treatment, and Recycling	n = 4	1.05	261.65
Grand Total	**n = 7**	**0.03**	**1220.57**

2.3.4.1.2 Characterization of Modeled Releases

As discussed in Section 2.2.1.1, releases of PCE were determined from three data sources (TRI, DMRs, and CDR) for the 2016 calendar year, and assigned to 16 TSCA COU categories. Overall, modeling was conducted on 94 unique active releasing facilities plus one industry with sites nationwide (12,822 commercial dry-cleaning sites). As some facilities may be in more than one OES category, and multiple facilities had both direct and indirect releases, a total of 103 facilities releases were modeled for both the maximum days of release and 20 days of release scenarios, as appropriate. The 94 active releasers were located in 28 states; states with the highest number of facilities (5 to 14 each) were TX, LA, IL, CO, CA, NY, and OH. The

remaining 21 states had 1 to 4 facilities each. Figure 2-9 gives a graphical representation of the number of active releasers were for each state.

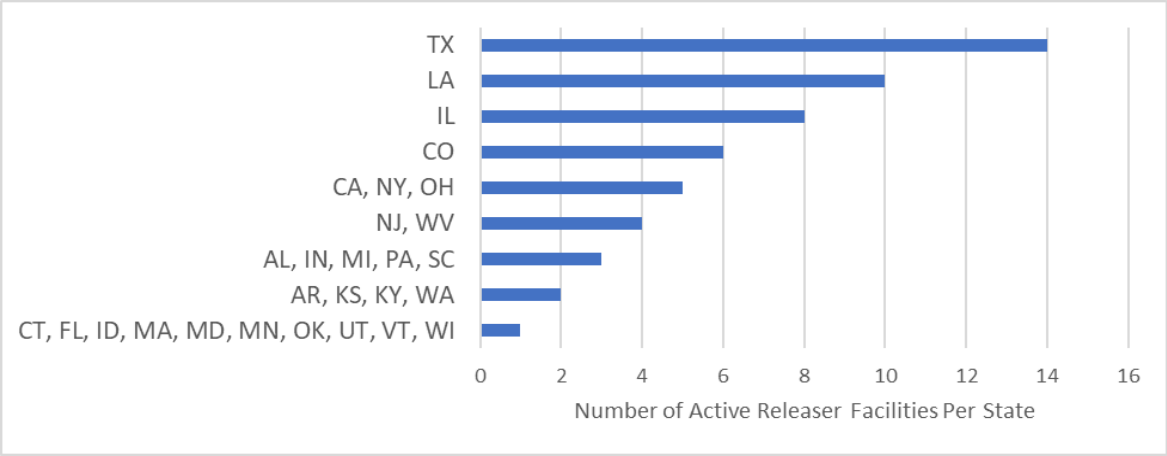


Figure 2-9. Distribution of Active Facility Releases Modeled

The location of the actual releases, when accounting for indirect dischargers, occurred in 27 states (all states as the active releaser, except CT). With respect to watersheds, the releases occurred across 66 HUC-8 areas and 82 HUC-12 areas. Over three quarters of the HUCs with facilities contained only 1 release location (76% for HUC-8 and 93% for HUC-12). The remaining HUCS contained 2 to 5 release locations each.

Direct and indirect dischargers accounted for 76% and 24% of the total releases modeled, respectively. Site-specific waterbody flow/dilution data (identified via NPDES) were available in E-FAST 2014 (U.S. EPA, 2014b) for the majority of the releases (51%); surrogate site-specific waterbody flow/dilution data were identified for 6% of the cases; and the remaining cases (43%) were run using a representative industry sector SIC code. For releases modeled with a NPDES (including a surrogate NPDES), surface water concentrations were calculated for free-flowing water bodies in 81% of the cases, and still water bodies for the remaining cases (19%). Figure 2-10 gives a graphical representation of the modeled releases described above.

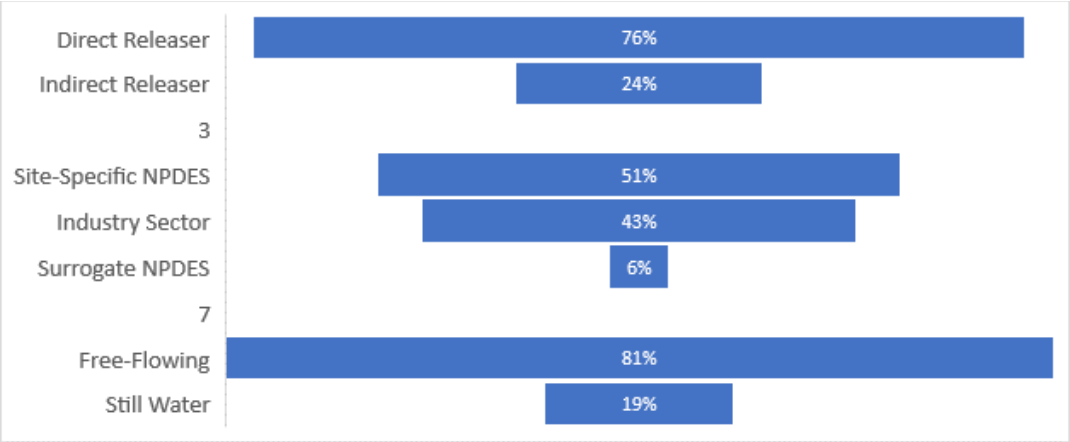


Figure 2-10. Modeled Release Characteristics (Percent Occurrence)

The predicted surface water concentrations for 65 modeled releases exceeded the lowest COC, and the PDM days of exceedance for 41 modeled releases was 20 days or more. In general, facilities with exceedances were facilities that had higher annual release amounts. Many releases, but not all, were modeled using surrogate stream flows based on the industry sector. Concentrations calculated using surrogate stream flows could be refined with the use of site-specific data.

For indirect releasers, Lord Corp in Saegertown, PA (OES: Incorporation into Formulation), had the highest surface water concentrations (both maximum days of release and 20 days of release scenarios). The annual release at this facility was the highest of all active releasers, and generally was an order of magnitude higher than all other releases. Stream flows for the receiving facility (EQ DETROIT INC, as determined from TRI) was not available in E-FAST (U.S. EPA, 2014b) and therefore the indirect release was modeled using a surrogate industry sector (SIC Code Option).

For direct releasers, GM Components Holdings LLC in Lockport, NY (OES: OTVD), had the highest surface water concentrations (both maximum days of release and 20 days of release scenarios). This facility had an annual release amount significantly lower than Lord Corp in Saegertown, PA described above, but was modeled using site-specific stream flow data for a free-flowing waterbody. A detailed summary table by facility is provided in the supplemental file "Risk Evaluation for PCE Data Extraction for Consumer and General Population Exposure Monitoring Studies."

2.3.4.2 Monitored Surface Water Concentrations

2.3.4.2.1 Measured Surface Water Concentrations from WQX/WQP

A summary of the WQX data obtained from the WQP is provided in Table 2-11 below for years 2013-2017. Per year, the cleansed datasets evaluated contained between 171 and 512 surface water samples collected from 89 to 193 unique monitoring stations. Detection frequencies were low, ranging from 5.5E-01 to 7.6%. Concentrations ranged from not detected (ND; <2.6E-02 to 5) to 9.2E-02 µg/L in 2013, ND (<2.2E-02 to 5) to 1.6 µg/L in 2014, ND (<3.4E-02 to 1.8) to 3.2E-02 µg/L in 2015, ND (<2.8E-02 to 5) to 5.2E-02 µg/L in 2016, and ND (<3.6E-02 to 5) to 6.2E-01 µg/L in 2017. The temporal trend based on the average and maximum concentrations of all samples is graphically presented in Figure 2-11**.** A peak was observed in 2014, however caution should be used in interpreting trends with this data due to the small number of samples and the lack of samples collected from the same sites over multiple years.

Table 2-11. Measured Concentrations of PCE in Surface Water Obtained from the Water Quality Portal: 2013-2017[13]

Year	Detection Frequency	Concentration in All Samples (µg/L)			Concentrations (µg/L) in Only Samples Above the Detection Limit		
		No. of Samples (No. of Unique Stations)	Range[14]	Average ± Standard Deviation (SD)	No. of Samples (No. of Unique Stations)	Range	Average ± SD[15]
2013	0.5%	366 (172)	ND (2.6E-02 to 5) to 9.2E-02	2.3E-01 ± 5.8E-01	2 (2)	7.2E-02 to 9.2E-02	8.2E-02 ± 1.4E-02
2014	7.6%	512 (193)	ND (2.2E-02 to 5) to 1.6	1.9E-01 ± 5.0E-01	39 (19)	1.1E-02 to 1.6	2.0E-01 ± 3.5E-01
2015	1.7%	347 (166)	ND (3.4E-02 to 1.8) to 3.2E-02	2.0E-01 ± 1.7E-01	6 (2)	1.7E-02 to 3.2E-02	2.5E-02 ± 6.0E-03
2016	3.5%	201 (91)	ND (2.8E-02 to 5) to 5.2E-02	2.9E-01 ± 7.6E-01	7 (4)	1.4E-02 to 5.2E-01	2.9E-02 ± 1.3E-02
2017	5.9%	171 (89)	ND (3.6E-02 to 5) to 6.2E-01	3.4E-01 ± 7.5E-01	10 (5)	1.8E-02 to 6.2E-01	2.4E-01 ± 2.6E-01
All 5 Years	4.0%	1597 (454)	ND (2.2E-02 to 5) to 1.6	2.3E-01 ± 5.5E-01	64 (27)	1.1E-01 to 1.6	1.7E-01 ± 2.9E-01

[13] Data were downloaded from the Water Quality Portal ((Nwqmc, 2017), www.waterqualitydata.us) on 10/3/2018 by selecting "Tetrachloroethene (NWIS, STORET)" for the Characteristic. Results were reviewed and filtered to obtain a cleansed dataset (i.e., samples/sites were eliminated if identified as estimated, quality control, media type other than surface water, Superfund, landfill, failed laboratory quality control, etc.).

[14] ND = Not Detected. Reported detection limits varied between samples, as shown in parentheses.

[15] Calculations were performed using ½ the reported detection limit when results were reported as not detected. If a detection limit was not provided, calculations were performed using ½ the average of the reported detection limits in all samples (average = 0.3 µg/L).

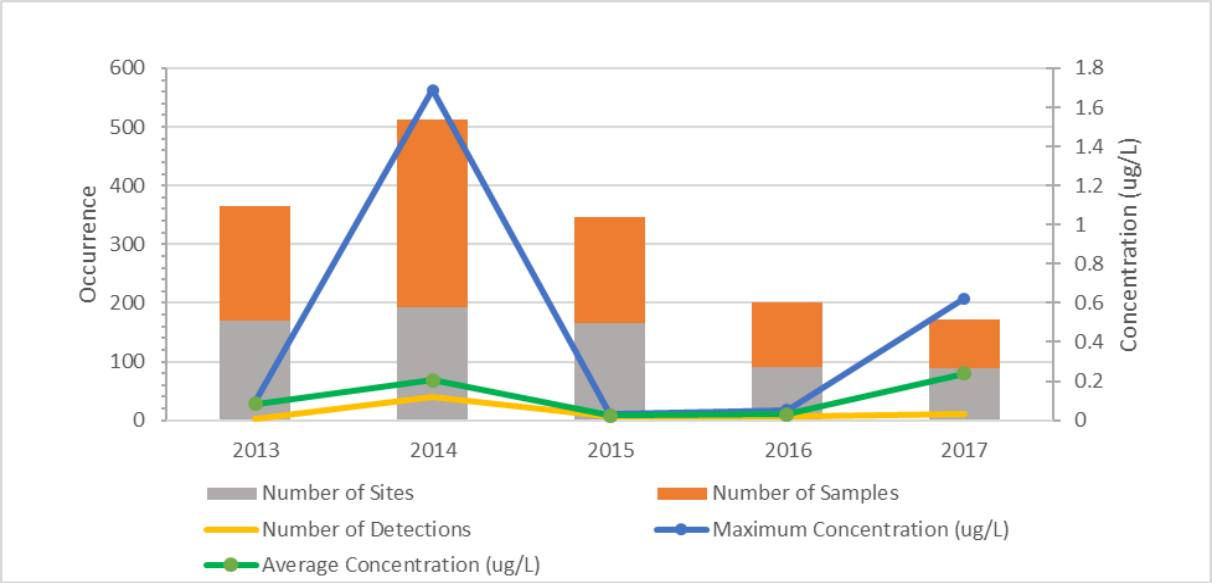


Figure 2-11. Temporal WQX Sampling and Surface Water Concentration Trends: 2013 - 2017

The quantitative ecological assessment used the 2016 data set only. For the 2016 data, only 7 samples from 4 monitoring sites (all in Tennessee) had PCE concentrations above the detection limit. The concentrations ranged from 1.4E-02 to 5.2E-02 µg/L, which are below the lowest COC of 1.4 µg/L.

Only one sample in the 2013-2017 dataset (Sample ID nwisnc.01.01400387) had a concentration that exceeded the lowest COC of 1.4 µg/L. This sample was collected in 2014 from Marsh Creek near New Hope, NC (Site ID USGS-0208732885) and had a concentration of 1.6 µg/L. The sample site was not co-located with any 2016 active releaser facility.

EPA performed a comparative trend analysis of environmental releases from 2015 to 2017 to assess the differences in environmental releases between each year. EPA determined that, 2016 (the selected data year), had a total of 137 reported environmental releases which was near the average number of releases (approximately 139) within this 3-year period. In 2016, there was 130 unique sites compared to 121 unique sites in 2015 and 148 unique sites in 2017. The number of sites with exceedance for 20 days of release did not differ significantly between the three-year period and was 36 in 2016 compared to 38 in 2015 and 2017. The number of sites with exceedance for 250 days of release did not differ significantly between the three-year and was 25 in 2016 compared to 23 in 2015 and 26 in 2017. In general, EPA determined that the environmental release data points did not differ significantly from 2015 and 2017, and in some cases 2016 data was close to the median or mean data points from 2015 to 2017. As a result, 2016 was selected as the data year for environmental releases of PCE.

2.3.4.2.2 Characterization of WQP Data

The original dataset downloaded contained 7,661 samples for years 2013 through 2017. Following the filtering and cleansing procedure, only 21% of the samples remained (n = 1,604). The majority of the samples (94%) were excluded because they were an off-topic media (*i.e.*, groundwater, artificial, bulk deposition, leachate, municipal waste, or stormwater) or location

type (*i.e.*, landfill, subsurface, spring, or well). A smaller number of samples were excluded because they were quality control samples (~2%), estimated values (~1%), or had other quality control issues (<1%). Samples associated with one Superfund site (Palermo Wellfield Superfund Site) were also excluded.

For the 2016 cleansed dataset (n = 201 samples), observations were made in 19 states/territories (AZ, IN, KS, LA, MD, MI, MN, MO, NJ, NM, NY, OH, OR, PA, PR, TN, TX, UT, and WI) at 91 unique monitoring sites, with 1 to 6 samples collected per sampling site. On a watershed level, observations were made in 47 HUC-8 areas and 68 HUC-12 areas. The majority of HUCs had only one monitoring site (68% for HUC-8; 78% for HUC-12). Up to 9 sites were present in a HUC-8 and up to 4 sites in a HUC-12. A list of individual HUCs, including the number of monitoring sites and samples in each HUC, is provided in Appendix E, Table_Apx E-2 for HUC-8 and Table_Apx E-3 for HUC-12.

An analysis of the 2016 cleansed dataset was also conducted to determine if any monitoring station may be associated with Superfund sites that could be contributing to PCE releases, and thus would not fall under the scope of this TSCA risk evaluation. For samples with concentrations above the detection limit, there are four monitoring stations within 5 miles of a Superfund site. However, there is no hydrologic connectivity as all four are located in a HUC that is adjacent to the superfund site and not in the same HUC itself. For monitoring stations that were also co-located in the same HUC as a facility, a search was also conducted for Superfund sites within 1 mile. There are two co-located monitoring stations within one mile of a superfund site: USGS-04092750 and USGS-04095090. While USGS-04092750 is found in the same HUC as a facility it is on a separate portion of the stream network from the facility. The other station USGS-04095090, is however immediately downstream of a superfund site and is closer to it (0.24 miles away) than it is to the upstream facility (2.3 miles away). Concentrations at this site were not detected (sampled in 2015-2017). No monitoring data from WQP was excluded based on proximity to a Superfund site through this analysis.

2.3.4.2.3 Measured Concentrations of PCE from Published Literature

EPA's review of published literature yielded only a minimal amount of surface water monitoring data for PCE in the U.S.; a summary of the individual studies is provided in Table 2-12. Only three studies were identified ((USGS, 2006), (USGS, 2003), and (Singh et al., 1983)), which encompassed 416 surface water samples collected from rivers and oceans between 1979 and 2001. The reported concentrations of PCE ranged from below the detection limit (1.0E-04 to 0.2) to 5.5 µg/L, with reported central tendency values ranging from <0.2 to 0.7 µg/L. The overall detection frequency is a maximum of approximately 12%. The maximum concentration was collected during a large nationwide survey of surface water for drinking water sources (rivers and reservoirs) between 1999 and 2000 (USGS, 2006)), in which PCE was only detected in 3 of 375 samples. The next highest reported concentration was only 2.8E-03 µg/L, from a sample collected in the Eastern Pacific Ocean in 1979-1981 (Singh et al., 1983).

Table 2-12. Levels of PCE in U.S. Surface Water from Published Literature

Country	Site Information	Date Sampled	N (Detection Frequency)	Concentration (µg/L)		HERO/ Source	Data Quality Score
				Range	Central Tendency (±SD)		
United States	Anchorage, AK; Chester Creek (6 urban sampling sites)	1998-2001	11 (0)	All ND (<0.2)		3975042	Medium
United States	Nation-wide; Surface water for drinking water sources (rivers and reservoirs)	1999-2000	375 (8.0E-03)	ND (<0.2)–5.5	NR	3975046	Medium
United States	Eastern Pacific Ocean (California, US to Valparaiso, Chile)	1979-1981	30 (0.9)	ND (<1.0E-04) – 2.8E-03	Mean: 0.7 (7.0E-04); Median: 4.0E-04	29192	Medium

NR = Not reported
ND = Not detected; detection limit reported in parentheses, if available.

2.3.4.2.4 Geospatial Analysis Comparing Predicted and Measured Surface Water Concentrations

A geospatial analysis at the watershed level (HUC-8 and HUC-12) was conducted to compare the measured and predicted surface water concentrations in 2016 and investigate if the facility releases may be associated with the observed concentrations in surface water. A geographic distribution of the concentrations can be found in Figure 4-3 and Figure 4-4 (east and west US, respectively) for the maximum days of release scenario, and in Figure 4-5 and Figure 4-6 (east and west US, respectively) for the 20-days of release scenario. Overall, there are 33 U.S. states/territories with either a measured concentration or a predicted concentration; at the watershed level, there are 109 HUC-8 areas and 149 HUC-12 areas with either measured or predicted concentrations. Appendix E Table_Apx E-2 and Table_Apx E-3 provides a list of states/territories with facility releases (as mapped) and/or monitoring sites.

2.3.4.2.5 Co-location of PCE Releasing Facilities and Monitoring Stations

The co-occurrence of PCE releasing facilities and monitoring stations in a HUC is shown in Figure 2-12 (Little Arkansas and Rush-vermillion) and Figure 2-13 (Little Calument-Galien and Lower Grand). There are four HUC-8 areas that have both measured and predicted concentrations. As the measured concentrations were below the detection limit and the number of samples collected was small, definitive conclusions could not be drawn on possible associations between measured concentrations in surface water and predicted concentrations from facility releases. The co-located facilities and monitoring stations are briefly described below and summarized in Table 2-13.

A. HUC 11030012 (Little Arkansas in Kansas) has one facility with modeled 7Q10 surface water concentrations ranging from 4.4E-02 to 6.6E-01 ppb, and 7 monitoring stations all with concentrations less than the reported detection limit (<0.1 ppb). The monitoring stations are over 20 miles downstream of the facility or are neither up nor downstream of the facility.

B. HUC 07040001 (Rush-Vermillion in Minnesota) has one facility with modeled 7Q10 surface water concentrations ranging from 2.8E-03 to 5.6E-02 ppb, and 1 monitoring station with a non-detect concentration (<0.1 ppb) that is located approximately 20 miles downstream of the facility.

C. HUC 04040001 (Little Calumet-Galien in Indiana) has one receiving facility with concentrations ranging from 0.1 to 1.7 ppb, and two monitoring stations with non-detect concentrations (<0.1 ppb). The monitoring stations are either over 2 miles downstream of the facility, or neither up nor downstream of the facility. It should be noted however, that a modeled receiving facility (East Chicago Municipal Sewage Treatment Plant; FRS 110006645531) is located just outside of the HUC on the south side. Monitoring site USGS-04092750 is located on a canal/ditch north of the facility; based on NHD water flows south from the monitoring site toward the facility.

D. HUC 04050006 (Lower Grand in Michigan), has one receiving facility with concentrations ranging from 0.1 to 1.0 ppb, and one monitoring station with non-detect concentrations (<0.1 ppb).

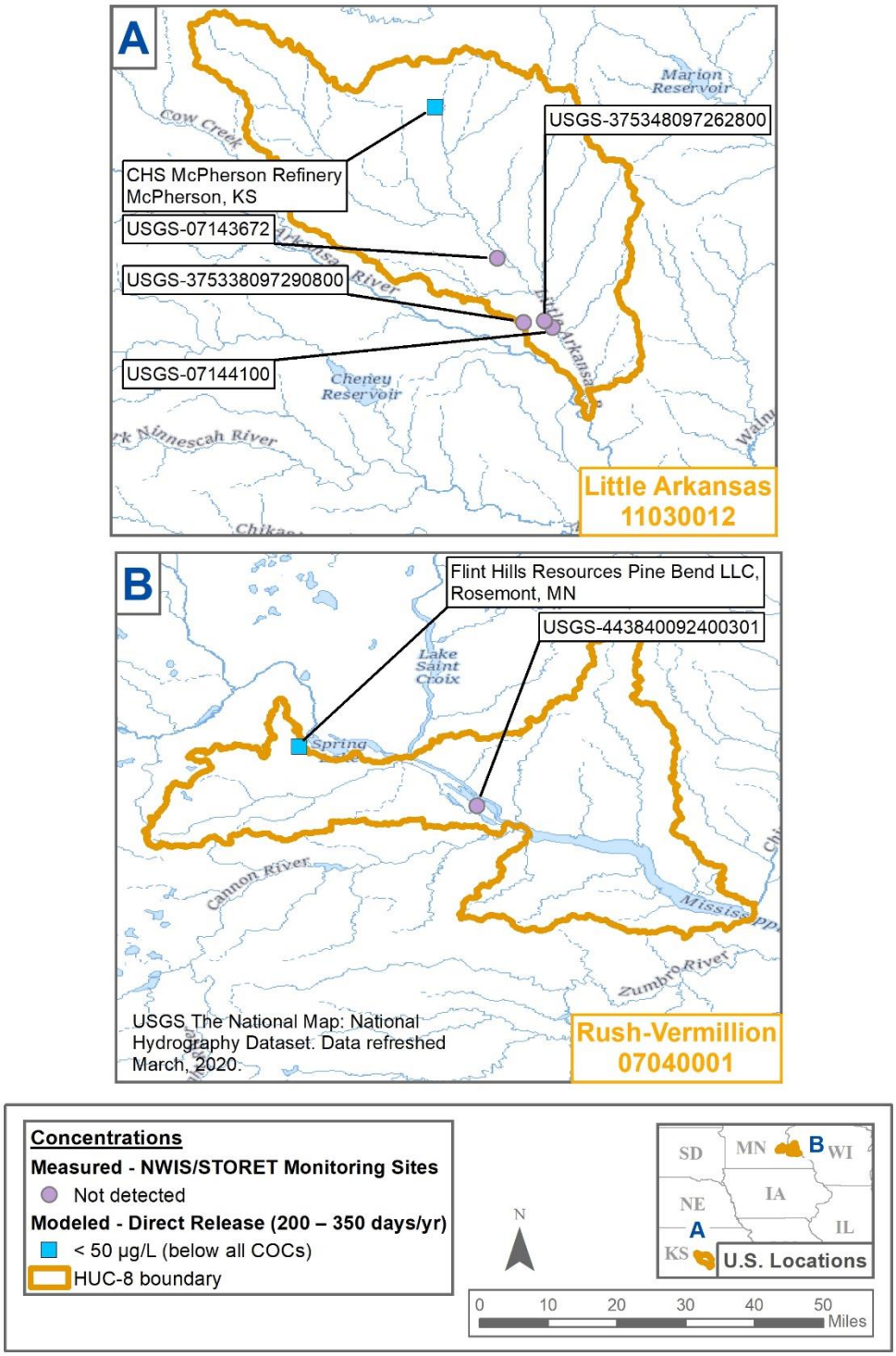


Figure 2-12. Co-Location of PCE Releasing Facilities and WQX Monitoring Stations at the HUC 8 and HUC 12 Level

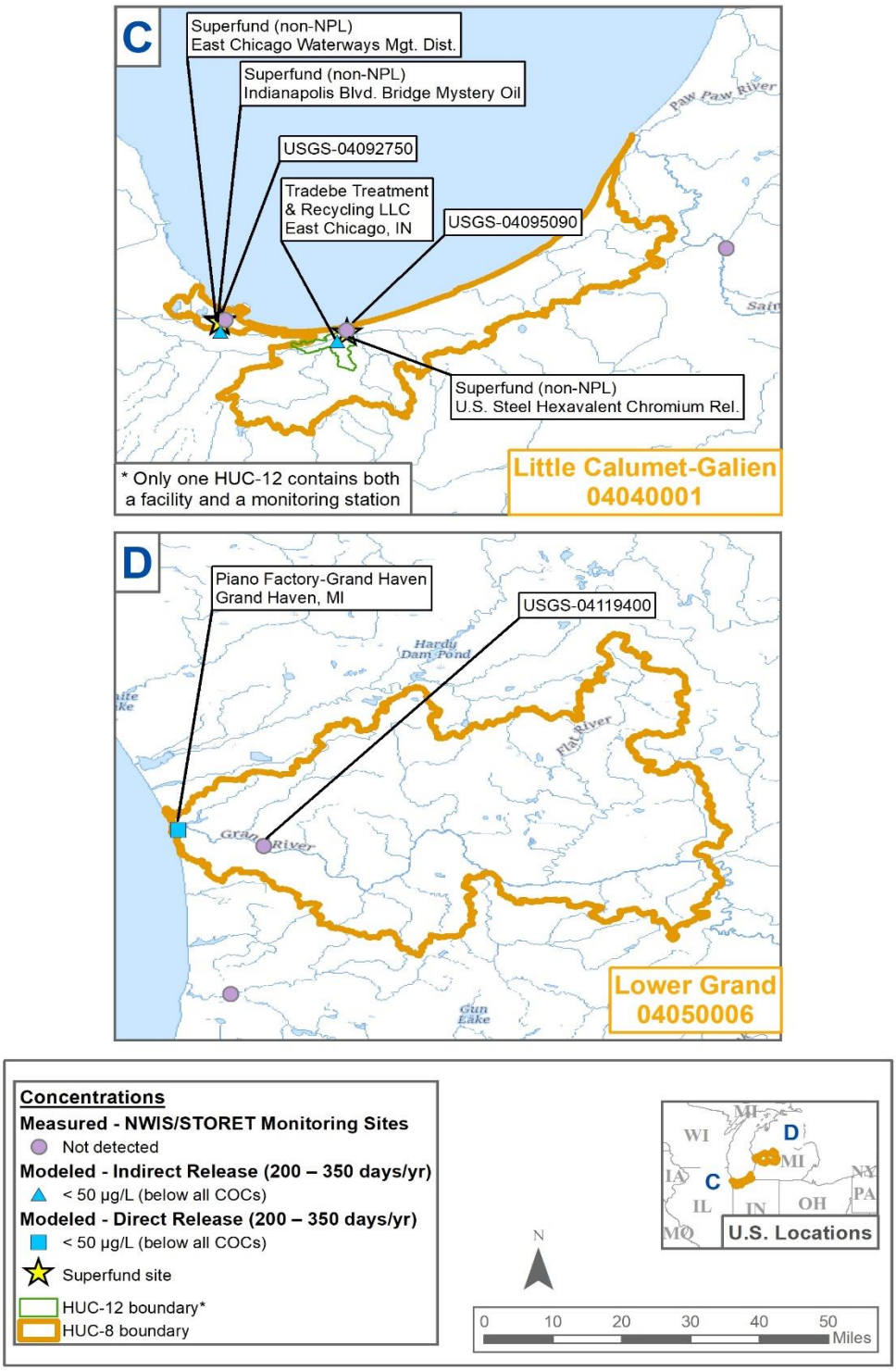


Figure 2-13. Co-Location of PCE Releasing Facilities and WQX Monitoring Stations at the HUC 8 and HUC 12 Level

Table 2-13. Co-Location of Facility Releases and Monitoring Sites within HUC 8 and HUC 12 Boundaries (2016)

Map	HUC 8	Facilities in HUC		Monitoring Sites in HUC			
		Site (Name, Location, FRS)	Modeled 7Q10 Surface Water Concentrations[a] (µg/L)	Monitoring Site ID	No. of Samples	Measured Surface Water Concentrations (µg/L)	Location Relative to Facility[b] (Miles)
A	11030012 Little Arkansas	CHS McPherson Refinery *McPherson, KS* (FRS 110015862440)	300 days: 0.0441 20 days: 0.66	USGS-07143672	4	<0.1 (all)	Downstream/23.1
				USGS-07144100	4	<0.1 (all)	Downstream/34.7
				USGS-375338097290800	2	<0.1 (all)	Downstream/33.5
				USGS-375348097262800	2	<0.1 (all)	Downstream/33.5
				USGS-375338097290800	2	<0.1 (all)	Neither/42.9
B	07040001 Rush-Vermillion	Flint Hills Resources Pine Bend LLC *Rosemount, MN* (FRS 110000424611)	350 days:0.00331 20 days: 0.0566	USGS-443840092400301	1	<0.16	Downstream/20.3
C	04040001 Little Calumet-Galien	Tradebe Treatment & Recycling LLC *East Chicago, IN* (FRS 110000397874) Receiving Facility (modeled site): Advanced Waste Services of Indiana LLC/Covanta Environmental Solutions LLC *Portage, IN* (FRS 110020159852)	250 days: 0.0841 20 days: 1.05	USGS-04095090[c]	1	<0.16	Downstream/2.3
				USGS-04092750[d]	4	<0.16 (all)	Neither/14.5
D	04050006 Lower Grand	Piano Factory-Grand Haven *Grand Haven, MI* (FRS 110006739832)	260 days: 0.0797 20 days: 1.04	USGS-04119400	4	<0.16 (all)	Upstream/10.8

[a] Concentrations above the COC of 50 µg/L are shown in bold. Concentrations leading to modeled days of exceedance ≥20 days are indicated by an asterisks (*).
[b] The number of miles between the facility and monitoring site are based on Euclidean distance.
[c] The HUC 8 co-located facility and monitoring station are also in the same HUC 12 (040400010509; Willow Creek-Burns Ditch).
[d] The East Chicago Municipal Sewage Treatment Plant (FRS 110006645531), which receives wastewater from Safety Kleen Systems, Inc. in East Chicago, IN is not located in the HUC, but is located just south of the HUC, near monitoring site USGS-04092750. This monitoring site is located on a canal/ditch, and according to NHD, the water flows south from the monitoring site toward the facility.

2.3.4.3 Assumptions and Key Sources of Uncertainty for Environmental Exposures

The WQP Tools contains data from USGS-NWIS and STORET databases, and is one of the largest environmental monitoring databases in the U.S. (Nwqmc, 2017); however, comprehensive information needed for data interpretation is not always reasonably available. In some instances, proprietary information may be withheld, or specific details regarding analytical techniques may be unclear, or not reported at all. As a result of all of these shortcomings, there are uncertainties in the reported data that are difficult to quantify with regard to impacts on exposure estimates.

The quality of the data provided in the USGS-NWIS and STORET datasets varies, and some of

the information provided is non-quantitative. While a large number of individual sampling results were obtained from these datasets, the monitoring studies used to collect the data were not necessarily specifically designed to evaluate PCE distribution across the U.S. The available data represent a variety of discrete locations and time periods; therefore, it is uncertain whether the reported data are representative of all possible nationwide conditions. Nevertheless, these limitations do not diminish the overall findings reported in this assessment that exposure data showed very few instances (*i.e.*, less than 0.01 percent) where measured PCE levels in the ambient environment exceeded the identified concentrations of concern for water or organisms (1.4 ppb). It is also important to note that only a few USGS-NWIS and STORET monitoring stations aligned with the watersheds of the PCE releasing facilities identified under the scope of this assessment, and the co-located monitoring stations had samples with concentrations below the detection limit; therefore, no direct correlation can be made between them. Generating co-located instream measurements with known discharging facilities would improve the characterization of instream concentrations of PCE in the environment and enhance modeled results.

The DMR, TRI and CDR databases represent comprehensive sources of environmental release data for the US; however, there are limitations and assumptions involved. These data are self-reported by facilities and subject to minimum reporting thresholds; therefore, they may not capture releases from smaller facilities (*i.e.*, environmental releases may be underestimated). Some of the reported information may be inaccurate because it reflects approximations rather than actual emissions or release data. TRI is based on mass balances and emission factors, whereas DMR is based on representative pollutant monitoring data at facility outfalls (mg/L) and corresponding wastewater discharge (million gallons per day). The assumed maximum days per year of release from each facility is uncertain and may in some cases lead to underestimation of daily release rates.

Use of release information from facility data used to estimate environmental exposures is constrained by a number of uncertainties including: the heterogeneity of processes and releases among facilities grouped within a given sector; assumptions made regarding sector definitions used to select facilities covered under the scope; and fluctuations in the level of production and associated environmental releases incurred as a result of changes in standard operating procedures. Uncertainty may also arise from omissions in the reporting data, such as sectors that are not required to report, facilities that fall below the reporting threshold, or facilities for which forms simply are not filed.

A major limitation associated with use of the E-FAST 2014 (U.S. EPA, 2014b) model relates to the assumptions made regarding missing information that was required for model input, such as site-specific stream flow data. When site-specific or surrogate site-specific stream flow data were not available, flow data based on a representative industry sector was used in the assessment. This includes cases where a receiving facility for an indirect release could not be determined.

The E-FAST model uses several physical-chemical and fate properties as estimated inputs (i.e., bioconcentration factor, removal in wastewater treatment, groundwater migration, etc.). The inputs for the Mackay fugacity model include degradation half-lives in environmental media, emission rates, organic carbon partition coefficient (K_{OC}), melting point, etc. Since these inputs are estimation, there may be associated errors. Due to the differences among study conditions,

generating confidence intervals for each physical-chemical and fate property would be very complex or even impossible, because EPA does not have a full extracted dataset of physical-chemical properties and there are broad differences in fate study conditions. However, the range and quality of available data were considered in the fate and exposure assessment of PCE.

The E-FAST model does not consider volatilization of PCE; and, for static water bodies, E-FAST doesn't take dilution into consideration. Therefore, in some ways the E-FAST estimates are overestimating exposure, because PCE is a volatile chemical.

Additionally, the data currently available in E-FAST 2014 (U.S. EPA, 2014b) are 15 to 30 years old. Although stream conditions do change over time, changes in the flow values are not expected to be drastic. More recent flow data are available through the National Hydrological Dataset (NHD). It is important to note however, that these limitations are unlikely to change the stated conclusions of this assessment because they are based on a series of conservative assumptions that likely overestimate exposure potential.

With respect to the geospatial analysis, a limitation is the accuracy of the latitudes and longitudes. The geographic coordinates for facilities were obtained from the FRS Interests geodatabase, which are assigned through various methods including photo-interpretation, address matching, and GPS. These are considered "Best Pick" coordinates. While EPA does assign accuracy values for each record based on the method used, the true accuracy of any individual point is unknown. Also, in some cases the receiving facilities for indirect releases could not be determined. In these cases, the location of the active releaser was mapped. As such, the co-location of facilities and monitoring sites may have been missed. As the number of unknown receiving facilities was small and most monitoring sites had samples with concentrations below the detection limit, this would have minimal impact on the watershed analysis.

2.3.4.3.1 Confidence in Aquatic Exposure Scenarios

Confidence ratings for aquatic exposure scenarios are informed by uncertainties surrounding inputs and approaches used in modeling surface water concentrations. In Section 2.2.1.1, confidence ratings are assigned to these estimated daily releases (kg/site-day) on a per occupational exposure scenario (OES) basis and primarily reflect moderate confidence (one OES shows high confidence for this estimate). These release estimates serve as the key exposure model inputs and are, therefore, an essential component of the overall aquatic exposure scenario confidence.

Other considerations that impact confidence in the aquatic exposure scenarios include the model used E-FAST 2014, (U.S. EPA, 2014b) and its associated default and user-selected values and related uncertainties. As described in Section 2.3.4.3, there are uncertainties related to the ability of E-FAST 2014 (U.S. EPA, 2014b) to incorporate downstream fate and transport; the likely number of release days from given discharging facilities; and, in some cases (*i.e.*, when the NPDES for the discharging facility cannot be found within the E-FAST database), the applied stream flow distribution.

There are monitoring data available in surface water that reflect both near-facility and ambient (*i.e.*, background) exposure levels in this media in the United States. Data from the open literature and the Water Quality Portal database reported background levels of PCE in surface water that ranged from non-detect (ND) to 310 µg/L.

2.4 Human Exposures

EPA evaluated acute and chronic exposures to workers by dermal and inhalation routes and occupational non-users (ONUs) by inhalation routes in association with PCE use in industrial and commercial applications. EPA also evaluated acute exposures to consumers by dermal and inhalation routes in association with PCE use in consumer applications. The assessed conditions of use are described above in Table 1-4; however, due to expected similarities in or lack of data to distinguish some conditions of use, both exposures/releases and occupational and consumer exposures for several of the subcategories of use in Table 1-4 were grouped and assessed together during risk evaluation. For example, subcategories for intermediate uses in industrial gas manufacturing, basic organic chemical manufacturing, and petroleum refineries may generally have similar worker activities, and EPA does not have data to distinguish whether workers are exposed differently for these subcategories. Therefore, EPA has grouped these intermediate conditions of use into one occupational scenario. A crosswalk of the conditions of use in Table 1-4 to the occupational and consumer scenarios assessed in this report is provided in Table 2-14 below. Table 2-14 also includes a crosswalk to the condition of use titles used in the supplemental file: *Supplemental Information Risk Calculator for Occupational Exposures.* The *Supplemental Information Risk Calculator for Occupational Exposures* [Risk Calculator] is an interactive spreadsheet that allows a user to view exposure results for a selected Occupational Exposure Scenario (OES) including exploring how risks change from the use of various degrees of PPE (*i.e.*, respirator assigned protection factor (APF) or glove protection factor (PF)). The user can select the desired OES, PPE options and for dermal exposures the worker type (either an average adult or a female of reproductive age) from a drop-down menu and see how risks change for the various human health hazards associated with PCE (see Section 3.2 for discussion of human health hazards).

Table 2-14. Crosswalk of Subcategories of Use Listed in Table 1-4 to Occupational Exposure Scenarios Assessed in the Risk Evaluation

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
Manufacture	Domestic manufacture	Domestic manufacture	Section 2.4.1.6– Manufacturing	Manufacturing	N/A
	Import	Import	Section 2.4.1.7 – Repackaging[c]	Repackaging	N/A
Processing	Processing as a reactant/ intermediate	Intermediate in industrial gas manufacturing	Section 2.4.1.8 – Processing as a Reactant	Processing as Reactant/ Intermediate	N/A
		Intermediate in basic organic chemical manufacturing			
		Intermediate in petroleum refineries			
		Reactant Use			
	Incorporated into formulation mixture or reaction product	Cleaning and degreasing products	Section 2.4.1.9 – Incorporation into Formulation, Mixture, or Reactant Product	Incorporation into Formulation - Degreasing Solvent; Incorporation into Formulation - Dry Cleaning Solvent;	N/A
		Adhesive and sealant products		Incorporation into Formulation - Degreasing Solvent; Incorporation into Formulation - Miscellaneous	

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
		Paint and coating products		Incorporation into Formulation - Degreasing Solvent; Incorporation into Formulation - Miscellaneous	
		Other chemical products and preparations		Incorporation into Formulation - Aerosol Packing;	
	Repackaging[c]	Solvent for cleaning or degreasing	Section 2.4.1.7– Repackaging	Repackaging	N/A
		Intermediate			
	Recycling	Recycling	Section 2.4.1.26– Waste Handling, Disposal, Treatment, and Recycling	Disposal/Recycling	N/A
Distribution in commerce	Distribution	Distribution	Activities related to distribution (*e.g.*, loading, unloading) are considered throughout the life cycle, rather than using a single distribution scenario.	N/A	N/A

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
Industrial use	Solvents (for cleaning or degreasing)	Solvents and/or Degreasers (cold, aerosol spray or vapor degreaser; not specified in comment)	See sections for specified degreasing and cleaning operations.	See sections for specified degreasing and cleaning operations.	N/A
		Batch vapor degreaser (*e.g.*, open-top, closed-loop)	Section 2.4.1.10– Batch Open-Top Vapor Degreasing; Section 2.4.1.11– Batch Closed-Loop Vapor Degreasing	Open-top Vapor Degreasing; Closed Loop Vapor Degreasing	
		In-line vapor degreaser (*e.g.*, conveyorized, web cleaner)	Section 2.4.1.12– Conveyorized Vapor Degreasing; Section 2.4.1.13– Web Degreasing	Conveyorized Vapor Degreasing; Web Degreasing	
		Cold cleaner	Section 2.4.1.14– Cold Cleaning	Cold Cleaning	
		Aerosol spray degreaser/cleaner	Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants	Aerosol Degreasing/ Lubricants	
		Dry cleaning solvent	Section 2.4.1.16– Dry Cleaning and Spot Cleaning	Post-2006 Dry Cleaning (including spot cleaning); 4th/5th Gen Only Dry Cleaning (including spot cleaning)	
		Spot cleaner			

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
	Lubricants and greases	Lubricants and greases - aerosol lubricants	Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants;	Aerosol Degreasing/ Lubricants;	N/A
		Lubricants and greases - penetrating lubricants, cutting tool coolants	Section 2.4.1.20– Metalworking Fluids	Metalworking Fluid	N/A
	Adhesives and sealants	Solvent-based adhesives and sealants	Section 2.4.1.17– Adhesive, Sealants, Paints, and Coatings	Adhesives	N/A
	Paints and coatings including paint and coating removers	Solvent-based paints and coatings, including for chemical milling	Section 2.4.1.17 – Adhesive, Sealants, Paints, and Coatings; Section 2.4.1.18– Maskant for Chemical Milling	Paints/Coatings; Chemical Maskant	N/A
	Processing aids, not otherwise listed	Pesticide, fertilizer and other agricultural chemical manufacturing	Section 2.4.1.19– Industrial Processing Aid	Industrial Processing Aid	N/A

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
	Processing aids, specific to petroleum production	Catalyst regeneration in petrochemical manufacturing	Section 2.4.1.19– Industrial Processing Aid	Industrial Processing Aid	N/A
	Other uses	Textile processing	Section 2.4.1.23– Other Industrial Uses	Other Industrial Uses – Textile Processing	N/A
		Wood furniture manufacturing	Section 2.4.1.23– Other Industrial Uses	Other Industrial Uses – Wood furniture manufacturing	
		Laboratory chemicals	Section 2.4.1.25– Laboratory Chemicals	Laboratory chemicals	
		Foundry applications	Section 2.4.1.23– Other Industrial Uses	Other Industrial Uses – Foundry Applications	
		Other DoD Uses	Section 2.4.1.23– Other Industrial Uses	Other DOD Uses – Water Pipe Repair; Other DOD Uses – Oil Analysis	

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
Commercial/consumer use	Cleaning and furniture care products	Cleaners and degreasers (other)	Section 2.4.1.21– Wipe Cleaning and Metal/Stone Polishes; Section 2.4.1.22– Other Spot Cleaning/Spot Removers (Including Carpet Cleaning); Section 2.4.1.24 – Other Commercial Uses	Wipe Cleaning and Metal/Stone Polishes; Other Spot Cleaning/Spot Removers (Including Carpet Cleaning); Other Commercial Uses - Mold Release	Section 2.4.2.3.1- Aerosol Degreasers (includes: marine cleaner, degreaser, coil cleaner, electric motor cleaner, parts cleaner, cable cleaner, stainless steel polish, electrical/ energized cleaner, wire and ignition demoisturants, electric motor cleaner; brake cleaners)
		Dry cleaning solvent	Section 2.4.1.16– Dry Cleaning and Spot Cleaning	Post-2006 Dry Cleaning (including spot cleaning); 4th/5th Gen Only Dry Cleaning (including spot cleaning)	Section 2.4.2.4- Dry-Cleaned Articles
		Spot cleaner			Section 2.4.2.3.3- Combined under Aerosol Cleaner

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
		Automotive care products (*e.g.*, engine degreaser and brake cleaner)	Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants	Aerosol Degreasing/ Lubricants	Section 2.4.2.3.1- Brake Cleaner
					Section 2.4.2.3.2- Parts Cleaner
		Aerosol cleaner			Section 2.4.2.3.3- Mold Cleaner, Weld Splatter Protectant
					Section 2.4.2.3.4– Vandalism Mark and Stain Remover
		Non-aerosol cleaner	Section 2.4.1.21– Wipe Cleaning and Metal/Stone Polishes	Wipe Cleaning and Metal/Stone Polishes	Section 2.4.2.3.5- Marble and Stone Polish (liquid)
	Lubricants and greases	Lubricants and greases (*e.g.*, penetrating lubricants, cutting tool coolants, aerosol lubricants)	Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants; Section 2.4.1.20 – Metalworking Fluids	Aerosol Degreasing/ Lubricants; Metalworking Fluid	Section 2.4.2.3.6- Cutting Fluid
					Section 2.4.2.3.7- Spray Lubricant and Penetrating Oil

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
	Adhesives and sealant chemicals	Adhesives for arts and crafts	Not assessed in occupational settings – consumer use only	N/A	Section 2.4.2.3.8- Adhesives (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant)
					Section 2.4.2.3.9 - Livestock Grooming Adhesive
		Light repair adhesives	Section 2.4.1.17– Adhesive, Sealants, Paints, and Coatings	Adhesives	Section 2.4.2.3.10- Column Adhesive, Caulk and Sealant
	Paints and coatings	Solvent-based paints and coatings	Section 2.4.1.17– Adhesive, Sealants, Paints, and Coatings	Paints/Coatings	Section 2.4.2.3.11- Outdoor watershield (liquid)
					Section 2.4.2.3.12- Coatings and primers (aerosol)

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
					Section 2.4.2.3.13-Rust Primer and Sealant (liquid)
					Section 2.4.2.3.14-Metallic Overglaze
	Other Uses	Carpet cleaning	Section 2.4.1.22–Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	Not found as consumer product
		Laboratory chemicals	Section 2.4.1.25–Laboratory Chemicals	Laboratory chemicals	Not assessed in consumer setting – occupational use only
		Metal (*e.g.*, stainless steel) and stone polishes	Section 2.4.1.21 - Wipe Cleaning and Metal/Stone Polishes	Wipe Cleaning and Metal/Stone Polishes	Section 2.4.2.3.15-Marble and Stone Polish (wax)

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
		Inks and ink removal products	Section 2.4.1.24 – Other Commercial Uses	Other Commercial Uses - Printing	Sections 2.4.2.5.3 and 2.4.2.3.4-Ink removal combined under Aerosol Cleaner (vandalism and stain remover); use in printing inks discussed as "other use"
		Welding[d]	Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants[b]	Aerosol Degreasing/ Lubricants	Section 2.4.2.3.3-Combined under Aerosol Cleaner (weld splatter protectant)
		Photographic film		Other Commercial Uses - Photographic Film	Not found as consumer product
		Mold cleaning, release and protectant products	Section 2.4.1.24 – Other Commercial Uses	Other Commercial Uses - Mold Release	Section 2.4.2.3.3-Combined under Aerosol Cleaner (mold cleaner)
Disposal[e]	Disposal	Industrial pre-treatment	Section 2.4.1.26 - Waste Handling, Disposal, Treatment and Recycling	Process Solvent Recycling and Worker Handling of Wastes	N/A
		Industrial wastewater treatment			

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario (OES)	Associated Condition of Use in Risk Calculator	Consumer Exposure Scenario
		Publicly owned treatment works (POTW)			
		Underground injection			
		Municipal solid waste landfill			
		Hazardous waste landfill			
		Other land disposal			
		Municipal waste incinerator			
		Hazardous waste incinerator			
		Off-site waste transfer			
		Off-site waste transfer			

[a] These categories of conditions of use appear in the Life Cycle Diagram, reflect CDR codes, and broadly represent conditions of use of PCE in industrial and/or commercial settings.

[b] These subcategories reflect more specific uses of PCE.

[c] The repackaging scenario covers only those sites that purchase PCE or PCE containing products from domestic and/or foreign suppliers and repackage the PCE from bulk containers into smaller containers for resale. Sites that import and directly process/use PCE are assessed in the relevant condition of use. Sites that import and either directly ship to a customer site for processing or use or warehouse the imported PCE and then ship to customers without repackaging are assumed to have no exposures or releases and only the processing/use of PCE at the customer sites are assessed in the relevant conditions of use.

[d] Identified welding products were anti-spatter aerosol products; therefore, the assessment is included with the assessment of other aerosol products.

[e] Each of the conditions of use of PCE may generate waste streams of the chemical that are collected and transported to third-party sites for disposal, treatment, or recycling. Industrial sites that treat, dispose, or directly discharge onsite wastes that they themselves generate are assessed in each condition of use assessment. This section only assesses wastes of PCE that are generated during a condition of use and sent to a third-party site for treatment, disposal, or recycling.

2.4.1 Occupational Exposures

The following subsections describe EPA's approach to assessing occupational exposures and results for each condition of use assessed. For additional details on development of approaches and results refer to the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d).

2.4.1.1 Approach to Workers and Occupational Non-Users

As described in the *Problem Formulation of the Risk Evaluation for Perchloroethylene (Ethene, 1,1,2,2-Tetrachloro)* (U.S. EPA, 2018d), for each condition of use, EPA endeavors to distinguish exposures for workers and occupational non-users (ONUs). Normally, a primary difference between workers and ONUs is that workers may handle PCE and have direct contact with the chemical, while ONUs are working in the general vicinity of workers but do not handle PCE and do not have direct contact with PCE being handled by the workers. The size of the area that ONUs may work can vary across each OES and across facilities within the same OES and will depend on the facility configuration, building and room sizes, presence of vapor barrier, and worker activity pattern. For example, an ONU can be a production employee whose workstation is located on the factory floor where a degreasing unit is installed. Absence of any vapor barrier (*e.g.,* walls) between the degreaser and the rest of the factory, this "area" can be an entire factory floor. Alternately, the area can be in a specific room of a building where a chemical is handled (*e.g.,* a room in a dry cleaning shop where the dry cleaning machine is installed and where dry-cleaned loads are unloaded, pressed, and finished). Where possible, for each condition of use, EPA identified job types and categories for workers and ONUs.

EPA evaluated inhalation exposures to workers and ONUs, and dermal exposures to workers. EPA did not assess dermal exposures to ONUs as EPA does not expect ONUs to have routine dermal exposures in the course of their work. Depending on the condition of use, ONUs may have incidental dermal exposures due to surface contamination. However, data (*e.g.,* frequency and amount of liquid on the skin after contact) were not identified to assess this exposure.

2.4.1.2 Number of Workers and Occupational Non-Users Approach and Methodology

Where available, EPA used CDR data to provide a basis to estimate the number of workers and ONUs. EPA supplemented the available CDR data using available market data; NAICS and SIC code data from TRI, DMR, and NEI sites identified for each condition of use (for number of sites estimated see Section 2.2.1.2.2); and analyzing Bureau of Labor Statistics (BLS) and U.S. Census data using the methodology described in the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d). Where market penetration data and site-specific NAICS/SIC codes from TRI/DMR/NEI were not available, EPA estimated the number of workers using data from Generic Scenarios (GSs) and Emission Scenario Documents (ESDs). For additional details on development of estimates of number of workers refer to Appendix A in the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d).

Table 2-15 presents the confidence rating of data that EPA used to estimate number of sites and workers.

Table 2-15. Data Evaluation of Sources Containing Number of Worker Estimates

Source Reference	Data Type	Data Quality Rating	Condition(s) of Use
(U.S. EPA, 2016d)	Number of Workers	High	Manufacturing
(U.S. BLS, 2016)	Number of Workers	High	Manufacturing; Repackaging; Processing as a Reactant; Incorporation into Formulation, Mixture, or Reaction Product; Cold Cleaning; Aerosol Degreasing and Aerosol Lubricants; Dry Cleaning and Spot Cleaning; Adhesives, Sealants, Paints, and Coatings; Chemical Maskants; Industrial Processing Aid; Other Industrial Uses; Laboratory Chemicals; Waste Handling, Disposal, Treatment, and Recycling
(U.S. Census Bureau, 2015)	Number of Workers	High	
(OECD, 2017a)	Number of Workers	N/A – ESD	Open-Top Vapor Degreasing, Closed-Loop Vapor Degreasing, Conveyorized Vapor Degreasing, Web Degreasing
(A. C. Products, 2017)	Number of Workers	High	Maskants for Chemical Milling
(Spirit AeroSystems, 2020)	Number of Workers	High	Maskants for Chemical Milling
(OECD, 2011)	Number of Workers	N/A – ESD	Metalworking Fluids
(OECD, 2017b)	Number of Workers	N/A – ESD	Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)
(U.S. EPA, 1994a)	Number of Workers	N/A – GS	
(CARB, 2000)	Market Penetration Data	High	Aerosol Degreasing and Aerosol Lubricants
(DLI/NCA, 2017)	Market Penetration Data	High	Dry Cleaning

2.4.1.3 Inhalation Exposures Approach and Methodology

To assess inhalation exposure, EPA reviewed exposure monitoring data identified through the systematic review process (described in Section 1.5) and monitoring data provided to EPA by other government agencies (*e.g.,* OSHA and DOD) and mapped them to specific conditions of use. Monitoring data used in the occupational exposure assessment include data collected by government agencies such as OSHA and NIOSH, and data found in published literature. For each exposure scenario and worker job category ("worker" or "occupational non-user"), where available, EPA provided results representative of *central tendency* and *high-end* exposure levels. For datasets with six or more data points, central tendency and high-end exposures were estimated using the 50th and 95th percentile value from the observed dataset, respectively. For datasets with three to five data points, the central tendency

and high-end exposures were estimated using the median and maximum values. For datasets with two data points, the midpoint and the maximum value were presented. Finally, datasets with only one data point were presented as-is. For datasets including exposure data that were reported as below the limit of detection (LOD), EPA estimated the exposure concentrations for these data, following EPA's *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994b)[16]. A dataset comprises the combined exposure monitoring data from all studies applicable to that condition of use.

For exposure assessment, personal breathing zone (PBZ) monitoring data were used to determine the time-weighted average (TWA) exposure concentration. TWA exposure concentrations are then used to calculate the Acute Concentration (AC) used for estimating acute risks (*i.e.*, risks associated from a single day or 24-hr of exposure); Average Daily Concentrations (ADC) used for estimating chronic, non-cancer risks; and Lifetime Average Daily Concentration (LADC) used for estimating chronic cancer risks. AC, ADC, and LADC are calculated using the approach and equations described in Appendix B and C of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d). Table 2-16 presents the data quality rating of monitoring data that EPA used to assess occupational exposures. EPA evaluated monitoring data using the evaluation strategies laid out in the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018b). All exposure monitoring data used in the assessment have a "high" or "medium" confidence rating.

EPA also presented TWA concentrations based on shorter averaging times (*e.g.*, 15-min, 30-min, 1-hr, and 4-hr) in addition to full-shift (either 8- or 12-hour) TWAs for several conditions of use. Although short-term exposures can be considered "acute exposures", they differ from the AC in that they are not representative of a full-day's exposure but, rather, represent exposures for a partial shift or single exposure activity. Short-term data are not used in assessing risks as health data were not reasonably available for shorter durations. AC, ADC, and LADC values are only calculated based on the full-shift (8- or 12-hr TWAs) as full-shift data represent the closest approximation to a worker's exposure for a full day (*i.e.*, 24-hr), assuming no exposure once the worker leaves the job site. The full-shift exposure results can then be averaged over 24 hours, working years, or lifetime years to estimate AC, ADC, and LADC, respectively. Short-term data may not be representative of a full day's exposure, thus, underestimating AC, ADC, and LADC results. Short-term TWAs are only presented for context where data were available to do so as EPA's primary concern for this assessment were full-shift exposures. Therefore, no effort was made to estimate shorter-term exposure values where data were not reasonably available.

For several conditions of use, EPA modeled exposure in occupational settings. The models were used to either supplement existing exposure monitoring data or to provide exposure estimates where measured data are unavailable. The use of modeling to supplement existing exposure monitoring data was primarily used to aid EPA's understanding of the monitoring data's representativeness of actual exposures within the condition of use. For example, where model results and monitoring data are similar, it helps corroborate the representativeness of the data to actual exposures. When determining unreasonable risks for scenarios with both monitoring data and modeling, EPA generally uses monitoring data results over modeling unless the data quality score for the monitoring data is low, or there were limited number of data points for the scenario such that the representativeness of the data is limited. Where measured monitoring data and models were not available, EPA estimated exposures using values from GSs and ESDs.

[16] Using the $\frac{LOD}{\sqrt{2}}$ if the geometric standard deviation of the data is less than 3.0 and $\frac{LOD}{2}$ if the geometric standard deviation is 3.0 or greater.

Table 2-17 provides a summary of the availability of monitoring data and models for estimating exposures for each OES, the number of inhalation monitoring data points (if any), the availability of monitoring data or models for workers and ONUs, the data quality scores of the monitoring data used in the assessment of each COU, and EPA's overall confidence in the exposure estimates for each OES.

Table 2-16. Data Evaluation of Sources Containing Occupational Exposure Monitoring Data

Source Reference	Data Type	Data Quality Rating	Condition of Use
(HSIA, 2018a)	PBZ Monitoring	High	Manufacturing; Processing as a Reactant
(Dow Chem, 1984a)	PBZ Monitoring	Medium	Repackaging
(Orris and Daniels, 1981)	PBZ Monitoring	High	Incorporation into Formulation, Mixture, or Reaction Product (Aerosol Packing Only)
(Gorman et al., 1984)	PBZ Monitoring	Medium	Open-Top Vapor Degreasing
(Ruhe, 1982)	PBZ Monitoring	Medium	Open-Top Vapor Degreasing
(NIOSH, 2002b)	PBZ Monitoring	High	Open-Top Vapor Degreasing
(NIOSH, 2002d)	PBZ Monitoring	High	Open-Top Vapor Degreasing
(NIOSH, 2002a)	PBZ Monitoring	High	Open-Top Vapor Degreasing; Closed-Loop Vapor Degreasing
(NIOSH, 2002c)	PBZ Monitoring	High	Closed-Loop Vapor Degreasing; Cold Cleaning
(Vulcan, 1994)	PBZ Monitoring	High	Cold Cleaning
(U.S. DOD and Environmental Health Readiness System - Industrial, 2018)	PBZ Monitoring	High	Aerosol Degreasing and Aerosol Lubricants; Dry Cleaning and Spot Cleaning; Adhesives, Sealants, Paints, and Coatings (Paints and Coatings Only); Chemical Maskant; Other DoD Uses
(Cosgrove and Hygiene, 1994)	PBZ Monitoring	High	Aerosol Degreasing and Aerosol Lubricants
(Vulcan, 1992)	PBZ Monitoring	High	Aerosol Degreasing and Aerosol Lubricants
(Vulcan, 1993)	PBZ Monitoring	High	Aerosol Degreasing and Aerosol Lubricants
(OSHA, 2017)	PBZ Monitoring	High	Dry Cleaning and Spot Cleaning

(NIOSH, 1995)	PBZ Monitoring	High	Dry Cleaning and Spot Cleaning
(Burroughs, 1999a)	PBZ Monitoring	High	Dry Cleaning and Spot Cleaning
(Burroughs, 1999b)	PBZ Monitoring	High	Dry Cleaning and Spot Cleaning
(Burroughs, 1999b)	PBZ Monitoring	High	Dry Cleaning and Spot Cleaning
(Burroughs, 2000)	PBZ Monitoring	High	Dry Cleaning and Spot Cleaning
(NIOSH, 2000)	PBZ Monitoring	High	Dry Cleaning and Spot Cleaning
(Gromiec et al., 2002)	PBZ Monitoring	Medium	Adhesives, Sealants, Paints, and Coatings (Adhesives Only)
(Chrostek and Levine, 1981)	PBZ Monitoring	High	Adhesives, Sealants, Paints, and Coatings (Paints and Coatings Only)
(Stephenson and Albrecht, 1986)	PBZ Monitoring	High	Adhesives, Sealants, Paints, and Coatings (Paints and Coatings Only)
(Hanley, 1993)	PBZ Monitoring	Medium	Adhesives, Sealants, Paints, and Coatings (Paints and Coatings Only)
(Ford Motor, 1981)	PBZ Monitoring	Medium	Adhesives, Sealants, Paints, and Coatings (Paints and Coatings Only)
(Hervin et al., 1977)	PBZ Monitoring	High	Chemical Maskant
(Dow Chem, 1983b)	PBZ Monitoring	Medium	Industrial Processing Aid
(Dow Chem, 1983a)	PBZ Monitoring	Medium	Industrial Processing Aid
(Dow Chem, 1982)	PBZ Monitoring	Medium	Industrial Processing Aid
(Dow Chem, 1979)	PBZ Monitoring	Medium	Industrial Processing Aid
(Gunter and Lybarger, 1979)	PBZ Monitoring	High	Wipe Cleaning and Metal/Stone Polishes
(Moody et al., 1983)	PBZ Monitoring	High	Wipe Cleaning and Metal/Stone Polishes
(Burton and Monestersky, 1996)	PBZ Monitoring	High	Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

(NIOSH, 1980)	PBZ Monitoring	Medium	Other Commercial Uses (Printing Only)
(Apol, 1981)	PBZ Monitoring	High	Other Commercial Uses (Printing Only)
(Love, 1982)	PBZ Monitoring	High	Other Commercial Uses (Printing Only)
(Ruhe, 1983)	PBZ Monitoring	High	Other Commercial Uses (Printing Only)
(Gunter et al., 1984)	PBZ Monitoring	High	Other Commercial Uses (Printing Only)
(Burotn, 1994)	PBZ Monitoring	Medium	Other Commercial Uses (Printing Only)
(Moseley, 1980)	PBZ Monitoring	Medium	Other Commercial Uses (Photographic Film Only)
(Stefaniak et al., 2000)	PBZ Monitoring	High	Other Commercial Uses (Photocopying Only)
(OSHA, 2020)	PBZ Monitoring	Medium	Repackaging, Incorporation into Formulation, Mixture, or Reaction Product (Aerosol Packing Only), Aerosol Degreasing and Aerosol Lubricants, Dry Cleaning and Spot Cleaning, Chemical Maskant, Other Spot Cleaning/Spot Removers (Including Carpet Cleaning), Other Commercial Uses (Printing Only), Other Industrial Uses, Laboratory Chemical, Waste Handling, Disposal, Treatment, and Recycling
(Moseley and McConnell, 1985)	PBZ Monitoring	High	Other Commercial Uses (Mold Release Only)
(A. C. Products, 2017)	PBZ Monitoring	High	Chemical Maskant
(Spirit AeroSystems, 2020)	PBZ Monitoring	High	Chemical Maskant

Table 2-17. A Summary of Approaches and Overall Confidence for Exposure Estimates for Each OES

Note: Where EPA was not able to estimate ONU inhalation exposure from monitoring data or models, this was assumed equivalent to the central tendency experienced by workers for the corresponding OES; dermal exposure for ONUs was not evaluated because they are not expected to be in direct contact with PCE and data to model incidental exposures were not available.

Occupational Exposure Scenario (OES)	Inhalation Exposure									Dermal Exposure Modeling[b]	
	Monitoring					Modeling		Overall Confidence			
	Monitoring Data	# Data Points[a]	Data Quality Rating	Worker	ONU	Worker	ONU	Worker	ONU	Worker	ONU
Manufacturing	✓	152[c]	H	✓	✓	×	×	H	M; H	✓	-
Repackaging	✓	11	M	✓	×	×	×	M	L	✓	-
Processing as a Reactant	✓	152[d]	H	✓	✓	×	×	M to H	M; M to H	✓	-
Incorporation into Formulation, Mixture, or Reaction Product (Aerosol Packing Only)	✓	8	M to H	✓	×	×	×	M to H	L	✓	-
Incorporation into Formulation, Mixture, or Reaction Product (Non-Aerosol Packing Only)	×	-	-	×	×	✓	×	M	L	✓	-
Batch Open-Top Vapor Degreasing	✓	75	M to H	✓	✓	×	×	M to H	M to H	✓	-
Batch Closed-Loop Vapor Degreasing	✓	15	H	✓	✓	×	×	H	H	✓	-
Conveyorized Vapor Degreasing	×	-	-	×	×	✓	✓	M	M	✓	-
Web Degreasing	×	-	-	×	×	✓	✓	M	M	✓	-
Cold Cleaning	✓	29	H	✓	×	✓	✓	M to H	M to H	✓	-
Aerosol Degreasing and Aerosol Lubricants	✓	144	M to H	✓	×	✓	✓	H	H	✓	-
Dry Cleaning and Spot Cleaning	✓	193[e]	M to H	✓	✓	✓	✓	H	H	✓	-
Adhesives, Sealants, Paints, and Coatings	✓	28[f]	M; M to H[g]	✓	×	×	×	M	L	✓	-
Maskant For Chemical Milling	✓	60	M to H	✓	✓	×	×	M to H	M to H	✓	-
Industrial Processing Aid	✓	89	M	✓	×	×	×	M	L	✓	-

Occupational Exposure Scenario (OES)	Inhalation Exposure									Dermal Exposure Modeling[b]	
	Monitoring					Modeling		Overall Confidence			
	Monitoring Data	# Data Points[a]	Data Quality Rating	Worker	ONU	Worker	ONU	Worker	ONU	Worker	ONU
Metalworking Fluids[h]	×	-	-	×	×	×	×	M	L	✓	-
Wipe Cleaning and Metal/Stone Polishes	✓	10	H	✓	✓	×	×	M to H	M to H	✓	-
Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	✓	4	M to H	✓	✓	×	×	M	L	✓	-
Other Industrial Uses	✓	57[i]	M	✓	×	×	×	L; M	L	✓	-
Other Commercial Uses	✓	116[j]	M to H; H; M; H[k]	✓	×	×	×	M to H; M	L	✓	-
Laboratory Chemicals	✓	1	M	✓	×	×	×	M	L	✓	-
Waste Handling, Disposal, Treatment, and Recycling	✓	12	M	✓	×	×	×	M	L	✓	-
Other Department of Defense Uses	✓	2[l]	H	✓	×	×	×	H	L	✓	-

✓ = Data or model was available; × = Data or model was not available

[a] This number only includes full-shift (8-hr and 12-hr TWAs) and does not include short-term samples (*i.e.*, 15-min, 30-min, 60-min, or 4-hr TWAs).

[b] EPA has a medium level of confidence in its dermal exposure estimates which are based on high-end/central tendency parameters and commercial/industrial settings.

[c] This count includes 75 8-hr TWA data points and 77 12-hr TWA data points.

[d] The data for this OES are the same monitoring data from PCE manufacturing sites used as surrogate for sites processing PCE as a reactant.

[e] This count includes 75 data points for the post-2006 NESHAP mix of machine generations and 118 data points for fourth and fifth generation machines only. See Section 2.4.1.16 for further discussion of the two data sets.

[f] This count includes 13 data points for adhesives/sealants and 15 data points for paints/coatings.

[g] For adhesives/sealants the data quality is M; for paints/coatings the data quality is M to H.

[h] Exposure to metalworking fluids were assessed using estimates from an ESD.

[i] This includes 38 data points for textile processing, 13 data points for wood furniture manufacturing, 4 data points for foundry applications, and 2 for miscellaneous uses.

[j] This includes 44 data points for printing applications, 3 data points for photocopying, 62 data points for photographic film applications, and 7 for mold release products.

[k] For printing applications the data quality is M to H; for photocopying the data quality is H; for photographic film applications the data quality is M; for mold release products the data quality is H.

[l] This count includes one data point for oil analysis uses at DoD sites and one data point for water pipe repair uses at DoD sites.

2.4.1.4 Consideration of Engineering Controls and Personal Protective Equipment

OSHA requires and NIOSH recommends employers utilize the hierarchy of controls to address hazardous exposures in the workplace. The hierarchy of controls strategy outlines, in descending order of priority, the use of elimination, substitution, engineering controls, administrative controls, and lastly personal protective equipment (PPE). The hierarchy of controls prioritizes the most effective measures first which is to eliminate or substitute the harmful chemical (*e.g.*, use a different process, substitute with a less hazardous material), thereby preventing or reducing exposure potential. Following elimination and substitution, the hierarchy recommends engineering controls to isolate employees from the hazard (*e.g.*, source enclosure, local exhaust ventilation systems), followed by administrative controls (*e.g.*, do not open machine doors when running), or changes in work practices (*e.g.*, maintenance plan to check equipment to insure no leaks) to reduce exposure potential. Administrative controls are policies and procedures instituted and overseen by the employer to limit worker exposures. Under Section 1910.1000, OSHA requires the use of engineering or administrative controls to bring exposures to the levels permitted under the air contaminants standard. The respirators do not replace engineering controls and they are implemented in addition to feasible engineering controls (29 CFR Section 1910.134(a)(1). As the last means of control, the use of PPE (*e.g.*, respirators, gloves) is recommended when the other control measures cannot reduce workplace exposure to an acceptable level.

OSHA's Respiratory Protection Standard (29 CFR Section 1910.134) requires employers in certain industries to address workplace hazards by implementing engineering control measures and, if these are not feasible, provide respirators that are applicable and suitable for the purpose intended. Engineering and administrative controls must be implemented whenever employees are exposed above the PEL. If engineering and administrative controls do not reduce exposures to below the PEL, respirators must be worn. Respirator selection provisions are provided in § 1910.134(d) and require that appropriate respirators are selected based on the respiratory hazard(s) to which the worker will be exposed and workplace and user factors that affect respirator performance and reliability. Assigned protection factors (APFs) are provided in Table 1 under Section 1910.134(d)(3)(i)(A) (see below in Table 2-18) and refer to the level of respiratory protection that a respirator or class of respirators could provide to employees when the employer implements a continuing, effective respiratory protection program. Implementation of a full respiratory protection program requires employers to provide training, appropriate selection, fit testing, cleaning, and change-out schedules in order to have confidence in the efficacy of the respiratory protection.

If respirators are necessary in atmospheres that are not immediately dangerous to life or health, workers must use NIOSH-certified air-purifying respirators or NIOSH-approved supplied-air respirators with the appropriate APF. Respirators that meet these criteria may include air-purifying respirators with organic vapor cartridges. Respirators must meet or exceed the required level of protection listed in Table 2-18 Based on the APF, inhalation exposures may be reduced by a factor of 5 to 10,000, if respirators are properly worn and fitted.

For atmospheres that are immediately dangerous to life and health, workers must use a full facepiece pressure demand self-contained breathing apparatus (SCBA) certified by NIOSH for a minimum service life of 30 minutes or a combination full facepiece pressure demand supplied-air respirator (SAR) with auxiliary self-contained air supply. Respirators that are provided only for escape from an atmosphere that is immediately dangerous to life and health must be NIOSH-certified for escape from the atmosphere in which they will be used. The NIOSH IDLH concentration for PCE is 150 ppm; however, PCE is considered a potential occupational carcinogen and, as part of its carcinogen policy, NIOSH recommends that the most protective respirators be worn for PCE at any detectable concentration.

Table 2-18. Assigned Protection Factors for Respirators in OSHA Standard 29 CFR 1910.134

Type of Respirator	Quarter Mask	Half Mask	Full Facepiece	Helmet/ Hood	Loose-fitting Facepiece
1. Air-Purifying Respirator	5	10	50		
2. Power Air-Purifying Respirator (PAPR)		50	1,000	25/1,000	25
3. Supplied-Air Respirator (SAR) or Airline Respirator					
• Demand mode		10	50		
• Continuous flow mode		50	1,000	25/1,000	25
• Pressure-demand or other positive-pressure mode		50	1,000		
4. Self-Contained Breathing Apparatus (SCBA)					
• Demand mode		10	50	50	
• Pressure-demand or other positive-pressure mode (*e.g.*, open/closed circuit)			10,000	10,000	

Source: 29 CFR Section 1910.134(d)(3)(i)(A)

The National Institute for Occupational Safety and Health (NIOSH) and the U.S. Department of Labor's Bureau of Labor Statistics (BLS) conducted a voluntary survey of U.S. employers regarding the use of respiratory protective devices between August 2001 and January 2002 (NIOSH, 2001b). Results of the survey include the number and percent of establishments and employees using respirators within 12 months prior to the survey. For additional information, please also refer to [*Memorandum_NIOSH_BLS Respirator Usage in Private Sector Firms*] (U.S. EPA, 2020n).

OSHA's hand protection standard (29 CFR Section 1910.138) requires employers select and require employees to use appropriate hand protection when expected to be exposed to hazards such as those from skin absorption of harmful substances; severe cuts or lacerations; severe abrasions; punctures; chemical burns; thermal burns; and harmful temperature extremes. Dermal protection selection provisions are provided in § 1910.138(b) and require that appropriate hand protection is selected based on the performance characteristics of the hand protection relative to the task(s) to be performed, conditions present, duration of use, and the hazards to which employees will be exposed.

Unlike respiratory protection, OSHA standards do not provide protection factors (PFs) associated with various hand protection PPE, such as gloves, and data about the frequency of effective glove use – that is, the proper use of effective gloves – is very limited in industrial settings. Initial literature review suggests that there is unlikely to be sufficient data to justify a specific probability distribution for effective glove use for a chemical or industry. Instead, the impact of effective glove use is explored by considering different percentages of effectiveness.

EPA made assumptions about glove use and associated protection factors (PF). Where workers wear gloves, workers are exposed to PCE-based product that may penetrate the gloves, such as seepage through the cuff from improper donning of the gloves, and if the gloves occlude the evaporation of PCE from the skin. Where workers do not wear gloves, workers are exposed through direct contact with PCE.

Gloves only offer barrier protection until the chemical breaks through the glove material. Using a conceptual model, Cherrie (2004) proposed a glove workplace protection factor – the ratio of estimated uptake through the hands without gloves to the estimated uptake though the hands while wearing gloves: this protection factor is driven by flux, and thus varies with time. The European Centre For Ecotoxicology and Toxicology of Chemicals Targeted Risk Assessment (ECETOC TRA) model represents the protection factor of gloves as a fixed, assigned protection factor equal to 5, 10, or 20 (Marquart et al., 2017) where, similar to the APF for respiratory protection, the inverse of the protection factor is the fraction of the chemical that penetrates the glove. It should be noted that the described PFs are not based on experimental values or field investigations of PPE effectiveness, but rather professional judgements used in the development of the ECETOC TRA model. EPA did not identify reasonably available information on PPE usage to corroborate the PFs used in this model.

As indicated in Table 2-19, use of protection factors above 1 is recommended only for glove materials that have been tested for permeation against the PCE-containing liquids associated with the condition of use. EPA has not found information that would indicate specific activity training (*e.g.*, procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur in a majority of sites in industrial only OESs, so the PF of 20 would usually not be expected to be achieved.

The plausibility of regular respirator and glove use by workers was considered on an OES-specific basis. See Table 4-3 and for determinations of whether respirator use was assumed for each OES during risk characterization and Table 4-125 for APFs and PFs considered in final risk determination.

Table 2-19. Glove Protection Factors for Different Dermal Protection Strategies from ECETOC TRA v3

Dermal Protection Characteristics	Affected User Group	Indicated Efficiency (%)	Protection Factor, PF
a. Any glove / gauntlet without permeation data and without employee training	Both industrial and professional users	0	1
b. Gloves with available permeation data indicating that the material of construction offers good protection for the substance		80	5
c. Chemically resistant gloves (*i.e.,* as *b* above) with "basic" employee training		90	10
d. Chemically resistant gloves in combination with specific activity training (*e.g.*, procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur	Industrial users only	95	20

2.4.1.5 Dermal Exposure Assessment Approach

Dermal exposure data was not reasonably available for the conditions of use in the assessment. Because PCE is a volatile liquid that readily evaporates from the skin, EPA estimated dermal exposures using the *Dermal Exposure to Volatile Liquids Model*. This model determines a dermal potential dose rate based on an assumed amount of liquid on skin during one contact event per day and the steady-state fractional

absorption for PCE based on a theoretical framework provided by Kasting and Miller (2006). The amount of liquid on the skin is adjusted by the weight fraction of PCE in the liquid to which the worker is exposed. Specific details of the dermal exposure assessment can be found in Section 2.4.1.28 and equations and sample calculations for estimated dermal exposures can be found in Appendix K of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d).

2.4.1.6 Manufacturing

2.4.1.6.1 Worker Activities

During manufacturing, workers are potentially exposed while connecting and disconnecting hoses and transfer lines to containers and packaging to be loaded with PCE product (*e.g.*, railcars, tank trucks, totes, drums, bottles) and intermediate storage vessels (*e.g.*, storage tanks, pressure vessels). Workers near loading racks and container filling stations are potentially exposed to fugitive emissions from equipment leaks and displaced vapor as containers are filled. These activities are potential sources of worker exposure through dermal contact with liquid and inhalation of vapors.

ONUs include employees that work at the site where PCE is manufactured, but they do not directly handle the chemical and therefore are assumed to have lower inhalation exposures and are not assumed to have dermal exposures. ONUs for manufacturing may include, but are not limited to, supervisors, managers, and tradesmen that may be in the manufacturing area but do not perform tasks that result in the same level of exposures as manufacturing workers.

2.4.1.6.2 Number of Workers and Occupational Non-Users

To determine the number of workers, EPA used the average of the ranges reported in the 2016 CDR for six sites where data were available and worker and ONUs estimates from the BLS analysis for the other two sites (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). For the BLS analysis EPA used the NAICS code 325199—All Other Basic Organic Chemical Manufacturing to estimate workers and ONUs. CDR data do not differentiate between workers and ONUs; therefore, EPA assumed the ratio of workers to ONUs would be similar as determined in the BLS data where approximately 68% of the exposed personnel are workers and 32% are ONUs (U.S. BLS, 2016). This resulted in approximately 970 workers and 460 ONUs (see Table 2-20).

Table 2-20. Estimated Number of Workers Potentially Exposed to PCE During Manufacturing

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
8	120	57	970	460	1,400

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.6.3 Occupational Inhalation Exposure Results

Table 2-21 summarizes 15-min, 30-min, 8-hr, and 12-hr TWA exposure results for manufacturing. The high-ends are the 95th percentile of the respective data sets and the central tendencies are the 50th percentile. The lone exception to this is 12-hr TWA exposure results for ONUs where all data points measured below the LOD; therefore, EPA assessed the central tendency and the high-end as half the LOD and the LOD, respectively. EPA assessed exposures using data submitted for three companies by

the Halogenated Solvent Industry Alliance (HSIA) (HSIA, 2018a). It should be noted that approximately 65% of the 8-hr TWA exposure data, 73% of the 12-hr TWA exposure data, 24% of the 15-min TWA exposure data, and 55% of the 30-min TWA exposure data were below the limit of detection (LOD). To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994b) as discussed in Section 2.4.1.3. The geometric standard deviation for the worker 8-hr TWA data, 12-hr TWA data, and 15-min TWA were all above 3.0; therefore, EPA used the $\frac{LOD}{2}$ to estimate the exposure value as specified in the guidelines (U.S. EPA, 1994b). The geometric standard deviation for the ONU 8-hr TWA and worker 30-min TWA were below 3.0; therefore, EPA used the $\frac{LOD}{\sqrt{2}}$ to estimate the exposure value as specified in the guidelines (U.S. EPA, 1994b). Because over 50% of the data are below the LOD for the 8-hr, 12-hr, and 30-min TWA data, calculating statistics from this data does present the potential to introduce biases into the results. Estimation of exposure values for results below the LOD may over- or under-estimate actual exposure thus skewing the calculated statistics higher or lower, respectively. The overall directional bias of the exposure assessment, accounting for both the overestimate and underestimate, is not known.

The 18 8-hr TWA exposure data points and five 30-min TWA data points from Company C were not included in the results as they were reported as being below the detection limit, but the company did not provide the value of the LOD. Therefore, EPA could not estimate a value for these data using the guidelines described above.

Table 2-21. Summary of Inhalation Monitoring Data for the Manufacture of PCE

Exposure Concentration Type	Worker Exposures			Occupational Non-User Exposures (ppm)			Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Number of Samples	Central Tendency (ppm)	High-End (ppm)	Number of Samples	
8-hr TWA Exposure Concentration	3.3E-2	2.7	63[a]	3.4E-2	9.2E-2	12	High
Acute Exposure Concentration (AC) based on 8-hr TWA	1.1E-2	0.9		1.1E-2	3.1E-2		
Average Daily Concentration (ADC) based on 8-hr TWA	7.4E-3	0.6		7.7E-3	2.1E-2		
Lifetime Average Daily Concentration (LADC) based on 8-hr TWA	2.9E-3	0.3		3.1E-3	1.1E-2		
12-hr TWA Exposure Concentration	2.1E-2	0.2	74	2.3E-2	4.5E-2	3	
Acute Exposure Concentration (AC) based on 12-hr TWA	1.0E-2	0.1		1.1E-2	2.3E-2		
Average Daily Concentration (ADC) based on 12-hr TWA	4.7E-3	4.9E-2		5.1E-3	1.0E-2		
Lifetime Average Daily Concentration (LADC) based on 12-hr TWA	1.9E-3	2.5E-2		2.0E-3	5.3E-3		
15-min TWA Exposure Concentration	2.0	15	161	EPA did not identify short-term data for ONUs.			
30-min TWA Exposure Concentration	0.7	12	38[b]				

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] Data does not include 18 data points that were reported as being below the detection limit, but for which the company did not provide the LOD for use in estimating an exposure value.
[b] Data does not include five data points that were reported as being below the detection limit, but for which the company did not provide the LOD for use in estimating an exposure value.
Sources: (HSIA, 2018a)

2.4.1.6.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers and ONUs is assessed using PCE personal breathing zone monitoring data collected at workplaces directly applicable to this condition of use, and the data were determined to have a "high" confidence rating through EPA's systematic review process. Specifically, the data were

determined to be highly representative in geographic scope and reflective of current operations. The source also provides metadata including sample type and sample duration.

The data includes exposure concentrations for a variety of worker and ONU tasks at each of the three manufacturing facilities from which the data were obtained. It is not known whether these data points would also be representative of the worker exposure level at other domestic manufacturing facilities. There is added uncertainty in the representativeness of the 12-hr TWA results for ONUs as there are only three data points. Despite the described uncertainties, EPA has a high level of confidence in the assessed 8- and 12-hr TWA worker exposures and the 8-hr TWA ONU exposures and a medium confidence in the 12-hr TWA ONU exposures based on the strength of the monitoring data.

2.4.1.7 Repackaging

2.4.1.7.1 Worker Activities

During repackaging, workers are potentially exposed while connecting and disconnecting hoses and transfer lines to containers and packaging to be unloaded (*e.g.*, railcars, tank trucks, totes), intermediate storage vessels (*e.g.*, storage tanks, pressure vessels), and final packaging containers (*e.g.*, drums, bottles). Workers near loading racks and container filling stations are potentially exposed to fugitive emissions from equipment leaks and displaced vapor as containers are filled. These activities are potential sources of worker exposure through dermal contact with liquid and inhalation of vapors.

ONUs include employees that work at the site where PCE is repackaged, but they do not directly handle the chemical and are therefore expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs for repackaging include supervisors, managers, and tradesmen that may be in the repackaging area but do not perform tasks that result in the same level of exposures as repackaging workers.

2.4.1.7.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during repackaging of PCE using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the primary NAICS and SIC code reported by each site in the 2016 TRI or 2016 DMR, respectively (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). This resulted in approximately 210 workers and 75 ONUs potentially exposed during repackaging of PCE (see Table 2-22).

Table 2-22. Estimated Number of Workers Potentially Exposed to PCE During Repackaging

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
51	4	1	210	75	280

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.7.3 Occupational Inhalation Exposure Results

EPA assessed inhalation exposures during import/repackaging using identified monitoring data. Table 2-23 summarizes 15-min, 30-min, and 8-hr TWA results obtained from data submitted to EPA by Dow Chemical under TSCA (Dow Chem, 1984a) and collected by OSHA (OSHA, 2020). For the 8-hr TWA results the 95th percentile and 50th percentiles are presented as the high-end and central tendency

exposure values, respectively. For the 15-min TWA, only two data points were available; therefore, EPA presents two scenarios: 1) using the maximum as a "higher value"; and 2) using the midpoint as a "midpoint value." For the 30-min TWA, only five data points were available; therefore, the maximum is presented as the high-end and the median is presented as the central tendency. It should be noted that two of the 30-min TWA samples measured below the LOD (Dow Chem, 1984a). To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (1994) as discussed in Section 2.4.1.3. The geometric standard deviation for was above 3.0; therefore, EPA used the $\frac{LOD}{2}$ to estimate the exposure value as specified in the guidelines (U.S. EPA, 1994b). Data were not available to estimate ONU exposures; EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-23. Summary of Inhalation Monitoring Data for Repackaging

Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)			
8-hr TWA Exposure Concentration	0.5	1.2	11	0.5	Medium
Acute Exposure Concentration (AC)	0.2	0.4		0.2	
Average Daily Concentration (ADC)	0.1	0.3		0.1	
Lifetime Average Daily Concentration (LADC)	4.2E-2	0.1		4.2E-2	
15-min TWA Exposure Concentration[b]	0.9	1.6	2	0.9	
30-min TWA Exposure Concentration	8.0E-02	5.7	5	8.0E-02	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
[b] Due to only two data points identified, EPA presents two scenarios: 1) using the higher of the two values; and 2) using the midpoint of the two values.
Sources: (Dow Chem, 1984a; OSHA, 2020)

2.4.1.7.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers is assessed using PCE personal breathing zone monitoring data collected at two repackaging facilities. The data were determined to have a "medium" confidence rating through EPA's systematic review process. However, the data may not be representative of exposures across other repackaging facilities (*e.g.*, those repackaging from and into different container sizes than used in the identified data). Based on reasonably available information above, EPA has a medium level of confidence in the assessed worker exposure.

Exposure to ONUs is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.8 Processing as a Reactant

2.4.1.8.1 Worker Activities

At industrial facilities, workers are potentially exposed when unloading PCE from transport containers into intermediate storage tanks and process vessels. Workers may be exposed via inhalation of vapor or via dermal contact with liquids while connecting and disconnecting hoses and transfer lines. Once PCE is unloaded into process vessels, it is consumed as a chemical intermediate.

ONUs are employees who work at the facilities that process and use PCE, but who do not directly handle the material. ONUs may also be exposed to PCE but are expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs for this condition of use may include supervisors, managers, engineers, and other personnel in nearby production areas.

2.4.1.8.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during processing of PCE as a reactant using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the primary NAICS and SIC code reported by each site in the 2016 TRI or 2016 DMR, respectively (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). This resulted in approximately 4,200 workers and 1,900 ONUs potentially exposed during processing of PCE as a reactant (see Table 2-24).

Table 2-24. Estimated Number of Workers Potentially Exposed to PCE During Processing as a Reactant

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed ONUs[a]	Total Exposed[a]
117	36	17	4,200	1,900	6,100

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.8.3 Occupational Inhalation Exposure Results

EPA did not identify any inhalation monitoring data to assess exposures during processing PCE as a reactant. EPA assumes that potential sources of exposure at sites using PCE as a reactant are similar to sites manufacturing raw PCE. Therefore, EPA assessed inhalation exposures during processing PCE as a reactant using monitoring data from manufacturing sites as a surrogate for sites processing PCE as a reactant. The results from the surrogate inhalation monitoring data are provided in Table 2-25.

Table 2-25. Summary of Inhalation Monitoring Results for Processing PCE as a Reactant[a]

Exposure Concentration Type	Worker Exposures			Occupational Non-User Exposures (ppm)			Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Number of Samples	Central Tendency (ppm)	High-End (ppm)	Number of Samples	
8-hr TWA Exposure Concentration	3.3E-2	2.7	63[b]	3.4E-02	9.2E-2	12	High
Acute Exposure Concentration (AC) based on 8-hr TWA	1.1E-2	0.9		1.1E-2	3.1E-2		
Average Daily Concentration (ADC) based on 8-hr TWA	7.4E-3	0.6		7.7E-3	2.1E-2		
Lifetime Average Daily Concentration (LADC) based on 8-hr TWA	2.9E-3	0.3		3.1E-3	1.1E-2		
12-hr TWA Exposure Concentration	2.1E-2	0.2	74	2.3E-2	4.5E-2	3	
Acute Exposure Concentration (AC) based on 12-hr TWA	1.0E-2	0.1		1.1E-2	2.3E-2		
Average Daily Concentration (ADC) based on 12-hr TWA	4.7E-3	4.9E-2		5.1E-3	1.0E-2		
Lifetime Average Daily Concentration (LADC) based on 12-hr TWA	1.9E-3	2.5E-2		2.0E-3	5.3E-3		
15-min TWA Exposure Concentration	2.0	15	161	EPA did not identify short-term data for ONUs.			
30-min TWA Exposure Concentration	0.7	12	38[c]				

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] These results are based on monitoring data from PCE manufacturing used as surrogate for sites processing PCE as a reactant.
[b] Data does not include 18 data points that were reported as being below the detection limit, but for which the company did not provide the LOD for use in estimating an exposure value.
[c] Data does not include five data points that were reported as being below the detection limit, but for which the company did not provide the LOD for use in estimating an exposure value.
Sources: (HSIA, 2018a)

2.4.1.8.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers and ONUs is assessed using PCE personal breathing zone monitoring data collected at facilities manufacturing PCE as a surrogate for facilities processing PCE as reactant. The data were determined to have a "high" confidence rating through EPA's systematic review process. Although these data are not directly applicable to processing of PCE as a reactant, EPA expects a high degree of overlap of worker tasks at both manufacturing sites and sites processing PCE as a reactant. Based on this expectation and the strength of the monitoring data, EPA has a medium to high level of confidence in the assessed 8- and 12-hr TWA worker exposures and the 8-hr TWA ONU. There is added uncertainty in the representativeness of the 12-hr TWA results for ONUs as there are only three data points. Therefore, EPA has a medium confidence in the 12-hr TWA results for ONUs.

2.4.1.9 Incorporation into Formulation, Mixture, or Reactant Product

2.4.1.9.1 Worker Activities

At formulation facilities, workers are potentially exposed when unloading PCE into mixing vessels, taking QC samples, and packaging formulated products into containers and tank trucks.

2.4.1.9.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during formulation of PCE-containing products using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the primary NAICS and SIC code reported by each site in the 2016 TRI or 2016 DMR, respectively (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report, (U.S. EPA, 2020d)) for number of sites estimated)). This resulted in approximately 800 workers and 310 ONUs potentially exposed during formulation of PCE-containing products (see Table 2-26).

Table 2-26. Estimated Number of Workers Potentially Exposed to PCE During Formulation

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
39	21	8	800	310	1,100

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.9.3 Occupational Inhalation Exposure Results

EPA identified inhalation exposure monitoring data related to the aerosol packing of PCE-containing products (Orris and Daniels, 1981; OSHA, 2020). However, no monitoring data was identified for other formulation sites and it is unlikely aerosol packing is representative of other formulation sites where workers are exposed during unloading of bulk containers (*i.e.*, tank trucks and rail cars) and loading of formulated products into smaller containers (*e.g.*, drums). Therefore, EPA used the monitoring data to assess exposures at aerosol packing facilities and the *EPA/OAQPS AP-42 Loading Model*, *EPA/OPPT Mass Balance Model* and Monte Carlo analysis to assess exposures at other non-aerosol packing facilities. Details of the model design and parameters is provided in Appendix F of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d).

Table 2-27 summarizes 8-hr TWA PBZ monitoring data for aerosol packing formulation sites. EPA calculated the 95th and 50th percentile to estimate the high-end and central tendency exposures, respectively. Data were not reasonably available to estimate short-term or ONU exposures; EPA

estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-27. Summary of Inhalation Exposure Monitoring Data for Aerosol Packing Formulation Sites

Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)			
8-hr TWA Exposure Concentration	8.7	25	8	8.7	Medium to High
Acute Exposure Concentration (AC)	2.9	8.5		2.9	
Average Daily Concentration (ADC)	2.0	5.8		2.0	
Lifetime Average Daily Concentration (LADC)	0.8	3.0		0.8	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
Sources: (Orris and Daniels, 1981; OSHA, 2020)

The modeling approach used to assess exposures at non-aerosol packing formulation sites estimates exposures to workers loading formulated PCE-based products into 55-gallon drums. Inhalation exposure to chemical vapor during loading is a function of physical properties of PCE, various EPA default constants, and other model parameters. While physical properties are fixed for a substance, some model parameters, such as weight fraction of PCE in the product, ventilation rate, mixing factor, and vapor saturation factor, are expected to vary from one facility to another. This approach addresses variability for these parameters using a Monte Carlo analysis.

The modeling approach requires an input on the number of containers loaded per day which is determined based on the throughput of PCE at each site and the weight fraction of PCE in the product. To determine these values EPA divided each site identified in Section 2.2.1.2.2 into one of the following categories: 1) sites formulating degreasing solvents; 2) sites formulating dry cleaning solvents, and 3) sites formulating “miscellaneous” PCE-containing products, including coatings, adhesives, metalworking fluids, and other niche use PCE-based products. The three categories were selected based on available market data from HSIA (2008), where the first two categories (degreasing and dry cleaning formulation) had market information indicating the percentage of the production volume used in those types of products. The HSIA (2008) market data did not include detailed production volume data for the third group so EPA could not divide the PCE production volume amongst the product types to calculate per site throughputs. Therefore, EPA assessed as a single category.

Table 2-28 summarizes model results for workers at non-aerosol packing formulation sites with the 50th percentile presented as the central tendency and the 95th percentile presented as the high-end. Data were not available to incorporate ONU exposures into the model. EPA estimates that ONU exposures are lower than worker exposures since ONUs do not typically directly handle the chemical. In lieu of ONU-

specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-28. Summary of Exposure Modeling Results for Formulation of Non-Aerosol PCE-Based Products

Formulation Type	Exposure Concentration Type	Worker Exposures		Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
		Central Tendency (ppm)	High-End (ppm)		
Degreasing Solvent	8-hr TWA Exposure Concentration	0.7	2.6	0.7	N/A – modeled data
	Acute Exposure Concentration (AC)	0.2	0.9	0.2	
	Average Daily Concentration (ADC)	0.2	0.6	0.2	
	Lifetime Average Daily Concentration (LADC)	6.3E-2	0.2	6.3E-2	
Dry Cleaning Solvent	8-hr TWA Exposure Concentration	4.0	14	4.0	
	Acute Exposure Concentration (AC)	1.3	4.7	1.3	
	Average Daily Concentration (ADC)	0.9	3.2	0.9	
	Lifetime Average Daily Concentration (LADC)	0.3	1.3	0.3	
Miscellaneous	8-hr TWA Exposure Concentration	0.4	1.4	0.4	
	Acute Exposure Concentration (AC)	0.1	0.5	0.1	
	Average Daily Concentration (ADC)	9.1E-2	0.3	9.1E-2	
	Lifetime Average Daily Concentration (LADC)	3.4E-2	0.1	3.4E-2	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.

2.4.1.9.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers at aerosol packing formulation sites is assessed using PCE personal breathing zone monitoring data collected at workplaces directly applicable to this condition of use, and the data were determined to have confidence ratings ranging from "medium" to "high", through EPA's systematic review process. Specifically, the data were determined to be highly reliable, and representative in geographic. The sources also provide metadata including sample type and sample duration. The data includes exposure at three aerosol packing facilities. It is not known whether these data points would also be representative of the worker exposure level at other similar facilities. Despite this uncertainty, EPA has a medium to high level of confidence in the assessed worker exposures based on the strength of the monitoring data.

The *EPA/OAQPS AP-42 Loading Model* and *EPA/OPPT Mass Balance Model* are used to estimate worker exposures for non-aerosol packing facilities. The model uses a Monte Carlo analysis to incorporate variability in the model input parameters. EPA believes the model exposures are likely to be representative of worker exposure associated with loading 55-gallon drums. However, it assumes all products are loaded into drums and does not consider the potential for loading of products into smaller containers instead of or in addition to drums.

The model also does not consider worker exposure from unloading raw PCE from bulk containers (*i.e.*, tank trucks or railcars). Although EPA can estimate exposures during this unloading activity using the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*, it is unclear if the same workers will perform both unloading and loading activities in the same day. Therefore, it may not be accurate to combine estimates from each model to estimate a total exposure. In the case where a worker is both unloading bulk containers and loading products into drums on the same day, the overall error from not including exposures during unloading in the results is expected to be small as the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model estimates an 8-hr TWA exposure of 0.01 ppm for tank truck unloading and an 8-hr TWA of 0.04 ppm for railcar unloading whereas the model for drum loading estimates 8-hr TWAs ranging from 0.60 to 14.1 ppm.

Furthermore, loading activities may be only a small part of the worker's day. The model does not account for other potential sources of exposure at industrial facilities, such as sampling, equipment cleaning, and other process activities that can contribute to a worker's overall 8-hr daily exposure. These model uncertainties could result in an underestimate of the worker 8-hr exposure. Based on reasonably available information above, EPA has a medium level of confidence in the assessed worker exposure.

Exposure to ONUs at both aerosol packing and non-aerosol packing facilities is assessed using the worker central tendency exposure values from the respective facility types. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.10 Batch Open-Top Vapor Degreasing

2.4.1.10.1 Worker Activities

When operating OTVD, workers manually load or unload fabricated parts directly into or out of the vapor cleaning zone. Worker exposure can occur from solvent dragout or vapor displacement when the substrates enter or exit the equipment, respectively (Kanegsberg and Kanegsberg, 2011). The amount of time a worker spends at the vapor degreaser can vary depending on the number of workloads needed to

be cleaned. Reports from NIOSH at three sites using OTVDs found degreaser operators may spend 0.5 to 2 hours per day at the degreaser (NIOSH, 2002a, b, d).

Worker exposure is also possible while charging new solvent or disposing spent solvent. The frequency of solvent charging can vary greatly from site-to-site and is dependent on the type, size, and amount of parts cleaned in the degreaser. NIOSH investigations found that one site added a 55-gallon drum of new solvent to the degreaser unit every one to two weeks; another site added one 55-gallon drum per month; and another site added two 55-gallon drums per month to its large degreaser and three 55 gallon drums per year to its small degreaser (NIOSH, 2002a, b, d).

EPA defined ONU as an employee who does not regularly handle PCE or operate the degreaser but performs work in the area around the degreaser.

2.4.1.10.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in OTVDs using the Draft ESD on the Use of Vapor Degreasers (OECD, 2017a). The ESD estimates seven workers and four ONUs per site (OECD, 2017a). EPA multiplied these values by the number of sites estimated in the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d). This resulted in approximately 2,800 workers and 1,600 ONUs using the number of sites estimated from the 95th percentile use-rate and 35,000 workers and 20,000 ONUs using the number of sites estimated from the 50th percentile use-rate. Table 2-29 summarizes these results. Note: These are bounding estimates and may overestimate actual number of workers.

Table 2-29. Estimated Number of Workers Potentially Exposed to PCE During Use in Open-Top Vapor Degreasing

Use-Rate Scenario	Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
95th Percentile	398	7	4	2,800	1,600	4,400
50th Percentile	4,942	7	4	35,000	20,000	54,000

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.10.3 Occupational Inhalation Exposure Results

Table 2-30 summarizes the 8-hr TWA monitoring data, 4-hr TWA monitoring data, and 15-minute TWA monitoring data for the use of PCE in OTVDs. The high-end and central tendency values for the 8-hr TWA data represent the 95th and 50th percentile, respectively. Due to the limited number of data points (three samples), the 4-hr TWA high-end is the maximum value and the central tendency is the 50th percentile. There is only a single 15-min TWA sample.

EPA recognizes that worker job titles and activities may vary significantly from site to site; therefore, EPA typically identified samples as worker samples unless it was explicitly clear from the job title (*e.g.*, inspectors) and the description of activities in the report that the employee was not operating the degreaser during the sampling period. Samples from employees determined not to be operating the degreasing equipment were designated as ONU samples.

EPA identified inhalation exposure monitoring data from NIOSH investigations at five sites using PCE as a degreasing solvent in OTVDs. Due to the large variety in shop types that may use PCE as a vapor degreasing solvent, there is some uncertainty in how representative these data are of a "typical" shop.

Table 2-30. Summary of Worker Inhalation Exposure Monitoring Data for Open-Top Vapor Degreasing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	Occupational Non-User Exposures		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hr TWA Exposure Concentration	2.1	32	63	0.6	5.2	12	Medium to High
Acute Exposure Concentration (AC)	0.7	11		0.2	1.7		
Average Daily Concentration (ADC)	0.5	7.3		0.1	1.2		
Lifetime Average Daily Concentration (LADC)	0.2	3.8		5.5E-2	0.6		
15-min TWA Exposure Concentration	17		1	No 4-hr or 15-minute data identified for ONUs			
4-hr TWA Exposure Concentration	1.3	1.6	3				

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Source: (NIOSH, 2002a, b, d; Gorman et al., 1984; Ruhe, 1982)

2.4.1.10.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using PCE personal breathing zone monitoring data from several different sources, with confidence rating of the data ranging from "medium" to "high", as determined through EPA's systematic review process. Due to the large variation amongst sites that operate OTVDs, there is some uncertainty in how representative the monitoring data of typical shops. Despite this uncertainty, EPA has a medium to high level of confidence in the assessed exposure for this condition of use, based on the strength of the monitoring data.

2.4.1.11 Batch Closed-Loop Vapor Degreasing

2.4.1.11.1 Worker Activities

For closed-loop vapor degreasing, worker activities can include placing or removing parts from the basket, as well as general equipment maintenance. Workers can be exposed to residual vapor as the door to the degreaser chamber opens after the cleaning cycle is completed. The amount of time workers spend in the degreaser area can vary greatly by site. One NIOSH report (NIOSH, 2002c) reported workers spent 1.5 to 2 hours per shift at the degreaser and another NIOSH report (NIOSH, 2002a) indicating that workers spent over 90% of their day in the degreaser area. Similarly, addition of fresh solvent to the degreasing machine can vary significantly with one site indicating 50 gallons of PCE per month were added and another site indicating 10 to 20 gallons of PCE per year were added to the machine (NIOSH, 2002a, c).

2.4.1.11.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in closed-loop degreasing using the same methodology as described for OTVDs. This resulted in approximately 97,000 workers and 56,000 ONUs using the number of sites estimated from the 95th percentile use-rate and 180,000 workers and 100,000 ONUs using the number of sites estimated from the 50th percentile use-rate (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). Table 2-31 summarizes these results. Note: These are bounding estimates and may overestimate actual number of workers.

Table 2-31. Estimated Number of Workers Potentially Exposed to PCE During Use in Closed-Loop Vapor Degreasing

Use-Rate Scenario	Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
95th Percentile	13,912	7	4	97,000	56,000	150,000
50th Percentile	25,546	7	4	180,000	100,000	280,000

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.11.3 Occupational Inhalation Exposure Results

EPA identified inhalation exposure monitoring data from NIOSH investigations at two sites using PCE as a degreasing solvent in batch closed-loop vapor degreasers. Due to the large variety in shop types that may use PCE as a vapor degreasing solvent, it is unclear how representative these data are of a "typical" shop. EPA does not have a model for estimating exposures from closed-loop degreasers; therefore, the assessment is based on the identified monitoring data.

Worker samples were determined to be any sample taken on a person while performing the degreasing tasks. ONUs samples were determined to be any sample taken on a person in the same location as the degreaser but not performing the degreasing themselves.

Table 2-32 summarizes the 8-hr TWA and 4-hr TWA monitoring data for the use of PCE in closed-loop vapor degreasers. For workers, the 8-hr TWA high-end and central tendency are based on the 95th and

50th percentiles, respectively. Due to the limited data points for worker 4-hr TWAs, EPA used the maximum and median as the high-end and central tendency, respectively. For ONUs, only two data points were available; therefore, EPA presents two scenarios: 1) using the maximum as a "higher value," and 2) using the midpoint as a "midpoint value."

When comparing to monitoring data from OTVDs, the data show a decrease in worker exposure of 99.2% at the 95th percentile and 96.6% at the 50th percentile and a decrease in ONU exposure of 98.2% at the 95th percentile and 89.2% at the 50th percentile. This is generally consistent with data in literature which found that solvent purchases for closed-loop systems were reduced by 83% to over 98% as compared to OTVDs and air emissions were reduced from 95% to over 99% as compared to OTVDs (Durkee, 2014; Newmoa, 2001).

Table 2-32. Summary of Worker Inhalation Exposure Monitoring Data for Closed-Loop Vapor Degreasing

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	Occupational Non-User Exposures[a]		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hr TWA Exposure Concentration	7.2E-2	0.3	13	6.5E-2	9.6E-2	2	High
Acute Exposure Concentration (AC)	2.4E-2	8.4E-2		2.2E-2	3.2E-2		
Average Daily Concentration (ADC)	1.6E-2	5.8E-2		1.5E-2	2.2E-2		
Lifetime Average Daily Concentration (LADC)	6.6E-3	3.0E-2		5.9E-3	1.1E-2		
4-hr TWA Exposure Concentration	2.0E-2	8.6E-2	3	No 4-hr data identified for ONUs			

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] Due to only two data points identified, EPA presents two scenarios: 1) using the higher of the two values; and 2) using the midpoint of the two values.
Source: (NIOSH, 2002a, c)

2.4.1.11.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using PCE personal breathing zone monitoring data from two sources with the data determined to have a "high" confidence rating, as determined through EPA's systematic review process. The data show a decrease in exposure concentrations as compared to OTVD monitoring data that agrees with literature expectations. There is added uncertainty in the representativeness of the results for ONUs as there are only two data points. Based on the reasonably available information above, EPA has a high level of confidence in the assessed worker exposures and a medium level of confidence in the ONU exposures for this condition of use.

2.4.1.12 Conveyorized Vapor Degreasing

2.4.1.12.1 Worker Activities

For conveyorized vapor degreasing, worker activities can include placing or removing parts from the basket, as well as general equipment maintenance. Depending on the level of enclosure and specific conveyor design, workers can be exposed to vapor emitted from the inlet and outlet of the conveyor portal.

2.4.1.12.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in conveyorized degreasing using the same methodology as described for OTVDs. This resulted in approximately 2,800 workers and 1,600 ONUs using the number of sites estimated from the 95th percentile use-rate and 4,000 workers and 2,300 ONUs using the number of sites estimated from the 50th percentile use-rate (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). Table 2-33 summarizes these results. Note: These are bounding estimates and may overestimate actual number of workers.

Table 2-33. Estimated Number of Workers Potentially Exposed to PCE During Use in Conveyorized Vapor Degreasing

Use-Rate Scenario	Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
95th Percentile	395	7	4	2,800	1,600	4,300
50th Percentile	568	7	4	4,000	2,300	6,200

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.12.3 Occupational Inhalation Exposure Results

EPA did not identify any inhalation exposure monitoring data related to the use of PCE in conveyorized degreasing. Therefore, EPA assessed inhalation exposures during conveyorized degreasing using the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model. Details of the model design and parameters is provided in Appendix G of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report, (U.S. EPA, 2020d)).

The key parameter in the model is the emission rate from the degreaser. Emission rates were modeled using the reported unit emissions of PCE from the single conveyorized degreaser in the 2014 NEI (U.S. EPA, 2018a). The model estimates exposures for both workers and ONUs. Workers estimates are based on concentrations in the near-field where the conveyorized degreasing work occurs, and ONU exposures are based on concentrations in the far-field away from the conveyorized degreaser. The results from the inhalation model are provided in Table 2-34. The high-end and central tendency are the 95th and 50th percentiles, respectively, calculated by the model.

Table 2-34. Summary of Exposure Modeling Results for Use of PCE in Conveyorized Vapor Degreasing

Exposure Concentration Type	Worker Exposures		Occupational Non-User Exposures		Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Central Tendency (ppm)	High-End (ppm)	
8-hr TWA Exposure Concentration	78	186	41	126	N/A – modeled data
Acute Exposure Concentration (AC)	26	62	14	42	
Average Daily Concentration (ADC)	18	42	9.3	29	
Lifetime Average Daily Concentration (LADC)	6.7	17	3.5	12	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.

2.4.1.12.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model. The model uses a Monte Carlo analysis, which incorporates variability in the model input parameters. Only a single emission rate data point was available for PCE conveyorized degreasing for use in the model and there is some uncertainty in how representative this data point is of a "typical" conveyorized degreaser. Based on the reasonably available information above, EPA has a medium level of confidence in the assessed exposure for this condition of use.

2.4.1.13 Web Degreasing

2.4.1.13.1 Worker Activities

Worker activities for web degreasing are expected to be similar to other degreasing uses and can include placing or removing parts from the degreasing machine, as well as general equipment maintenance. Depending on the level of enclosure and specific design, workers can be exposed to vapor emitted from the inlet and outlet of the conveyor portal.

2.4.1.13.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in web degreasing using the same methodology as described for OTVDs. This resulted in approximately 2,800 workers and 1,600 ONUs using the number of sites estimated from the 95th percentile use-rate and 4,000 workers and 2,300 ONUs using the number of sites estimated from the 50th percentile use-rate (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). Table 2-35 summarizes these results. Note: These are bounding estimates and may overestimate actual number of workers.

Table 2-35. Estimated Number of Workers Potentially Exposed to PCE During Use in Web Degreasing

Use-Rate Scenario	Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
95th Percentile	395	7	4	2,800	1,600	4,300
50th Percentile	568	7	4	4,000	2,300	6,200

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.13.3 Occupational Inhalation Exposure Results

EPA did not identify any inhalation exposure monitoring data related to the use of PCE in web degreasing. Therefore, EPA assessed inhalation exposures during web degreasing using the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model. Details of the model design and parameters are provided in Appendix G of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d).

The key parameter in the model is the emission rate from the degreaser. Emission rates were modeled using the reported unit emissions of PCE from web degreasers in the 2014 NEI (U.S. EPA, 2018a). The model estimates exposures for both workers and ONUs. Workers estimates are based on concentrations in the near-field where the web degreasing work occurs, and ONU exposures are based on concentrations in the far-field away from the web degreaser. The results from the inhalation model are provided in Table 2-36. The high-end and central tendency are the 95th and 50th percentiles, respectively, calculated by the model.

Table 2-36. Summary of Exposure Modeling Results for Use of PCE in Web Degreasing

Exposure Concentration Type	Worker Exposures		Occupational Non-User Exposures		Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Central Tendency (ppm)	High-End (ppm)	
8-hr TWA Exposure Concentration	0.6	1.8	0.3	1.2	N/A – modeled data
Acute Exposure Concentration (AC)	0.2	0.6	0.1	0.4	
Average Daily Concentration (ADC)	0.1	0.4	7.3E-2	0.3	
Lifetime Average Daily Concentration (LADC)	5.3E-2	0.2	2.7E-2	0.1	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.

2.4.1.13.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model. The model uses a Monte Carlo analysis, which incorporates variability in the model input parameters. Due to the limited number of data points, there is some uncertainty on the representativeness of emission rates from the 2014 NEI (U.S. EPA, 2018a) of "typical" web degreasers. Based on the reasonably available information above, EPA has a medium level of confidence in the assessed exposure for this condition of use.

2.4.1.14 Cold Cleaning

2.4.1.14.1 Worker Activities

The general worker activities for cold cleaning include placing the parts that require cleaning into a vessel. The vessel is usually something that will hold the parts but not the liquid solvent (*i.e.*, a wire basket). The vessel is then lowered into the machine, where the parts could be sprayed, and then completely immersed in the solvent. After a short time, the vessel is removed from the solvent and allowed to drip/air dry. Depending on the industry and/or company, these operations may be performed manually (*i.e.*, by hand) or mechanically. Sometimes parts require more extensive cleaning; in these cases, additional operations are performed including directly spraying solvent on the part, agitation of the solvent or parts, wipe cleaning and brushing (NIOSH, 2001a; U.S. EPA, 1997).

2.4.1.14.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in cold cleaners using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS code reported by the site in the 2014 NEI (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). In the 2014 NEI (U.S. EPA, 2018a), four sites reported NAICS code for which there was no Census data available. To estimate the number of workers/ONUs at these sites, EPA referenced the 2017 Emission Scenario Document (ESD) on the Use of Vapor Degreasers (OECD, 2017a)[17]. There are approximately 710 workers and 420 ONUs potentially exposed during use of PCE in cold cleaning (see Table 2-37).

It should be noted that this number is expected to underestimate the total number of workers and ONUs exposed to PCE during cold cleaning as NEI data do not include cold cleaner operations that are classified as area sources. Area sources are reported at the county level and do not include site-specific information. Therefore, any sites operating a cold cleaning machine that is classified as an area source would not be included in the count of sites in the 2014 NEI. EPA does not have sufficient information to estimate the number of area sources that may operate cold cleaning machines.

Table 2-37. Estimated Number of Workers Potentially Exposed to PCE During Use in Cold Cleaning

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
17	42	25	710	420	1,100

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

[17] Although the ESD covers vapor degreasers not cold cleaners, the types of industries using cold cleaners are assumed to be similar to those using vapor degreasers. Therefore, the number of workers/ONUs are assumed to be similar.

2.4.1.14.3 Occupational Inhalation Exposure Results

Table 2-38 summarizes the 8-hr TWA and 4-hr TWA monitoring data for the use of PCE in cold cleaners. For the 8-hr TWA, the 95th percentile and 50th percentile of the identified exposure data are presented as the high-end and central tendency exposure values, respectively. Due to the limited number of data points for the 4-hr TWA, the maximum and 50th percentile (median) of the data are presented as the high-end and central tendency, respectively. The data were obtained from two sources: 1) a NIOSH In-Depth Survey Report (NIOSH, 2002c); and 2) a study submitted to EPA by Vulcan Chemicals (1994) under TSCA.

Worker samples were determined to be any sample taken on a person while performing the cold cleaning tasks. ONU samples were determined to be any sample taken on a person in the same location as the cold cleaning machine but not performing the cold cleaning themselves. The results only include values for workers as monitoring data for ONUs were not identified. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical.

Table 2-38. Summary of Worker Inhalation Exposure Monitoring Data for Use of PCE in Cold Cleaning

Exposure Concentration Type	Central Tendency (ppm)	High-End (ppm)	Number of Samples	Data Quality Rating of Air Concentration Data
8-hr TWA Exposure Concentration	1.4	4.1	29	High
Acute Exposure Concentration (AC)	0.5	1.4		
Average Daily Concentration (ADC)	0.3	0.9		
Lifetime Average Daily Concentration (LADC)	0.1	0.5		
4-hr TWA Exposure Concentration	2.9	4.3	5	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Source: (NIOSH, 2002c; Vulcan, 1994)

Due to the large variety in shop types that may use PCE as a cold cleaning solvent, it is unclear how representative these data are of a "typical" shop. Therefore, EPA supplemented the identified monitoring data using the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model. Details of the model design and parameters is provided in Appendix G of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d). The results from the model are provided in Table 2-39. For model results, the high-end and central tendency are the 95th and 50th percentiles, respectively.

The key parameter in the model is the emission rate from the cold cleaning machine. Emission rates were modeled using a discrete distribution of reported cold cleaning machine unit emissions of PCE in the 2014 NEI (U.S. EPA, 2018a). The model estimates exposures for both workers and ONUs. Workers estimates are based on concentrations in the near-field where the cold cleaning work occurs, and ONU exposures are based on concentrations in the far-field away from the cold cleaning machine.

The high-end results of the model are within the same order of magnitude as the high-end and central tendency found in the monitoring data. However, the central tendency estimated by the model is three

orders of magnitude lower than the central tendency from the monitoring data. This may be due to the limited number of sites from which the monitoring data were taken whereas the model is meant to capture a broader range of scenarios.

Table 2-39. Summary of Exposure Modeling Results for Use of PCE in Cold Cleaning

Exposure Concentration Type	Worker Exposures		Occupational Non-User Exposures		Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Central Tendency (ppm)	High-End (ppm)	
8-hr TWA Exposure Concentration	2.4E-3	1.5	1.2E-3	0.8	N/A – modeled data
Acute Exposure Concentration (AC)	8.0E-4	0.5	4.1E-4	0.3	
Average Daily Concentration (ADC)	5.5E-4	0.4	2.8E-4	0.2	
Lifetime Average Daily Concentration (LADC)	2.0E-4	0.1	1.1E-4	6.7E-2	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.

2.4.1.14.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using PCE personal breathing zone monitoring data from two sources with the data determined to have a "high" confidence rating, as determined through EPA's systematic review process. The exposure data are supplemented with near-field/far-field exposure modeling using a Monte Carlo analysis, which incorporates variability in the model input parameters. The high-end model results generally agree with both high-end and central tendency results from the monitoring data. However, the central tendency model results are three orders of magnitude lower than both the high-end and central tendency results from the monitoring data. This may be due to uncertainty in the representativeness of the monitoring data of "typical" exposures from cold cleaning. Based on the reasonably available information above, EPA has a medium to high level of confidence in the assessed exposure for this condition of use.

2.4.1.15 Aerosol Degreasing and Aerosol Lubricants

2.4.1.15.1 Worker Activities

PCE-based aerosol products include degreasers for applications such as brake cleaning, engine degreasing, electric motor cleaners, cable cleaners, coil cleaners, and other metal product cleaning. Additional aerosol products include penetrating lubricants and oils, high pressure non-melt red greases, white lithium greases, silicone lubricants, chain and cable lubricants, vandal mark removers, mold cleaners, and weld anti-spatter protectants. EPA expects significant overlap in the industry sectors that use aerosol-based products; therefore, these uses are assessed together.

One example of a commercial setting with aerosol degreasing operations is repair shops, where service items are cleaned to remove any contaminants that would otherwise compromise the service item's operation. Internal components may be cleaned in place or removed from the service item, cleaned, and then re-installed once dry (U.S. EPA, 2014a).

Workers at these facilities are expected to be exposed through dermal contact with and inhalation of mists during application of the aerosol product to the service item. ONUs are expected to have lower inhalation exposures and are not expected to have dermal exposures.

2.4.1.15.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed to aerosol degreasers and aerosol lubricants containing PCE using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). Based on the market penetration of 29.6% and data from the BLS and U.S. Census, there are approximately 250,000 workers and 29,000 occupational non-users potentially exposed to PCE as an aerosol degreasing solvent or aerosol lubricant (see Table 2-40) (U.S. BLS, 2016; U.S. Census Bureau, 2015; CARB, 2000).

Table 2-40. Estimated Number of Workers Potentially Exposed to PCE During Use of Aerosol Degreasers and Aerosol Lubricants

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers[b]	Total Exposed Occupational Non-Users[b]	Total Exposed[b]
75,938	3	0.4	250,000	29,000	280,000

[a] Number of workers and occupational non-users per site are calculated by dividing the exposed number of workers or occupational non-users by the number of establishments. The number of workers per site is rounded to the nearest integer. The number of occupational non-users per site is shown as 0.4, as it rounds down to zero.
[b] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.15.3 Occupational Inhalation Exposure Results

EPA identified inhalation exposure monitoring data related to the use of PCE in aerosol degreasers for brake servicing. However, PCE is used in a variety of other aerosol degreasing applications and other aerosol products for which EPA did not identify any inhalation exposure monitoring data. Therefore, EPA supplemented the identified monitoring data using the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. EPA used the brake servicing model as a representative scenario for this condition of use as there was ample data describing the brake servicing use and it is a significant use of PCE-based aerosol products. Details of the model design and parameters is provided in Appendix H of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d).

Table 2-41 summarizes 8-hr TWA PBZ monitoring data and 15-min TWA PBZ monitoring data for the use of PCE-based aerosol products. The 95th percentile of the identified monitoring data is presented as the high-end exposure and the 50th percentile is presented as the central tendency. The data were obtained from three studies on the use of aerosol brake cleaners during commercial brake servicing, OSHA CEHD and from data provided to EPA from the Department of Defense (DoD) (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; Cosgrove and Hygiene, 1994; Vulcan, 1993, 1992; OSHA, 2020). It should be noted that one study evaluated various formulations of aerosol degreasers containing 25% PCE, and another study evaluated one formulation containing 30% PCE, and one with 60% PCE. Based on data from CARB (CARB, 2000) and modeling results, PCE concentration in brake cleaning products ranges from 20% to 99% with a median concentration of 78.4%. The

monitoring data collected in these two studies may underestimate "typical" exposures as the PCE concentration in the evaluated formulations were all below the median concentration.

Worker samples were determined to be any sample taken on a person while performing the aerosol degreasing tasks. ONU samples were determined to be any sample taken on a person in the same location as the aerosol degreasing but not performing the aerosol degreasing themselves. The results only include values for workers as monitoring data for ONUs were not identified.

Table 2-41. Summary of Worker Inhalation Exposure Monitoring Data for Aerosol Degreasing

Exposure Concentration Type	Central Tendency (ppm)	High-End (ppm)	Number of Samples	Data Quality Rating of Air Concentration Data
8-hr TWA Exposure Concentration	1.4	7.5	144	Medium to High
Acute Exposure Concentration (AC)	0.5	2.5		
Average Daily Concentration (ADC)	0.3	1.7		
Lifetime Average Daily Concentration (LADC)	0.1	0.9		
15-min TWA Exposure Concentration	29	123	67	

AC = Acute Concentration; ADC = Average Daily Concentration and LADC = Lifetime Average Daily Concentration.
Source: (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; Cosgrove and Hygiene, 1994; Vulcan, 1993, 1992; OSHA, 2020)

Key model inputs include number of aerosol applications per job, the amount of degreaser applied per brake job, and the concentration (weight fraction) of PCE in the aerosol degreaser. The values and distributions for these inputs are largely based on site data from maintenance and auto repair shops obtained by CARB (2000) for brake cleaning activities. The model estimates exposures for both workers and ONUs. Workers estimates are based on concentrations in the near-field where the aerosol degreasing work occurs, and ONU exposures are based on concentrations in the far-field away from the aerosol degreasing applications.

The results from model are provided in Table 2-42 It calculates both 8-hr TWA exposure concentrations and maximum 1-hr TWA exposure concentrations. The high-end and central tendency are the 95th and 50th percentiles, respectively, calculated by the model. The model exposure levels at both the central tendency and high-end for workers are higher than that found in the monitoring data but are within one order of magnitude of the monitoring data. The discrepancy is not unexpected as the model is meant to capture a wider range of shop conditions than is found in the monitoring data, and the monitoring data includes data for sites using brake cleaning formulations containing concentrations less than the median concentration (78.4%) used in the model.

Table 2-42. Summary of Exposure Modeling Results for Use of PCE in Aerosol Degreasing and Aerosol Lubricants

Exposure Concentration Type	Worker Exposures		Occupational Non-User Exposures		Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Central Tendency (ppm)	High-End (ppm)	
8-hr TWA Exposure Concentration	5.5	17	0.1	0.7	N/A – modeled data
Acute Exposure Concentration (AC)	1.8	5.7	3.4E-2	0.2	
Average Daily Concentration (ADC)	1.3	3.9	2.0E-2	0.2	
Lifetime Average Daily Concentration (LADC)	0.5	1.6	1.0E-2	7.0E-2	
Maximum 1-hr TWA Exposure Concentration	17	50	0.3	2.2	

AC = Acute Concentration; ADC = Average Daily Concentration and LADC = Lifetime Average Daily Concentration.

2.4.1.15.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using PCE personal breathing zone monitoring data from several different sources, with confidence ratings ranging from "medium" to "high", as determined through EPA's systematic review process. The exposure data are supplemented with near-field/far-field exposure modeling using a Monte Carlo analysis, which incorporates variability in the model input parameters. Model results are and monitoring data are in good agreement and are within an order of magnitude of monitoring data. However, the monitoring data includes data from four sources that had concentrations of PCE in the aerosol formulation below the median value predicted by the model. Based on the reasonably available information above, EPA has a high level of confidence in the assessed exposure for this condition of use.

2.4.1.16 Dry Cleaning and Spot Cleaning

2.4.1.16.1 Worker Activities

Worker activities at dry cleaning shops can include:

- Receiving garments and tagging garments for identification;
- Inspecting and sorting garments by color, weight, finish;
- Pre-treating any visible stain on the garment with a spotter, typically from a spray or squeeze bottle;
- Loading garments into the machine, running the wash cycle, and unloading the cleaned garments;
- Post-spotting any stain that was not already removed during the dry cleaning process; and
- Pressing and finishing, after which the pressed garment is returned to an overhead rack and wrapped in plastic for customer pickup (NIOSH, 1997a).

EPA expects worker exposure at dry cleaning facilities to primarily occur when workers are: 1) unloading and loading garments from the machines; 2) performing manual stain removal (*i.e.*, spot cleaning); and 3) transferring solvent from a storage container to the machine. Workers can also be exposed during maintenance activities, such as cleaning the machine lint trap, button trap and still, changing solvent filters, and disposing hazardous wastes. However, these maintenance activities occur on a much less frequent basis (NIOSH, 1997a).

ONUs at dry cleaning facilities are employees who are not expected to handle PCE, operate dry cleaning machines, or perform spotting or finishing operations. They include cashiers, counter clerks and other similar employees.

2.4.1.16.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed to PCE at dry cleaners using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). Based on a market penetration of 60% for commercial facilities, assuming 12 industrial dry cleaners (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)), and data from the BLS and U.S. Census, there are approximately 44,000 workers and 14,000 occupational non-users potentially exposed to PCE at dry cleaning facilities (see Table 2-43) (DLI/NCA, 2017; U.S. BLS, 2016; U.S. Census Bureau, 2015; U.S. EPA, 2006c).

Table 2-43. Estimated Number of Workers Potentially Exposed to PCE During Dry Cleaning

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
12,834	3	1	44,000	14,000	57,000

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.16.3 Occupational Inhalation Exposure Results

Table 2-44 summarizes the 8-hr TWA PBZ monitoring data for workers and ONUs at dry cleaners obtained from OSHA facility inspections, NIOSH studies and data provided to EPA from DoD (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; OSHA, 2017; Burroughs, 2000; NIOSH, 2000; Burroughs, 1999a, b; NIOSH, 1995; OSHA, 2020). The data are divided into two categories: 1) statistics for data collected after the promulgation of the 2006 PCE NESHAP for Dry Cleaning Facilities; and 2) data collected for fourth or fifth generation machines only. The post-2006 NESHAP data are expected to contain exposures from shops using third, fourth and fifth generation machines as the purchase of new first generation (transfer machines) and second generation (dry-to-dry, vented machines) dry cleaning machines were banned in the 1993 Perchloroethylene NESHAP for Dry Cleaning Facilities, the 2006 Perchloroethylene NESHAP for Dry Cleaning Facilities banned the use of PCE in all first-generation machines, and the typical useful life of these machines is approximately 15 years (U.S. EPA, 2006c).

Third generation equipment are non-vented, dry-to-dry machines with refrigerated condensers. These machines are essentially closed systems and are only open to the atmosphere when the machine door is opened. In third generation machines, heated drying air is recirculated back to the drying drum through a vapor recovery system (NIOSH, 1997b).

Fourth generation dry cleaning equipment are essentially third-generation machines with added secondary vapor control. These machines "rely on both a refrigerated condenser and carbon adsorbent to reduce the PCE concentration at the cylinder outlet below 300 ppm at the end of the dry cycle" and are more effective at recovering solvent vapors (NIOSH, 1997b). Fifth generation equipment have the same features as fourth generation machines, but also have a monitor inside the machine drum and an interlocking system to ensure that the concentration is below approximately 300 ppm before the loading door can be opened (NIOSH, 1997b).

For workers, the 95th percentile is presented as the high-end and the 50th percentile is presented as the central tendency. For the post-2006 NESHAP data, only a single data point was available for ONUs. For fourth and fifth generation machines, there was only four ONU data points available; therefore, the maximum is presented as the high-end and the median as the central tendency.

Approximately 28% of respondents to a 2003 survey of California dry cleaners indicated they used fourth generation machines and approximately 61% of respondents to a 2010 survey of dry cleaners in King County, WA reported using fourth or fifth generation machines (Whittaker and Johanson, 2011; California Air Resources, 2006). EPA did not identify data for other locales or for the overall U.S.; therefore, EPA used the California and King County, WA data to approximate the overall U.S. trends. Based on these survey results, EPA expects the industry to be trending towards higher usage of fourth and fifth generation machines as compared to third generation machines and expects current exposures at dry cleaning shops to fall somewhere between the post-2006 exposure concentrations and the concentrations from fourth and fifth generation machines only.

Worker samples were determined to be any sample taken on a person who engages in loading/unloading clothes from dry cleaning equipment, finishing operations, spot cleaning, and/or maintenance activities for the dry cleaning machine (*e.g.*, replenishing spent solvent). ONUs samples were determined to be any sample taken on a person not expected to perform these activities (*e.g.*, cashiers).

Table 2-44. Summary of Inhalation Exposure Monitoring Data for Dry Cleaning

Data Category	Exposure Concentration Type	Worker Exposures		Number of Worker Samples	Occupational Non-User Exposures		Number of ONU Samples	Data Quality Rating of Air Concentration Data
		Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
Post-2006 NESHAP Data[a]	8-hr TWA Exposure Concentration	2.2	17	74	0.3[c]		1[d]	Medium to High
	Acute Exposure Concentration (AC)	0.7	5.7		0.1	0.1		
	Average Daily Concentration (ADC)	0.5	4.5		8.2E-2	9.3E-2		
	Lifetime Average Daily Concentration (LADC)	0.2	2.3		3.3E-2	4.8E-2		
	15-min TWA Exposure Concentration	33	94	9	No 15-min data identified for ONUs			
Fourth and Fifth Generation Statistics[b]	8-hr TWA Exposure Concentration	1.0	5.6	114	1.4E-2	0.1	4	High
	Acute Exposure Concentration (AC)	0.3	1.9		4.7E-3	4.1E-2		
	Average Daily Concentration (ADC)	0.2	1.5		3.3E-3	3.3E-2		
	Lifetime Average Daily Concentration (LADC)	9.2E-2	0.8		1.3E-3	1.7E-2		
	15-min TWA Exposure Concentration	48	899	6	No 15-min data identified for ONUs			

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.

[a] Post-2006 NESHAP data are air samples collected from OSHA inspections or DoD and, based on the date of collection, EPA assumed to be representative of the post-2006 mix of machine types as provided in the 2010 King County, WA survey (Whittaker and Johanson, 2011).

[b] Fourth and fifth generation data include only data where EPA could clearly identify the machine type in the study as fourth or fifth generation. It does not include OSHA data, which are representative of a mix of machine generations but for which machine types for individual samples could not be determined.

[c] Only one data point was available for this scenario. However, different parameters are used for calculating high-end and central tendency ADC and LADC. Therefore, a high-end and central tendency are presented based on the single data point.

[d] The single ONU data point comes from a sample taken on an inspector at a dry cleaning site. EPA assumes exposures to the inspector would be similar to that of an ONU as inspectors are not expected to handle the chemical or operator dry cleaning machines.

Source: (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; OSHA, 2017; Burroughs, 2000; NIOSH, 2000; Burroughs, 1999a, b; NIOSH, 1995; OSHA, 2020)

As estimated in Section 2.2.1.2.2, PCE is expected to be used in thousands of dry cleaning shops throughout the U.S. and the monitoring data only captures a small fraction of those shops. Therefore, EPA supplemented the identified monitoring data using the Dry cleaning Multi-Zone Inhalation Exposure Model to capture variation amongst dry cleaning shops that may not be captured in the monitoring data. Details of the model design and parameters are provided in Appendix I of *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d).

Key model input parameters include solvent in concentration in the dry cleaning machine after the clean cycle has complete, residual solvent in clothing removed from the dry cleaning machine, and spot cleaning use rates. The value and distribution used for each of these parameters in the model are based on data observed in literature. The model estimates exposures for workers, spot cleaners, and ONUs. Workers estimates are based on concentrations in the near-field zone corresponding to unloading clothes from the dry cleaning equipment and the near-field zone corresponding to where finishing and pressing activities occur. Spot cleaner estimates are based on concentrations in the near-field zone corresponding to where the spot cleaning activity occurs. ONU exposures are based on concentrations in the far-field which corresponds to any area outside the near-field zones. The results from the model are provided in Table 2-45. The high-end and central tendency are the 95th and 50th percentiles, respectively, calculated by the model. It should be noted that the model calculates 12-hr TWAs based on suggestions from the peer review of the 2016 Draft Risk Assessment for the TSCA Work Plan Chemical 1-Bromopropane that dry cleaning workers may work up to 12 hours per day (U.S. EPA, 2016e).

It should be noted that EPA did not identify information to estimate the use rate of PCE in spot cleaners; however, IRTA (2007) and ERG (2005) indicate that the use of PCE in spot cleaners is minimal. Specifically, IRTA (2007) state that only 150 gal of PCE -based spotting agents are used annually in California (compared to 42,000 gal of PCE -based spotting agents). ERG (2005) stated that many PCE spotting agents are categorized as oily type paint removers (OTPR), but that the majority of OTPR spotting agents contain no PCE. Therefore, EPA set the use rate of PCE spotting agents to zero causing the spotting zone of the model to become part of the far-field with exposure concentrations equivalent to ONUs.

When comparing the model results to the post-2006 NESHAP monitoring data results for workers, the model high-end is higher than the monitoring data. This is likely because the model is meant to capture a wider range of conditions than is likely captured in the monitoring data. The model central tendency for workers is slightly less than half the central tendency for the post-2006 NESHAP monitoring data. This may be due to the fact the majority of the post-2006 NESHAP data are from OSHA compliance inspections that are often performed as a result of worker complaints and, therefore, may not necessarily be representative of PCE concentrations encountered in the typical commercial dry cleaning establishment. Additionally, the assumption that post-2006 NESHAP data is representative of the 2010 King County, WA survey results may be inaccurate, and the data could actually represent sites with a higher frequency of third generation machines, resulting in higher exposures. However, model results and monitoring data for the post-2006 NESHAP are within the same order of magnitude.

When comparing the model results to the fourth/fifth generation monitoring data results for workers, the model high-end and central tendency are both an order of magnitude greater than the monitoring data. This is expected as the model captures exposures from facilities with third and fourth/fifth generation machines.

Table 2-45. Summary of Worker and Occupational Non-Uses Inhalation Exposure Modeling Results for Dry Cleaning

Exposure Concentration Type	Worker Exposures		Occupational Non-User Exposures		Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Central Tendency (ppm)	High-End (ppm)	
8-hr TWA Exposure Concentration	1.4	30	0.1	1.5	N/A – modeled data
Acute Exposure Concentration (AC)	0.7	15	5.4E-2	0.8	
Average Daily Concentration (ADC)	0.5	10	3.8E-2	0.6	
Lifetime Average Daily Concentration (LADC)	0.2	4.1	1.4E-2	0.2	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.

Because many dry cleaners are family owned and operated, it is possible that children may be present at the dry cleaners, during which they may be exposed at similar air concentration levels as occupational non-users. EPA assumed that infants and toddlers who are not yet school age could spend the full workday at the facility, multiple days a week. However, once the children reach school age, they would expected to be present for shorter durations. EPA assumed that the cumulative exposures to children would represent <10% of their lifetime, and therefore, EPA did not estimate chronic non-cancer or cancer risks for children present at dry cleaners (U.S. EPA, 2002). In order to account for differential exposure parameters between adults and children, EPA derived lifestage-adjusted Points of Departure (POD) for key hazard endpoints (Section 3.2.5.4.1).

2.4.1.16.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using PCE personal breathing zone monitoring data from several different sources, with confidence ratings ranging from “medium” to “high”, as determined through EPA’s systematic review process. The exposure data are supplemented with multi-zone exposure modeling using a Monte Carlo analysis, which incorporates variability in the model input parameters. This model was peer reviewed as part of the 2016 1-BP Draft Risk Assessment (U.S. EPA, 2016f) has been updated to address peer review comments, incorporate additional available data, and use PCE-relevant data. Both model results and monitoring data show good agreement and are within an order of magnitude for the post-2006 NESHAP data. The model results are higher than the fourth and fifth generation machine monitoring data which is expected as the model incorporates third generation machines. Based on the reasonably available information above, EPA has a high level of confidence in the assessed exposure for this condition of use.

2.4.1.17 Adhesives, Sealants, Paints, and Coatings

2.4.1.17.1 Worker Activities

Worker activities may include unloading adhesive or coating products from containers into application equipment, and, where used, manual application of the adhesive or coatings (*e.g.*, use of spray guns or brushes to apply product to substrate) (OECD, 2015). Workers may be exposed to PCE during the

application process if mists are generated such as during spray and roll applications (OECD, 2015). Workers may also be exposed to PCE vapors that evaporate from the adhesive or coating as it is applied or during the drying/curing process (OECD, 2015). EPA expects ONUs may be exposed to mists or vapors that enter their breathing zone during routine work in areas where coating applications are occurring.

2.4.1.17.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE-containing adhesives and coatings using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS code reported by sites in the 2014 NEI (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)) (U.S. EPA, 2018a). In the 2014 NEI, there were two sites with coating operations that reported a NAICS code for which no Census data were available. To estimate the number of workers and ONUs at these sites, EPA used the average workers per site and ONUs per site from the sites with known data. There are approximately 410 workers and 160 ONUs potentially exposed during use of adhesives/sealants and 1,900 workers and 1,100 ONUs potentially exposed during use of paints/coatings (see Table 2-46).

Table 2-46. Estimated Number of Workers Potentially Exposed to PCE During of Use Adhesives, Sealants, Paints, and Coatings

Scenario	Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
Adhesives/Sealants	14	30	11	410	160	570
Paints/Coatings	46	41	24	1,900	1,100	3,000

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.17.3 Occupational Inhalation Exposure Results

EPA identified inhalation exposure monitoring data from a study at a single site in Poland using a PCE-based adhesive, from three NIOSH investigations at three sites using PCE-based coatings, a study submitted to EPA under TSCA for a truck plant using PCE-based coatings, and data provided to EPA from DoD for spray coating processes (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; Gromiec et al., 2002; Hanley, 1993; Stephenson and Albrecht, 1986; Chrostek and Levine, 1981; Ford Motor, 1981). Due to the large variety in shop types that may use PCE-based adhesives and coatings, it is unclear how representative these data are of a "typical" site using these products. However, EPA does not have a model for estimating exposures from use of adhesives or paints/coatings; therefore, the assessment is based on the identified monitoring data. Table 2-47 summarizes the identified monitoring data.

Worker samples were determined to be any sample taken on a person while performing adhesive or coating applications. ONUs samples were determined to be any sample taken on a person in the same location as the applications but not performing the adhesive/coating application themselves. The results only include values for workers as monitoring data for ONUs were not identified. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

For adhesives, the study did not provide discrete sample results; therefore, the high-end exposure value is based on the max concentration and the central tendency is based on the mean reported in the study (Gromiec et al., 2002). For paints/coatings 8-hr TWA, the 95th percentile of the data is presented as the high-end and the 50th percentile as the central tendency. Due to the limited number of data points for the 15-minute TWA, the maximum is presented as the high-end and the median is the central tendency.

Table 2-47. Summary of Inhalation Exposure Monitoring Data for Use of PCE-Based Adhesives, Sealants, Paints, and Coatings

Scenario	Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
		Central Tendency (ppm)	High-End (ppm)			
Adhesives/ Sealants	8-hr TWA Exposure Concentration[b]	8.8E-2	0.8	13	8.8E-2	Medium
	Acute Exposure Concentration (AC)	2.9E-2	0.3		2.9E-2	
	Average Daily Concentration (ADC)	2.0E-2	0.2		2.0E-2	
	Lifetime Average Daily Concentration (LADC)	8.0E-3	9.5E-2		8.0E-3	
Paints/ Coatings	8-hr TWA Exposure Concentration	0.2	4.6	15	0.2	Medium to High
	Acute Exposure Concentration (AC)	7.8E-2	1.5		7.8E-2	
	Average Daily Concentration (ADC)	5.3E-2	1.0		5.3E-2	
	Lifetime Average Daily Concentration (LADC)	2.1E-2	0.5		2.1E-2	
	15-min TWA Exposure Concentration	4.1	7.9	5	4.1	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
[b] Exact sample times not given in study; however, study indicates that samples were taken for a minimum of 75% of the shift (360 min). Therefore, EPA assumes that the results are representative of an 8-hr TWA exposure.
Source: (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; Gromiec et al., 2002; Hanley, 1993; Stephenson and Albrecht, 1986; Chrostek and Levine, 1981; Ford Motor, 1981)

2.4.1.17.4 Strengths, Limitations, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers is assessed using PCE personal breathing zone monitoring data from several different sources, with confidence rating of the data ranging from medium to high, as determined through EPA's systematic review process. Due to potential variations in the types of sites that may use PCE-based adhesives, sealants, paints, and coatings, there is some uncertainty in how representative the

monitoring data are of other sites using these types of products. Despite this uncertainty, EPA has a medium level of confidence in the assessed worker exposure for this condition of use.

Exposure to ONUs is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.18 Maskant for Chemical Milling

2.4.1.18.1 Worker Activities

Information from stakeholder meetings and public comments indicate that in typical maskant application processes the potential for exposure is low as the process is automated and performed in a dedicated room (Ducommun, 2017; Spirit AeroSystems, 2017; Tech Met, 2017). However, at least one stakeholder indicated that employees may be exposed during maintenance operations (Spirit AeroSystems, 2017). Specific maintenance activities were not described but may include adding fresh maskant and handling of re-captured maskants.

2.4.1.18.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE as a chemical maskant using data from public comments. Public commenters provided worker and ONU data for 3 of the 71 sites using PCE-based maskants; EPA assessed the remaining sites using the average from the public comment (A. C. Products, 2017; Spirit AeroSystems, 2020). One public commenter provided a range of workers and ONUs at their site; therefore, EPA assessed the number of workers and ONUs at this site using the midpoint of the range (Spirit AeroSystems, 2020) (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report, (U.S. EPA, 2020d) for number of sites estimated)). This resulted in 7 workers per site and 30 ONUs per site at the unknown sites and a total of approximately 460 workers and 2,100 ONUs potentially exposed during maskant uses of PCE (see Table 2-48).

Table 2-48. Estimated Number of Workers Potentially Exposed to PCE During Use of Chemical Maskants

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
71	7	30	460	2,100	2,600

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.18.3 Occupational Inhalation Exposure Results

Table 2-49 summarizes the 8-hr, 4-hr, and 15-min TWA PBZ monitoring data for workers and ONUs at sites performing maskant operations obtained from OSHA facility inspections, NIOSH studies, data submitted by public commenters, and data provided to EPA from DoD (Hervin et al., 1977; U.S. DOD and Environmental Health Readiness System - Industrial 2018; Spirit AeroSystems, 2020; A. C. Products, 2017; OSHA, 2020). The sources do not specify if PCE is the primary solvent in the maskant, the concentration of PCE in the maskant, or the typical maskant use rates at the site. The 95th percentile of the data is presented as the high-end and the 50th percentile as the central tendency. In the 15-min TWA data 9 of the 20 samples were measured below the LOD (U.S. DOD and Environmental Health Readiness System - Industrial, 2018). To estimate exposure concentrations for data below the LOD,

EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994b) as discussed in Section 2.4.1.3. The geometric standard deviation for the data was above 3.0; therefore, EPA used the $\frac{LOD}{2}$ to estimate the exposure value as specified in the guidelines (U.S. EPA, 1994b).

Based on information from public commenters, employees who directly operate masking equipment and/or oversee the masking process are considered workers and workers who only handle parts either before maskant has been applied or after the chemical milling when the maskant has cured (and thus the majority of PCE expected to have volatilized) are considered ONUs (A. C. Products, 2017). Examples of ONU tasks include scribing, where cured maskant is removed from the areas to be etched, demasking, where etchant and maskant are removed from the part, and hanging parts on racks prior to parts entry into maskant equipment (Spirit AeroSystems, 2020; A. C. Products, 2017).

The 8-hr and 4-hr data from Hervin et al. (1977) were collected prior to the promulgation of the Aerospace Manufacturing and Rework Facilities NESHAP which regulates the emissions of hazardous air pollutants (HAPs) from various operation at aerospace facilities including chemical milling. However, comparison of these data to more recent data from 2015 to 2020 submitted via public comment (Spirit AeroSystems, 2020; A. C. Products, 2017) did not indicate emissions controls implemented as a result of the NESHAP reduced exposures. For comparison, 8-hr TWAs for workers in the Hervin et al. (1977) study ranged from 0.7 to 2.1 ppm with a median of 1.2 ppm and 8-hr TWAs from public comments ranged from 0.87 to 66 ppm with a median of 4.7 ppm.

Table 2-49. Summary of Inhalation Exposure Monitoring Data for Chemical Maskants

Exposure Concentration Type	Worker Exposures			Occupational Non-User Exposures (ppm)[a]			Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)	Number of Samples	Central Tendency (ppm)	High-End (ppm)	Number of Samples	
8-hr TWA Exposure Concentration	2.2	57	43	1.0	2.2	17	Medium to High
Acute Exposure Concentration (AC)	0.7	19		0.3	0.7		
Average Daily Concentration (ADC)	0.5	13		0.2	0.5		
Lifetime Average Daily Concentration (LADC)	0.2	6.6		9.5E-2	0.3		
15-min TWA Exposure Concentration	0.6	28	20	EPA did not identify short-term data for ONUs.			
4-hr TWA Exposure Concentration	2.2	2.4	6				

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
Source: (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; Hervin et al., 1977; Spirit AeroSystems, 2020; A. C. Products, 2017; OSHA, 2020)

2.4.1.18.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers is assessed using PCE personal breathing zone monitoring data from five sources with confidence ratings ranging from "medium" to "high", as determined through EPA's systematic review process. EPA has a medium to high level of confidence in the assessed worker exposure for this condition of use, based on the strength of the monitoring data.

2.4.1.19 Industrial Processing Aid

2.4.1.19.1 Worker Activities

At industrial facilities, workers are potentially exposed when unloading PCE from transport containers into intermediate storage tanks and process vessels. Workers may be exposed via inhalation of vapor or via dermal contact with liquids while connecting and disconnecting hoses and transfer lines. Once PCE is unloaded into process vessels, it may be consumed in the process (*e.g.*, when used for catalyst regeneration) or be used until spent and sent for disposal.

ONUs are employees who work at the facilities that process and use PCE, but who do not directly handle the material. ONUs may also be exposed to PCE but are expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs for this condition of use may include supervisors, managers, engineers, and other personnel in nearby production areas.

2.4.1.19.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE as a processing aid using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the primary NAICS and SIC code reported by each site in the 2016 TRI or 2016 DMR, respectively (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). This results in approximately 14,000 workers and 6,000 ONUs potentially exposed during use of PCE as a processing aid (see Table 2-50).

Table 2-50. Estimated Number of Workers Potentially Exposed to PCE During Use of Processing Aids

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
98	140	61	14,000	6,000	20,000

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.19.3 Occupational Inhalation Exposure Results

EPA identified inhalation exposure monitoring data from four studies submitted to EPA under TSCA by Dow Chemical (Dow Chem, 1983a, b, 1982, 1979). The exact function of PCE in each study is not explicitly stated; however, the data were collected in the agricultural chemical production and distribution, trichloroethylene production, and chloropyridines process areas. Based on CDR reporting, PCE is used as a processing aid in agricultural chemical manufacturing; therefore, monitoring data collected in the agricultural chemical production area is assessed as a processing aid use of PCE. Similarly, chloropyridines are used as intermediates in both the pharmaceutical and agrochemical industries (Scriven and Murugan, 2005). Both pharmaceutical and agrochemical industries are expected to use PCE as a processing aid; therefore, monitoring data collected in the chloropyridine unit are also assessed as a processing aid use. PCE can also be used as an inert material in trichloroethylene

production (Snedecor et al., 2004). Use as an inert material would fall under processing aid uses; therefore, monitoring data collected during trichloroethylene production is assessed as a processing aid use.

Worker samples were determined to be any sample taken on a person while directly handling PCE. ONUs samples were determined to be any sample taken on a person in the same location as the PCE use but not handling PCE. The results only include values for workers as monitoring data for ONUs were not identified. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-51 presents a summary of the identified 8-hr TWA and 30-minute TWA monitoring data. For the 8-hr TWA, the 95th percentile is presented as the high-end and the 50th percentile presented as the central tendency. It should be noted that approximately 55% of the 8-hr TWA data were below the LOD. To estimate exposure concentrations for these data, EPA followed *the Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994b). The geometric standard deviation for the data was above 3.0; therefore, EPA used the $\frac{LOD}{2}$ to estimate the exposure value as specified in the guidelines (U.S. EPA, 1994b). Because over 50% of the data are below the LOD, calculating statistics from these data does present the potential to introduce biases into the results. Estimation of exposure values for results below the LOD may over- or under-estimate actual exposure thus skewing the calculated statistics higher or lower, respectively. The overall directional bias of the exposure assessment, accounting for both the overestimate and underestimate, is not known.

For the 30-minute TWA, only two data point were available, one of which measured below the LOD. Because only a single data point with a measured value was available, EPA could not calculate a geometric standard deviation. Therefore, EPA presents two scenarios: 1) using the maximum as a "higher value"; and 2) using the midpoint between the maximum and the LOD as a "midpoint" value.

Table 2-51. Summary of Worker Inhalation Exposure Monitoring Data for Use of PCE as a Processing Aid

Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)			
8-hr TWA Exposure Concentration	6.0E-2	1.2	89	6.0E-02	Medium
Acute Exposure Concentration (AC)	2.0E-2	0.4		2.0E-02	
Average Daily Concentration (ADC)	1.4E-2	0.3		1.4E-02	
Lifetime Average Daily Concentration (LADC)	5.4E-3	0.1		5.4E-03	
30-min TWA Exposure Concentration[b]	1.7	2.2	2	1.7	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
[b] Due to only two data points, one of which measured below the LOD, EPA presents two scenarios: 1) using the higher of the two values; and 2) using the midpoint of the LOD and the maximum.
Source: (Dow Chem, 1983a, b, 1982, 1979)

2.4.1.19.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers is assessed using PCE personal breathing zone monitoring data from several different sources all with a confidence rating of "medium," as determined through EPA's systematic review process. There is some uncertainty in how PCE is used within each process, but literature corroborates categorizing the use as a processing aid. Based on the available information above, EPA has a medium level of confidence in the assessed worker exposure for this condition of use.

Exposure to ONUs is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.20 Metalworking Fluids

2.4.1.20.1 Worker Activities

Workers are expected to unload the metalworking fluid from containers; clean containers; dilute water-based metalworking fluids; transfer fluids to the trough; performing metal shaping operations; rinse, wipe, and/or transfer the completed part; change filters; transfer spent fluids; and clean equipment (OECD, 2011).

ONUs include employees that work at the site where PCE is used in an industrial setting as a metalworking fluid, but they typically do not directly handle the chemical and are therefore expected to have lower exposures. ONUs for metalworking fluids include supervisors, managers, and tradesmen that may be in the processing area but do not perform tasks that result in the same level of exposures as machinists.

Since PCE has a high vapor pressure (18.5 mmHg at 25°C), workers may be exposed to PCE when handling liquid metalworking fluid, such as unloading, transferring, and disposing spent metalworking fluids and cleaning machines and troughs. The greatest source of potential exposure is during metal shaping operations. The high machine speeds can generate airborne mists of the metalworking fluids to which workers can be exposed. Additionally, the high vapor pressure of PCE may lead to its evaporation from the airborne mist droplets, potentially creating a fog of vapor and mist.

2.4.1.20.2 Number of Workers and Occupational Non-Users

The ESD on the Use of Metalworking Fluids cites a NIOSH study of 79 small machine shops, which observed an average of 46 machinists per site (OECD, 2011). The ESD also cites an EPA effluent limit guideline development for the MP&M industry, which estimated a single shift supervisor per shift, who may perform tasks such as transferring and diluting neat metalworking fluids, disposing spent metalworking fluids, and cleaning the machines and troughs (OECD, 2011). Since the machinists perform the metal shaping operations, during which metalworking fluid mists are generated, EPA assesses the machinists as workers, as they have the highest potential exposure. EPA assessed the single shift supervisor per site as an ONU, as this employee is not expected to have as high an exposure as the machinists. Assuming two shifts per day (hence two shift supervisors per day), EPA assesses 46 workers and two ONUs per site (OECD, 2011). The number of establishments that use PCE-based metalworking fluids is unknown (see discussion in the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d)); therefore, EPA does not have data to estimate the total workers and ONUs exposed to PCE from use of metalworking fluids.

2.4.1.20.3 Occupational Inhalation Exposure Results

EPA did not identify any inhalation exposure monitoring data related to the use of PCE-based metalworking fluids. Therefore, EPA assessed inhalation exposures using the ESD on the Use of Metalworking Fluids (OECD, 2011). The ESD estimates typical and high-end exposures for different types of metalworking fluids. The "typical" mist concentration is the geometric mean of the data and the "high-end" is the 90th percentile of the data (OECD, 2011). The recommended use of the PCE-based metalworking fluid is an oil-based cutting and tapping fluid; therefore, EPA assesses exposure to the PCE-based metalworking fluids using the straight oil mist concentrations and the max concentration of PCE in the metalworking fluid (M.S.C. Industrial Supply Inc., 2019; Winfield Brooks, 2014). Straight oils are not diluted; therefore, the concentration of PCE specified in the identified SDS (<10%) is equal to the concentration of PCE in the mist (M.S.C. Industrial Supply Inc., 2019; Winfield Brooks, 2014).

Table 2-52 presents the exposure estimates for the use of PCE-based metalworking fluids. It should be noted that these estimates may underestimate exposures to PCE during use of metalworking fluids as they do not account for exposure to PCE that evaporates from the mist droplets into the air. EPA did not identify reasonably available data to estimate exposure from PCE that evaporates from mists; therefore, it is not considered in this assessment. However, due to the relatively low concentration of PCE in the metalworking fluid, the partial pressure may be low enough such that evaporation of PCE from the mist is limited and this not a significant route of exposure.

The results only include values for workers as the ESD does not include an approach for estimating ONU exposures. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-52. Summary of Exposure Results for Use of PCE in Metalworking Fluids Based on ESD Estimates

Exposure Concentration Type	Worker Exposure		Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		
8-hr TWA Exposure Concentration[b]	5.8E-3	2.1E-2	5.8E-3	N/A – ESD data
Acute Exposure Concentration (AC)	1.9E-3	7.0E-3	1.9E-3	
Average Daily Concentration (ADC)	1.3E-3	4.8E-3	1.3E-3	
Lifetime Average Daily Concentration (LADC)	5.2E-4	2.5E-3	5.2E-4	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
[b] The PCE exposure concentrations are calculated by multiplying the straight oil mist concentrations in the ESD by 10% (the concentration of PCE in the metalworking fluid) and converting to ppm.

2.4.1.20.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure to workers is assessed using estimates from the Metalworking Fluid ESD for typical and high-end mist exposures for straight oils. The ESD estimates are for a "generic" straight oil rather than a PCE-specific metalworking fluid; therefore, there is some uncertainty in how this data applies to PCE-based metalworking fluids. Additionally, the ESD estimates also only account for the exposure to mist; however, PCE is volatile and expected to evaporate from the mist into the air. Therefore, the ESD estimates may underestimate actual PCE exposure. Due to the low concentration of PCE in the metalworking fluid, the partial pressure of PCE in the mist may be low enough such that this is not a significant route of exposure, thus mitigating the overall underestimate. Based on the available information above, EPA has a medium level of confidence in the assessed worker exposure for this condition of use.

Exposure to ONUs is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.21 Wipe Cleaning and Metal/Stone Polishes

2.4.1.21.1 Worker Activities

Wipe cleaning includes the use of liquid PCE degreasers soaked onto rags that are subsequently used to wipe down parts. Workers are expected to be exposed to PCE vapors that evaporate from the PCE-soaked rag or the solvent residue left behind on the substrate after wiping. Additional activities and use patterns will vary depending on the specific site at which the PCE cleaning product or polish is being used.

2.4.1.21.2 Number of Workers and Occupational Non-Users

EPA did not identify information to estimate the number of workers or ONUs exposed to PCE during use for wipe cleaning and metal/stone polishes. It is possible some workers/ONUs at sites using vapor degreasers or cold cleaners are also exposed to PCE from wipe cleaning activities.

2.4.1.21.3 Occupational Inhalation Exposure Results

EPA identified inhalation exposure monitoring data from NIOSH investigations at two sites using PCE for wipe cleaning (Moody et al., 1983; Gunter and Lybarger, 1979). EPA did not identify exposure data specific to metal/stone polish applications; therefore, the NIOSH data were also used to assess the use of metal/stone polishes based on expected similarities in the uses. Due to the large variety in the types of shops that may use PCE as a wipe cleaning solvent or metal/stone polish, it is unclear how representative these data are of a "typical" site. EPA does not have a model for estimating exposures from wipe cleaning or metal/stone polishes; therefore, the assessment is based on the identified monitoring data. Table 2-53 summarizes 8-hr, 4-hr and 15-minute TWA monitoring data for the use of PCE as a wipe cleaning solvent and metal/stone polish.

Worker samples were determined to be any sample taken on a person while performing the wipe cleaning or polishing task. ONUs samples were determined to be any sample taken on a person in the same location as the wipe cleaning or polishing task but were not performing the wipe cleaning or polishing themselves.

Due to the limited number of data points for workers 8-hr and 15-minute TWA results, the maximum of identified data is presented as the high-end and the median is presented as the central tendency. There is only a single 4-hr TWA data point for workers. Results based on a single value are plausible exposure concentrations, but EPA cannot determine the statistical representativeness of the value. For the ONU 8-hr TWA, the 95th percentile is presented as the high-end and the 50th percentile as the central tendency. The ONU data included four data points that are below the LOD. To estimate exposure concentrations for these data, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994b). The geometric standard deviation for the data was above 3.0; therefore, EPA used the $\frac{LOD}{2}$ to estimate the exposure value as specified in the guidelines (U.S. EPA, 1994b).

Table 2-53. Summary of Worker Inhalation Monitoring Data for Use of PCE as a Wipe Cleaning Solvent and Metal/Stone Polish

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	Occupational Non-User Exposures		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hr TWA Exposure Concentration	132	228	4	2.2E-2	23	6	High
Acute Exposure Concentration (AC)	44	76		7.3E-3	7.7		
Average Daily Concentration (ADC)	30	52		5.0E-3	5.3		
Lifetime Average Daily Concentration (LADC)	12	27		2.0E-3	2.7		
15-min TWA Exposure Concentration	66	103	9	No 15-min or 4-hr data identified for ONUs			
4-hr TWA Exposure Concentration	9.5		1				

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Source: (Moody et al., 1983; Gunter and Lybarger, 1979)

2.4.1.21.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using PCE personal breathing zone monitoring data from two sources with a confidence rating of "high", as determined through EPA's systematic review process. There is some uncertainty in how representative these data are of exposure at other facilities performing wipe cleaning or polishing tasks. The data identified are also specific to wipe cleaning activities not polishing. Although the application processes are expected to be similar, the frequency and duration of polish applications may be less than those used for wipe cleaning. Therefore, the exposure values may overestimate exposures during use of polishes. Despite these uncertainties, EPA has a medium level of confidence in the assessed exposure for this condition of use.

2.4.1.22 Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

2.4.1.22.1 Worker Activities

As previously described, workers are expected to spray PCE on to the stained textiles and then manually scrape away the stain using a brush or fingers.

2.4.1.22.2 Number of Workers and Occupational Non-Users

EPA did not identify information to estimate the total number of workers and ONUs exposed from use of spot cleaners/spot removers. Both the Fabric Finishing GS (U.S. EPA, 1994a) and the ESD on the Use of Textile Dyes (OECD, 2017b) estimate three to six workers exposed per site. It is unknown how many of those workers may be involved in the spot cleaning process.

2.4.1.22.3 Occupational Inhalation Exposure Results

EPA identified inhalation exposure monitoring data from a NIOSH investigation at a garment manufacturer and from OSHA facility inspections (Burton and Monestersky, 1996; OSHA, 2020). It is unclear how representative these data are of a "typical" spot cleaning/spot remover scenario. Table 2-54 summarizes the 8-hr TWA monitoring data for the use of PCE in spot cleaners/spot removers. Due to the limited number of data points (four) for workers, EPA calculated the 50th percentile and maximum to estimate the central tendency and high-end exposure results, respectively. For ONUs, there was only a single data point available.

Worker samples were determined to be any sample taken on a person while directly handling PCE. ONUs samples were determined to be any sample taken on a person in the same location as the PCE use but not handling PCE.

Table 2-54. Summary of Worker Inhalation Exposure Monitoring Data for Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

Exposure Concentration Type	Worker Exposures		Number of Worker Samples	Occupational Non-User Exposures[a]		Number of ONU Samples	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)		Central Tendency (ppm)	High-End (ppm)		
8-hr TWA Exposure Concentration	1.5	3.4	4	3.0E-2		1	Medium to High
Acute Exposure Concentration (AC)	0.5	1.1		1.0E-2	1.0E-2		
Average Daily Concentration (ADC)	0.3	0.8		6.8E-3	6.8E-3		
Lifetime Average Daily Concentration (LADC)	0.1	0.4		2.7E-3	3.5E-3		

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] Only one data point identified for ONUs; however, different parameters are used for calculating high-end and central tendency ADC and LADC. Therefore, a high-end and central tendency are presented based on the single data point.
Source: (Burton and Monestersky, 1996; OSHA, 2020)

2.4.1.22.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Exposure is assessed using PCE personal breathing zone monitoring data from two sources with confidence ratings ranging from "medium" to "high", as determined through EPA's systematic review process. There is some uncertainty in how representative these data are of exposure at other facilities performing carpet cleaning or spot remover tasks. There is added uncertainty in the representativeness of the data as there are only four data points for workers and one data point for ONUs. Based on the available information above, EPA has a medium level of confidence in the assessed worker exposure and a low level of confidence in the assessed ONU exposures for this condition of use.

2.4.1.23 Other Industrial Uses

2.4.1.23.1 Worker Activities

Based on information identified in EPA's data gathering and information obtained from TRI and DMR, a variety of other industrial uses of PCE may exist. Based on information in the Use Document (U.S. EPA, 2017f), market profile (U.S. EPA, 2017b), and NAICS/SIC codes reported in TRI (U.S. EPA, 2017j) and DMR (U.S. EPA, 2016a), examples of these uses include, but are not limited to, uses in textile processing, wood furniture manufacturing, foundry applications, food manufacturing, and scientific research and development. EPA did not identify information on how PCE may be used at these facilities.

Although information on worker activities at these sites was not identified, EPA expects workers to perform activities similar to other industrial facilities. Therefore, workers may potentially be exposed when unloading PCE from transport containers into intermediate storage tanks and process vessels. Workers may be exposed via inhalation of vapor or via dermal contact with liquids while connecting and disconnecting hoses and transfer lines.

ONUs are employees who work at the facilities that process and use PCE, but who do not directly handle the material. ONUs may also be exposed to PCE but are expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs for this condition of use may include supervisors, managers, engineers, and other personnel in nearby production areas.

In addition to the above scenarios, EPA also reached out to the Department of Defense (DoD) for monitoring data for the first 10 chemical substances that are the subject of the Agency's initial chemical risk evaluations. The DoD provided monitoring data from its Defense Occupational and Environmental Health Readiness System – Industrial Hygiene (DOEHRS-IH), which collects occupational and environmental health risk data from each service branch. The DoD provided inhalation monitoring data for three branches of the military: Army, Air Force, and Navy (U.S. DOD and Environmental Health Readiness System - Industrial, 2018). These data are not distinguished among the three branches.

Where the condition of use of the collected monitoring data could be clearly determined and fit into one of the other OES it was incorporated into the results of that OES; the following conditions of use incorporated these DoD data:

- Aerosol Degreasing;
- Dry Cleaning;
- Adhesives, Sealants, Paints, and Coatings; and
- Chemical Maskants.

However, two additional full-shift data points were available that did not fit into other OES. One described the use as "oil analysis" and the other as "water pipe repair." EPA assessed these two uses in this OES for other industrial uses. The DoD data did not provide worker activities for these data.

2.4.1.23.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during processing of PCE as a reactant using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the primary NAICS and SIC code reported by each site in the 2016 TRI or 2016 DMR, respectively (see the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d) for number of sites estimated)). In

the 2016 DMR (U.S. EPA, 2016a) there was one site that did not report a SIC code but after review of the company's website, EPA determined that NAICS 311411 – Frozen Fruit, Juice, and Vegetable Manufacturing was the most appropriate NAICS code to use for this site. There are approximately 2,700 workers and 1,300 ONUs potentially exposed during other industrial uses (see Table 2-55).

Table 2-55. Estimated Number of Workers Potentially Exposed to PCE During Other Industrial Uses

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
130	21	10	2,700	1,300	4,000

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.23.3 Occupational Inhalation Exposure Results

For textile processing, wood furniture manufacturing, foundry applications, and miscellaneous uses (*i.e.*, industrial uses that did not fit into another OES), EPA assessed exposure to other industrial uses of PCE using data from OSHA facility inspections (OSHA, 2020). Table 2-56 summarizes the 8-hr TWA data identified for these uses. For textile processing and furniture manufacturing, EPA calculated 50th and 95th percentiles to estimate central tendency and high-end exposure results, respectively. Due to the limited number of data points, EPA calculated the 50th percentile and maximum to estimate the central tendency and high-end exposure results, respectively, for foundry applications. For miscellaneous uses, only two data points were available; therefore, EPA presented two scenarios: 1) using the maximum as a "higher value," and 2) using the midpoint as a "midpoint value."

For the DoD oil analysis process, one data point was available; however, different parameters are used for calculating high-end and central tendency ADC and LADC. Therefore, a high-end and central tendency are presented based on the single data point. EPA adjusted the exposure frequency when calculating ADC and LADC to reflect the expected number of exposure days based on the process frequency reported by DoD. For the oil analysis the frequency was two to three times per week (U.S. DOD and Environmental Health Readiness System - Industrial, 2018). EPA used the midpoint of the ranges to estimate the central tendency ADC and LADC and the maximum frequency to calculate the high-end ADC and LADC. This resulted in 150 exposure days/yr at the high-end and 125 exposure days at the central tendency for the oil analysis.

For the DoD use for water pipe repair, there was only one data point available as well; however, it measured below the LOD. To estimate values below the LOD, EPA referenced the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994b). However, there is only a single data point, so the geometric standard deviation is not statistically meaningful. Therefore, EPA assesses the exposure as ranging from zero to the LOD (2.31 ppm) and presents two scenarios: 1) using the LOD as a "higher value"; and 2) using half the LOD as a "midpoint" value. EPA adjusted the exposure frequency when calculating ADC and LADC to reflect the expected number of exposure days based on the process frequency reported by DoD. For the water pipe repair the frequency was two to three times per month. EPA used the midpoint of the ranges to estimate the central tendency ADC and LADC and the maximum frequency to calculate the high-end ADC and LADC. This resulted in 36 exposure days/yr at the high-end and 30 exposure days at the central tendency for the water pipe repair.

Job descriptions associated with the identified monitoring data were not provided; therefore, EPA assumed all samples were associated with workers. EPA estimates that ONU exposures are lower than

worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-56. Summary of Exposure Results for Other Industrial Uses of PCE

Scenario	Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
		Central Tendency (ppm)	High-End (ppm)			
Textile Processing	8-hr TWA Exposure Concentration	1.2	18	38	1.2	Medium
	Acute Exposure Concentration (AC)	0.4	6.1		0.4	
	Average Daily Concentration (ADC)	0.3	4.1		0.3	
	Lifetime Average Daily Concentration (LADC)	0.1	2.1		0.1	
Wood Furniture Manufacturing	8-hr TWA Exposure Concentration	7.4	44	13	7.4	
	Acute Exposure Concentration (AC)	2.5	15		2.5	
	Average Daily Concentration (ADC)	1.7	10		1.7	
	Lifetime Average Daily Concentration (LADC)	0.7	5.2		0.7	
Foundry Applications	8-hr TWA Exposure Concentration	15	240	4	15	
	Acute Exposure Concentration (AC)	4.9	80		4.9	
	Average Daily Concentration (ADC)	3.4	55		3.4	
	Lifetime Average Daily Concentration (LADC)	1.3	28		1.3	
Miscellaneous	8-hr TWA Exposure Concentration	3.7	4.4	2	3.7	
	Acute Exposure Concentration (AC)	1.2	1.5		1.2	
	Average Daily Concentration (ADC)	0.8	1.0		0.8	

Scenario	Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
		Central Tendency (ppm)	High-End (ppm)			
	Lifetime Average Daily Concentration (LADC)	0.3	0.5		0.3	
DoD Use – Oil Analysis	8-hr TWA Exposure Concentration	0.9[b]		1	0.9	High
	Acute Exposure Concentration (AC)	0.3	0.3		0.3	
	Average Daily Concentration (ADC)	0.1	0.1		0.1	
	Lifetime Average Daily Concentration (LADC)	4.0E-2	6.2E-2		4.0E-2	
	15-min TWA Exposure Concentration	4.2		1	4.2	
	1-hr TWA Exposure Concentration	6.6		1	6.6	
DoD Use – Water Pipe Repair	8-hr TWA Exposure Concentration	1.2	2.3	1[c]	1.2	
	Acute Exposure Concentration (AC)	0.4	0.8		0.4	
	Average Daily Concentration (ADC)	3.2E-2	7.6E-2		3.2E-2	
	Lifetime Average Daily Concentration (LADC)	1.3E-2	3.9E-2		1.3E-2	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
[b] Only one data point was identified for oil analysis. However, different parameters are used for calculating high-end and central tendency ADC and LADC. Therefore, a high-end and central tendency are presented based on the single data point.
[c] Only one data point was identified for water pipe repair. This data point measured below the LOD; therefore, EPA assessed the exposure as ranging from zero to the LOD (2.31 ppm) and presents two scenarios: 1) using the LOD as a "higher value"; and 2) using half the LOD as a "midpoint" value.
Source: (U.S. DOD and Environmental Health Readiness System - Industrial, 2018; OSHA, 2020)

2.4.1.23.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

For textile processing, wood furniture manufacturing, foundry applications, and miscellaneous uses, worker exposure is assessed using PCE personal breathing zone monitoring data from a single source with confidence rating of "medium", as determined through EPA's systematic review process. EPA has a medium of confidence in the assessed worker exposure for these uses based on the strength of the monitoring data.

For the two DoD uses, exposure to workers is assessed using PCE personal breathing zone monitoring data from DoD which has a confidence rating of "high", as determined through EPA's systematic review process. The data is directly applicable to the use being assessed. For the water pipe repair there is some uncertainty in the assessed values as the measurement was below the LOD. There is added uncertainty in the representativeness of the data for both uses as there is only one data point for each. Therefore, EPA has a low level of confidence in the assessed worker exposure for these.

Exposure to ONUs is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.24 Other Commercial Uses

2.4.1.24.1 Worker Activities

The worker activity, use pattern, and associated exposure will vary for each condition of use. For polishes, ink removal products, and mold release, EPA expects workers may be exposed to PCE vapors that evaporate from the application material (rag, brush, etc.) or the substrate surface during use. For inks, workers may be exposed to mists generated during the ink application process. For photographic film, workers may be exposed to PCE that evaporates from the gating process.

2.4.1.24.2 Number of Workers and Occupational Non-Users

EPA has not identified information on the number of sites and potentially exposed workers associated with these uses. The use of PCE for these conditions of use is expected to be minimal.

2.4.1.24.3 Occupational Inhalation Exposure Results

EPA assessed exposure to other commercial uses of PCE using data from identified studies. EPA identified exposure data for printing uses (inks and ink removal products), photocopy shops, photographic film, and mold release uses. Table 2-57 summarizes the 8-hr TWA and 15-min TWA data identified for these uses. Note: Data for mold release products are measured below the LOD; therefore, EPA assessed the half the LOD and the LOD for the central tendency and high-end exposure results, respectively.

Worker samples were determined to be any sample taken on a person while directly handling PCE. ONU samples were determined to be any sample taken on a person in the same location as the PCE use but not handling PCE. The results only include values for workers as monitoring data for ONUs were not identified. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-57. Summary of Exposure Monitoring Data for Other Commercial Uses of PCE

Scenario	Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
		Central Tendency (ppm)	High-End (ppm)			
Printing Applications (Ink and Ink Removal Products)	8-hr TWA Exposure Concentration	1.6	13	44	1.6	Medium to High
	Acute Exposure Concentration (AC)	0.5	4.5		0.5	
	Average Daily Concentration (ADC)	0.4	3.1		0.4	
	Lifetime Average Daily Concentration (LADC)	0.1	1.6		0.1	
	15-min TWA Exposure Concentration	0.2		1	0.2	
Photocopying	8-hr TWA Exposure Concentration	1.9E-4	5.0E-4	3	1.9E-4	High
	Acute Exposure Concentration (AC)	6.3E-5	1.7E-4		6.3E-5	
	Average Daily Concentration (ADC)	4.3E-5	1.1E-4		4.3E-5	
	Lifetime Average Daily Concentration (LADC)	1.7E-5	5.9E-5		1.7E-5	
Photographic Film Applications	8-hr TWA Exposure Concentration	6.3	56	62	6.3	Medium
	Acute Exposure Concentration (AC)	2.1	19		2.1	
	Average Daily Concentration (ADC)	1.4	13		1.4	
	Lifetime Average Daily Concentration (LADC)	0.6	6.6		0.6	
	15-min TWA Exposure Concentration	13	117	40	13	

Scenario	Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
		Central Tendency (ppm)	High-End (ppm)			
Mold Release Products	8-hr TWA Exposure Concentration	5.7E-2	0.1	7	5.7E-2	High
	Acute Exposure Concentration (AC)	1.9E-2	3.8E-2		1.9E-2	
	Average Daily Concentration (ADC)	1.3E-2	2.6E-2		1.3E-2	
	Lifetime Average Daily Concentration (LADC)	5.1E-3	1.3E-2		5.1E-3	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
Source: (Gold et al., 2008; NIOSH, 1980; OSHA, 2020; Moseley and McConnell, 1985)

2.4.1.24.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Worker exposure is assessed using PCE personal breathing zone monitoring data from multiple sources with confidence ratings ranging from "medium" to "high", as determined through EPA's systematic review process. EPA has a medium to high level of confidence in the assessed worker exposure for these uses based on the strength of the monitoring data.

Exposure to ONUs is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.25 Laboratory Chemicals

2.4.1.25.1 Worker Activities

Specific worker activities for using laboratory uses were not identified, but EPA expects that workers may be potentially exposed to PCE in laboratories during multiple activities, including unloading of PCE from the containers in which they were received, transferring PCE into laboratory equipment (*i.e.*, beakers, flasks, other intermediate storage containers), dissolving substances into PCE or otherwise preparing samples that contain PCE, analyzing these samples, and discarding the samples.

ONUs for this condition of use include supervisors, managers, and other employees that may be in the laboratory but do not perform tasks that result in the same level of exposures as those workers that engage in tasks related to the use of PCE.

2.4.1.25.2 Number of Workers and Occupational Non-Users

EPA did not identify information to estimate the total number of workers exposed to PCE at laboratory facilities. However, EPA estimated the number of workers and ONUs per site using information from

the Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). EPA identified the NAICS code 541380, Testing Laboratories, as the code expected to include laboratory chemical uses of PCE. Based on data from the BLS for this NAICS code and related SOC codes, there are an average of one worker and nine ONUs per site, or a total of ten potentially exposed workers and ONUs per site.

2.4.1.25.3 Occupational Inhalation Exposure Results

EPA assessed two subcategories of laboratories: 1) university laboratories; and 2) commercial laboratories. EPA assessed exposures to at university laboratories using data from OSHA facility inspections (OSHA, 2020). Table 2-58 summarizes the 8-hr TWA data identified for laboratory uses. Only one data point was available; however, different parameters are used for calculating high-end and central tendency ADC and LADC. Therefore, a high-end and central tendency are presented based on the single data point. Job descriptions associated with the identified monitoring data were not provided; therefore, EPA assumed all samples were associated with workers. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

For commercial laboratories, EPA does not have reasonably available information to assess worker exposures and due to likely differences in uses, did not extrapolate data from use in a university laboratory to commercial laboratory uses. However, due to the expected safety practices when using chemicals in a commercial laboratory, PCE is expected to be applied in small amounts under a fume hood, thus reducing the potential for inhalation exposures.

Table 2-58. Summary of Exposure Monitoring Data for University Laboratory Uses of PCE

Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)			
8-hr TWA Exposure Concentration	1.2		1	1.2	Medium
Acute Exposure Concentration (AC)	0.4	0.4		0.4	
Average Daily Concentration (ADC)	0.3	0.3		0.3	
Lifetime Average Daily Concentration (LADC)	0.1	0.1		0.1	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
Source: (OSHA, 2020)

2.4.1.25.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Worker exposure in university laboratories is assessed using PCE personal breathing zone monitoring data from a single source with confidence rating of "medium", as determined through EPA's systematic review process. EPA has low confidence in the assessed worker exposure for this use based on the limited number of monitoring data.

Exposure to ONUs in university laboratories is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

For commercial laboratories, EPA has no reasonably available data and qualitatively assessed that exposures will be low due to expected safety practices and use rates of PCE. Due to the lack of data, EPA has a low confidence in this assessment.

2.4.1.26 Waste Handling, Disposal, Treatment, and Recycling

2.4.1.26.1 Worker Activities

At waste disposal sites, workers are potentially exposed via dermal contact with waste containing PCE or via inhalation of PCE vapor. Depending on the concentration of PCE in the waste stream, the route and level of exposure may be similar to that associated with container unloading activities. See Section 2.4.1.23 for the assessment of worker exposure from chemical unloading activities.

2.4.1.26.2 Number of Workers and Occupational Non-Users

EPA estimated the number of workers and occupational non-users potentially exposed during disposal/treatment of PCE using Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the primary NAICS and SIC code reported by each site in the 2016 TRI or 2016 DMR, respectively. There are approximately 1,600 workers and 700 ONUs potentially exposed during disposal/treatment of PCE wastes (see Table 2-59).

Table 2-59. Estimated Number of Workers Potentially Exposed to PCE During Waste Handling, Disposal, Treatment, and Recycling

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers[a]	Total Exposed Occupational Non-Users[a]	Total Exposed[a]
94	17	7	1,600	700	2,300

[a] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.4.1.26.3 Occupational Inhalation Exposure Results

EPA assessed exposure from disposal/treatment of PCE using data from OSHA facility inspections (OSHA, 2020). Table 2-60 summarizes the 8-hr TWA data identified for laboratory uses. EPA calculated the 50th and 95th percentile to estimate central tendency and high-end exposure results, respectively.

Job descriptions associated with the identified monitoring data were not provided; therefore, EPA assumed all samples were associated with workers. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs.

Table 2-60. Summary of Exposure Monitoring Results for Waste Handling, Disposal, Treatment, and Recycling

Exposure Concentration Type	Worker Exposures		Number of Samples	Occupational Non-User Exposures (ppm)[a]	Data Quality Rating of Air Concentration Data
	Central Tendency (ppm)	High-End (ppm)			
8-hr TWA Exposure Concentration	3.8E-3	0.1	12	3.8E-3	Medium
Acute Exposure Concentration (AC)	1.3E-3	3.3E-2		1.3E-3	
Average Daily Concentration (ADC)	8.7E-4	2.3E-2		8.7E-4	
Lifetime Average Daily Concentration (LADC)	3.5E-4	1.2E-2		3.5E-4	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
Source: (OSHA, 2020)

2.4.1.26.4 Strength, Limitation, and Uncertainty of the Inhalation Exposure Assessment

Worker exposure is assessed using PCE personal breathing zone monitoring data from a single source with confidence rating of "medium", as determined through EPA's systematic review process. EPA has a medium level of confidence in the assessed worker exposure for these uses based on the strength of the monitoring data.

Exposure to ONUs is assessed using the worker central tendency exposure values. The statistical representativeness of this value for ONUs is unknown; however, the central tendency for ONUs is expected to be lower than that of workers as EPA expects ONUs to be farther from the source of exposure than workers. Therefore, EPA's confidence in the exposure estimate for ONUs is low.

2.4.1.27 Summary of Inhalation Exposure Assessment

The following table summarizes the inhalation exposure estimates for all occupational exposure scenarios. Where statistics can be calculated, the central tendency estimate represents the 50th percentile exposure level of the available data set, and the high-end estimate represents the 95th percentile exposure level.

Table 2-61. Summary of Inhalation Exposure Results

Condition of Use	Category	8- or 12-Hour TWA Exposures (ppm)		AC (ppm)		ADC (ppm)		LADC (ppm)		Statistical Value for Central Tendency and High-End	Data Type
		High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency		
Manufacturing (8-hr TWA)	Worker	2.7	3.3E-2	0.9	1.1E-2	0.6	7.4E-3	0.3	2.9E-3	50th and 95th Percentile	Monitoring Data
Manufacturing (8-hr TWA)	ONU	9.2E-2	3.4E-2	3.1E-2	1.1E-2	2.1E-2	7.7E-3	1.1E-2	3.1E-3	50th and 95th Percentile	Monitoring Data
Manufacturing (12-hr TWA)	Worker	0.2	2.1E-2	0.1	1.0E-2	4.9E-2	4.7E-3	2.5E-2	1.9E-3	50th and 95th Percentile	Monitoring Data
Manufacturing (12-hr TWA)	ONU	4.5E-2	2.3E-2	2.3E-2	1.1E-2	1.0E-2	5.1E-3	5.3E-3	2.0E-3	Half the LOD and the LOD	Monitoring Data
Repackaging	Worker	1.2	0.5	0.4	0.2	0.3	0.1	0.1	4.2E-2	50th and 95th Percentile	Monitoring Data
Repackaging	ONU[a]	0.5		0.2		0.1		4.2E-2		Unknown	Worker Central Tendency
Processing as Reactant/ Intermediate (8-hr TWA)	Worker	2.7	3.3E-2	0.9	1.1E-2	0.6	7.4E-3	0.3	2.9E-3	50th and 95th Percentile	Monitoring Data
Processing as Reactant/ Intermediate (8-hr TWA)	ONU	9.2E-2	3.4E-2	3.1E-2	1.1E-2	2.1E-2	7.7E-3	1.1E-2	3.1E-3	50th and 95th Percentile	Monitoring Data
Processing as Reactant/ Intermediate (12-hr TWA)	Worker	0.2	2.1E-2	0.1	1.0E-2	4.9E-2	4.7E-3	2.5E-2	1.9E-3	50th and 95th Percentile	Monitoring Data
Processing as Reactant/ Intermediate (12-hr TWA)	ONU	4.5E-2	2.3E-2	2.3E-2	1.1E-2	1.0E-2	5.1E-3	5.3E-3	2.0E-3	Half the LOD and the LOD	Monitoring Data
Incorporation into Formulation - Aerosol Packing	Worker	25	8.7	8.5	2.9	5.8	2.0	3.0	0.8	50th and 95th Percentile	Monitoring Data

Condition of Use	Category	8- or 12-Hour TWA Exposures (ppm)		AC (ppm)		ADC (ppm)		LADC (ppm)		Statistical Value for Central Tendency and High-End	Data Type
		High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency		
Incorporation into Formulation - Aerosol Packing	ONU[a]	8.7		2.9		2.0		0.8		Unknown	Worker Central Tendency
Incorporation into Formulation - Degreasing Solvent	Worker	2.6	0.7	0.9	0.2	0.6	0.2	0.2	6.3E-2	50th and 95th Percentile	Model (probabilistic)
Incorporation into Formulation - Degreasing Solvent	ONU[a]	0.7		0.2		0.2		6.3E-2		Unknown	Worker Central Tendency
Incorporation into Formulation - Dry Cleaning Solvent	Worker	14	4.0	4.7	1.3	3.2	0.9	1.3	0.3	50th and 95th Percentile	Model (probabilistic)
Incorporation into Formulation - Dry Cleaning Solvent	ONU[a]	4.0		1.3		0.9		0.3		Unknown	Worker Central Tendency
Incorporation into Formulation - Miscellaneous	Worker	1.4	0.4	0.5	0.1	0.3	9.1E-2	0.1	3.4E-2	50th and 95th Percentile	Model (probabilistic)
Incorporation into Formulation - Miscellaneous	ONUa	0.4		0.1		9.1E-2		3.4E-2		Unknown	Worker Central Tendency
OTVD	Worker	32	2.1	11	0.7	7.3	0.5	3.8	0.2	50th and 95th Percentile	Monitoring Data
OTVD	ONU	5.2	0.6	1.7	0.2	1.2	0.1	0.6	5.5E-2	50th and 95th Percentile	Monitoring Data

Condition of Use	Category	8- or 12-Hour TWA Exposures (ppm)		AC (ppm)		ADC (ppm)		LADC (ppm)		Statistical Value for Central Tendency and High-End	Data Type
		High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency		
Closed Loop Vapor Degreasing	Worker	0.3	7.2E-2	8.4E-2	2.4E-2	5.8E-2	1.6E-2	3.0E-2	6.6E-3	50th and 95th Percentile	Monitoring Data
Closed Loop Vapor Degreasing	ONU	0.1	6.5E-2	3.2E-2	2.2E-2	2.2E-2	1.5E-2	1.1E-2	5.9E-3	Median and Maximum	Monitoring Data
Conveyorized Vapor Degreasing	Worker	186	78	62	26	42	18	17	6.7	50^{th} and 95^{th} Percentile	Model (probabilistic)
Conveyorized Vapor Degreasing	ONU	126	41	42	14	29	9.3	12	3.5	50^{th} and 95^{th} Percentile	Model (probabilistic)
Web Degreasing	Worker	1.8	0.6	0.6	0.2	0.4	0.1	0.2	5.3E-2	50^{th} and 95^{th} Percentile	Model (probabilistic)
Web Degreasing	ONU	1.3	0.3	0.4	0.1	0.3	7.3E-2	0.1	2.7E-2	50^{th} and 95^{th} Percentile	Model (probabilistic)
Cold Cleaning	Worker	4.1	1.4	1.4	0.5	0.9	0.3	0.5	0.1	50^{th} and 95^{th} Percentile	Monitoring Data
Cold Cleaning	Worker	1.5	2.4E-3	0.5	8.0E-4	0.4	5.5E-4	0.1	2.0E-4	50^{th} and 95^{th} Percentile	Model (probabilistic)
Cold Cleaning	ONU	0.8	1.2E-3	0.3	4.1E-4	0.2	2.8E-4	6.7E-2	1.1E-4	50^{th} and 95^{th} Percentile	Model (probabilistic)
Aerosol Degreasing/ Lubricants	Worker	7.5	1.4	2.5	0.5	1.7	0.3	0.9	0.1	50^{th} and 95^{th} Percentile	Monitoring Data
Aerosol Degreasing/ Lubricants	Worker	17	5.5	5.7	1.8	3.9	1.3	1.6	0.5	50^{th} and 95^{th} Percentile	Model (probabilistic)
Aerosol Degreasing/ Lubricants	ONU	0.7	0.1	0.2	3.4E-2	0.2	2.0E-2	7.0E-2	1.0E-2	50^{th} and 95^{th} Percentile	Model (probabilistic)
Post-2006 NESHAP Dry Cleaning	Worker	17	2.2	5.7	0.7	4.5	0.5	2.3	0.2	50^{th} and 95^{th} Percentile	Monitoring Data
Post-2006 NESHAP Dry Cleaning	ONU	0.3	0.3	0.1	0.1	9.3E-2	8.2E-2	4.8E-2	3.3E-2	N/A (one data point)	Monitoring Data

Condition of Use	Category	8- or 12-Hour TWA Exposures (ppm)		AC (ppm)		ADC (ppm)		LADC (ppm)		Statistical Value for Central Tendency and High-End	Data Type
		High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency		
4th/5th Gen Only Dry Cleaning	Worker	5.6	1.0	1.9	0.3	1.5	0.2	0.8	9.2E-2	50th and 95th Percentile	Monitoring Data
4th/5th Gen Only Dry Cleaning	ONU	0.1	1.4E-2	4.1E-2	4.7E-3	3.3E-2	3.3E-3	1.7E-2	1.3E-3	Median and Maximum	Monitoring Data
Dry Cleaning (12-hr TWA)	Worker	30	1.4	15	0.7	10	0.5	4.1	0.2	50th and 95th Percentile	Model (probabilistic)
Dry Cleaning (12-hr TWA)	ONU	1.5	0.1	0.8	5.4E-2	0.6	3.8E-2	0.2	1.4E-2	50th and 95th Percentile	Model (probabilistic)
Paints/Coatings	Worker	4.6	0.2	1.5	7.8E-2	1.0	5.3E-2	0.5	2.1E-2	50th and 95th Percentile	Monitoring Data
Paints/Coatings	ONU[a]	0.2		7.8E-2		5.3E-2		2.1E-2		Unknown	Worker Central Tendency
Adhesives	Worker	0.8	8.8E-2	0.3	2.9E-2	0.2	2.0E-2	9.5E-2	8.0E-3	Arithmetic Mean and Maximum	Monitoring Data
Adhesives	ONU[a]	8.8E-2		2.9E-2		2.0E-2		8.0E-3		Unknown	Worker Central Tendency
Chemical Maskant	Worker	57	2.2	19	0.7	13	0.5	6.6	0.2	50th and 95th Percentile	Monitoring Data
Chemical Maskant	ONU	2.2	1.0	0.7	0.3	0.5	0.2	0.3	9.5E-2	50th and 95th Percentile	Monitoring Data
Industrial Processing Aid	Worker	1.2	6.0E-2	0.4	2.0E-2	0.3	1.4E-2	0.1	5.4E-3	50th and 95th Percentile	Monitoring Data
Industrial Processing Aid	ONU[a]	6.0E-2		2.0E-2		1.4E-2		5.4E-3		Unknown	Worker Central Tendency
Other Industrial Uses – Textile Processing	Worker	18	1.2	6.1	0.4	4.1	0.3	2.1	0.1	50th and 95th Percentile	Monitoring Data
Other Industrial Uses – Textile Processing	ONU[a]	1.2		0.4		0.3		0.1		Unknown	Worker Central Tendency
Other Industrial Uses – Wood Furniture Manufacturing	Worker	44	7.4	15	2.5	10	1.7	5.2	0.7	50th and 95th Percentile	Monitoring Data

Condition of Use	Category	8- or 12-Hour TWA Exposures (ppm)		AC (ppm)		ADC (ppm)		LADC (ppm)		Statistical Value for Central Tendency and High-End	Data Type
		High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency		
Other Industrial Uses – Wood Furniture Manufacturing	ONU[a]	7.4		2.5		1.7		0.7		Unknown	Worker Central Tendency
Other Industrial Uses – Foundry Applications	Worker	240	15	80	4.9	55	3.4	28	1.3	Median and Maximum	Monitoring Data
Other Industrial Uses – Foundry Applications	ONU[a]	15		4.9		3.4		1.3		Unknown	Worker Central Tendency
Other Industrial Uses – Miscellaneous	Worker	4.4	3.7	1.5	1.2	1.0	0.8	0.5	0.3	Midpoint and Maximum	Monitoring Data
Other Industrial Uses – Miscellaneous	ONU[a]	3.7		1.2		0.8		0.3		Unknown	Worker Central Tendency
Other Industrial Uses - DoD Water Pipe Repair	Worker	2.3	1.2	0.8	0.4	7.6E-2	3.2E-2	3.9E-2	1.3E-2	Half the LOD and the LOD	Monitoring Data
Other Industrial Uses - DoD Water Pipe Repair	ONU[a]	1.2		0.4		3.2E-2		1.3E-2		Unknown	Worker Central Tendency
Other Industrial Uses - DoD Oil analysis	Worker	0.9[b]		0.3	0.3	0.1	0.1	6.2E-2	4.0E-2	N/A (one data point)	Monitoring Data
Other Industrial Uses - DoD Oil analysis	ONU[a]	0.9		0.3		0.1		4.0E-2		Unknown	Worker Central Tendency
Metalworking Fluid	Worker	2.1E-2	5.8E-3	7.0E-3	1.9E-3	4.8E-3	1.3E-3	2.5E-3	5.2E-4	Geometric mean and 90th percentile	ESD
Metalworking Fluid	ONU[a]	5.8E-3		1.9E-3		1.3E-3		5.2E-4		Unknown	Worker Central Tendency

Condition of Use	Category	8- or 12-Hour TWA Exposures (ppm)		AC (ppm)		ADC (ppm)		LADC (ppm)		Statistical Value for Central Tendency and High-End	Data Type
		High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency		
Wipe Cleaning and Metal/Stone Polishes	Worker	228	132	76	44	52	30	27	12	Median and Maximum	Monitoring Data
Wipe Cleaning and Metal/Stone Polishes	ONU	23	2.2E-2	7.7	7.3E-3	5.3	5.0E-3	2.7	2.0E-3	50th and 95th Percentile	Monitoring Data
Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	Worker	3.4	1.5	1.1	0.5	0.8	0.3	0.4	0.1	Median and Maximum	Monitoring Data
Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	ONU	3.0E-2[b]		1.0E-2	1.0E-2	6.8E-3	6.8E-3	3.5E-3	2.7E-3	N/A (one data point)	Monitoring Data
Other Commercial Uses - Printing	Worker	13	1.6	4.5	0.5	3.1	0.4	1.6	0.1	50th and 95th Percentile	Monitoring Data
Other Commercial Uses - Printing	ONU[a]	1.6		0.5		0.4		0.1		Unknown	Worker Central Tendency
Other Commercial Uses - Photocopying	Worker	5.0E-4	1.9E-4	1.7E-4	6.3E-5	1.1E-4	4.3E-5	5.9E-5	1.7E-5	Median and Maximum	Monitoring Data
Other Commercial Uses - Photocopying	ONU[a]	1.9E-4		6.3E-5		4.3E-5		1.7E-5		Unknown	Worker Central Tendency

Condition of Use	Category	8- or 12-Hour TWA Exposures (ppm)		AC (ppm)		ADC (ppm)		LADC (ppm)		Statistical Value for Central Tendency and High-End	Data Type
		High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency	High-End	Central Tendency		
Other Commercial Uses - Photographic Film	Worker	56	6.3	19	2.1	13	1.4	6.6	0.6	50th and 95th Percentile	Monitoring Data
Other Commercial Uses - Photographic Film	ONU[a]	6.3		2.1		1.4		0.6		Unknown	Worker Central Tendency
Other Commercial Uses - Mold Release	Worker	0.1	5.7E-2	3.8E-2	1.9E-2	2.6E-2	1.3E-2	1.3E-2	5.1E-3	Half the LOD and the LOD	Monitoring Data
Other Commercial Uses - Mold Release	ONU[a]	5.7E-2		1.9E-2		1.3E-2		5.1E-3		Unknown	Worker Central Tendency
Laboratory Chemicals (University)	Worker	1.2[b]		0.4	0.4	0.3	0.3	0.1	0.1	N/A (one data point)	Monitoring Dat
Laboratory Chemicals (University)	ONU[a]	1.2		0.4		0.3		0.1		Unknown	Worker Central Tendency
Laboratory Chemicals (Commercial)	EPA did not identify reasonable available data to assess occupational exposures for this OES.										
Disposal/ Recycling	Worker	1.0E-2	3.8E-3	3.3E-2	1.3E-3	2.3E-2	8.7E-4	1.2E-2	3.5E-4	50th and 95th Percentile	Monitoring Data
Disposal/ Recycling	ONU[a]	3.8E-3		1.3E-3		8.7E-4		3.5E-4		Unknown	Worker Central Tendency

[a] EPA did not identify monitoring data or models to estimate exposures for ONUs. In lieu of ONU-specific data, EPA uses worker central tendency exposure results as a surrogate to estimate exposures for ONUs. The statistical representativeness of this value for ONUs is unknown.
[b] Only a single data point was available for this condition of use.

2.4.1.28 Dermal Exposure Assessment

Dermal absorption of PCE depends on the type and duration of exposure. Where exposure is non-occluded, only a fraction of PCE that comes into contact with the skin will be absorbed as the chemical readily evaporates from the skin. However, dermal exposure may be significant in cases of occluded exposure, repeated contacts, or dermal immersion. For example, work activities with a high degree of splash potential may result in PCE liquids trapped inside the gloves, inhibiting the evaporation of PCE and increasing the exposure duration. EPA considered occluded exposures but data to evaluate such exposures were not reasonably available.

To assess exposure, EPA used the *Dermal Exposure to Volatile Liquids Model* (see following equation and Appendix K of the *Environmental Releases and Occupational Exposure Assessment* (Supplemental Engineering Report) (U.S. EPA, 2020d)) to calculate the dermal retained dose. The equation modifies *EPA/OPPT 2-Hand Dermal Exposure to Liquids Model* (peer reviewed) by incorporating a "fraction absorbed (f_{abs})" parameter to account for the evaporation of volatile chemicals and a "protection factor (PF)" to account for glove use:

$$D_{exp} = \frac{S \times (Q_u \times f_{abs}) \times Y_{derm} \times FT}{PF \times BW}$$

Where:

D_{exp} is the dermal retained dose (mg/kg-day)
S is the surface area of contact (cm^2)
Q_u is the quantity remaining on the skin after an exposure event (mg/cm^2-event)
Y_{derm} is the weight fraction of the chemical of interest in the liquid ($0 \leq Y_{derm} \leq 1$)
FT is the frequency of events (integer number per day)
f_{abs} is the fraction of applied mass that is absorbed (Default for PCE: 0.13 for industrial facilities and 0.19 for commercial facilities[18])
PF is the glove protection factor (Default: see Table 2-62)
BW is the body weight (Default: 80 kg)

Default glove PF values, which vary depending on the type of glove used and the presence of employee training program, are shown in Table 2-62. A more detailed discussion on the basis of glove PF values used in the assessment can be found in Appendix K.5 of the Supplemental Engineering Report (U.S. EPA, 2020d).

[18] The absorbed fraction (f_{abs}) is a function of indoor air speed, which differs for industrial and commercial settings.

Table 2-62. "What-if" Glove Protection Factors for Different Dermal Protection Strategies

Dermal Protection Characteristics	Setting	Protection Factor, PF
a. No gloves used, or any glove / gauntlet without permeation data and without employee training	Industrial and Commercial Uses	1
b. Gloves with available permeation data indicating that the material of construction offers good protection for the substance		5
c. Chemically resistant gloves (*i.e.*, as *b* above) with "basic" employee training		10
d. Chemically resistant gloves in combination with specific activity training (*e.g.*, procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur	Industrial Uses Only	20

Source: (Marquart et al., 2017)

Table 2-63 presents the estimated dermal acute retained dose for *workers* in various exposure scenarios, including what-if scenarios for glove use. The dose estimates assume one exposure event (applied dose) per workday and that 13 to 19 percent of the applied dose is absorbed through the skin. The exposure estimates are provided for each condition of use, where the conditions of uses are "binned" based on the maximum possible exposure concentration (Y_{derm}) and the likely level of exposure. The exposure concentration is determined based on EPA's review of currently available products and formulations containing PCE:

- **Bin 1:** Bin 1 covers industrial uses that generally occur in closed systems. For these uses, activities resulting in dermal contact with PCE are likely limited to chemical loading/unloading activities (*e.g.*, connecting hoses) and taking quality control samples which EPA expects to occur a minimum of once per day. Contact events may be zero where workers do not perform any of these activities in a day or higher than one where workers perform multiple activities or the same activity multiple times in the same day. However, due to the use of closed-systems, EPA expects the potential for workers to have more than one contact event per day to be less than that for other bins where open-systems are used. Where multiple contact events occur, EPA expects the total number of contacts to be less than the total at sites operating open systems.
- **Bin 2:** Bin 2 covers industrial degreasing and chemical maskant uses, which are not closed systems. For these uses, there is greater opportunity for dermal exposure during activities such as charging and draining degreasing/milling equipment, drumming waste solvent, handling recycled/re-captured maskants, and removing waste sludge. EPA expects workers will, at a minimum, perform at least one of these activities per day. Contact events may be higher than one where workers perform multiple activities or the same activity multiple times in the same day. Due to the use of open-systems, EPA expects the potential for workers to have multiple contact events per day to be higher than that for bins where closed-systems are used. Where multiple contact events occur, EPA expects the total number of contacts to be greater than the total at sites operating closed systems.
- **Bin 3:** Bin 3 covers aerosol uses, where workers are likely to have direct dermal contact with film applied to substrate and incidental deposition of aerosol to skin. EPA expects workers will, at a minimum, perform at least one activity resulting in dermal contact per day. Contact events may be higher than one where workers perform multiple activities or the same activity multiple times in the same day. Due to the use of open-systems, EPA expects the potential for workers to

have multiple contact events per day to be higher than that for bins where closed-systems are used. Where multiple contact events occur, EPA expects the total number of contacts to be greater than the total at sites operating closed systems.

- **Bin 4:** Bin 4 cover dry cleaning uses of PCE. At dry cleaning shops, workers may be exposed to bulk liquids while charging and draining solvent to/from machines, removing and disposing sludge, and maintaining equipment. Workers can also be exposed to PCE used in spot cleaning products at the same shop. EPA expects workers will, at a minimum, perform at least one activity resulting in dermal contact per day. Contact events may be higher than one where workers perform multiple activities or the same activity multiple times in the same day. Due to the use of open-systems, EPA expects the potential for workers to have multiple contact events per day to be higher than that for bins where closed-systems are used. Where multiple contact events occur, EPA expects the total number of contacts to be greater than the total at sites operating closed systems.
- **Bin 5:** Bin 5 covers commercial activities of similar maximum PCE concentration (all activities may use PCE at 100wt%). Most of these uses are expected to have direct dermal contact with bulk liquids. EPA expects workers will, at a minimum, perform at least one activity resulting in dermal contact per day. Contact events may be higher than one where workers perform multiple activities or the same activity multiple times in the same day. Due to the use of open-systems, EPA expects the potential for workers to have multiple contact events per day to be higher than that for bins where closed-systems are used. Where multiple contact events occur, EPA expects the total number of contacts to be greater than the total at sites operating closed systems.
- **Bin 6:** Bin 6 covers uses of metalworking fluids containing PCE. These product formulations are expected to be used in industrial settings and workers may be exposed when unloading the metalworking fluid from containers; transferring fluids to the trough; and performing metal shaping operations. EPA expects workers will, at a minimum, perform at least one activity resulting in dermal contact per day. Contact events may be higher than one where workers perform multiple activities or the same activity multiple times in the same day. Due to the use of open-systems, EPA expects the potential for workers to have multiple contact events per day to be higher than that for bins where closed-systems are used. Where multiple contact events occur, EPA expects the total number of contacts to be greater than the total at sites operating closed systems.
- **Bin 7:** Bin 7 covers uses of adhesives, sealants, paints, and coatings containing PCE. These product formulations may have both industrial and commercial uses and workers may be exposed when mixing coating/adhesive, charging products to application equipment (*e.g.*, spray guns, roll applicators, etc.), and cleaning application equipment. Other workers may also have incidental contact with applied products during subsequent fabrication steps. EPA expects workers will, at a minimum, perform at least one activity resulting in dermal contact per day. Contact events may be higher than one where workers perform multiple activities or the same activity multiple times in the same day. Due to the use of open-systems, EPA expects the potential for workers to have multiple contact events per day to be higher than that for bins where closed-systems are used. Where multiple contact events occur, EPA expects the total number of contacts to be greater than the total at sites operating closed systems.

Dermal exposure to liquid is not expected for occupational non-users, as they do not directly handle PCE.

As shown in the table, certain bins have the same acute retained dose despite being described as having different dermal exposure potentials above. One reason for this is due to EPA's use of one contact event

per day for all OES. Regardless of OES, the minimum number of contact events EPA expects at a facility using PCE or PCE-based products is one; however, the number of contact events may be greater than one, with the greatest number of contact events occurring at facilities that use PCE in open systems. For example, the acute retained dose for bins 1 and 2 are shown to be equal; however, EPA expects the primary route of dermal exposure for bin 1 OES to be from unloading/loading of containers and QC sampling likely resulting in fewer dermal contacts for workers than those in the OES in bin 2 where additional worker tasks may result in a greater number of contact events. However, the model used to estimate dermal exposures does not currently have the capability to evaluate multiple contact events as dermal exposures are a function of both number of contact events and duration between contact events. For example, if the first contact event resulted in a high, super-saturated applied dose and the subsequent contact event was soon afterwards, before appreciable evaporation or absorption took place, there may not be an appreciable increase in absorbed dose. EPA has not identified reasonably available data to determine number of contact events and time between events to adapt the model to account for the differences in dermal exposure potential between bins. However, EPA still divided the OES into separate bins to at least attempt to capture potential differences qualitatively, if not quantitatively.

Another reason certain bins may have the same acute retained dose despite being described as having different exposure potentials is the potential for occluded exposures to occur. For example, EPA expects the use of PCE in closed systems such as those in bin 1 to have low potential for occlusion whereas the use in open systems such as those in bin 2 are more likely to result in occluded exposures. Again, EPA did not identify reasonably available data to estimate occluded exposures but used separate bins to qualitatively acknowledge this potential difference in OES.

A final reason the results in Table 2-63 for multiple bins are equal is that this table only represents acute retained doses. The difference in some bins may not be in the acute retained dose but the chronic retained dose due to differences in the number of exposure days. The result of such differences can be seen in risk characterization in Section 4.2.3. For example, the acute retained dose for bins 3 and 4 are equal; however, the number of exposure days will be higher for workers in bin 4 as compared to bin 3.

Strength, Limitation, and Uncertainty of the Dermal Exposure Assessment

Dermal exposures are assessed using *the Dermal Exposure to Volatile Liquids Model*, which relies on the theoretical framework presented by Kasting and Miller (2006) to estimate the fractional absorption in accounting for chemical volatilization. EPA has a medium level of confidence in the assessed baseline exposure. Glove protection factors are presented as what-if scenarios to show the potential effect of glove use on exposure levels. EPA does not know the actual frequency, type, and effectiveness of glove use in specific workplaces with PCE conditions of use.

Table 2-63. Estimated Dermal Acute Retained Dose for Workers in All Conditions of Use

Exposure Scenario	Bin	Max Y_{derm}	Dermal Exposure (mg/kg-day)			
			No Gloves (PF = 1)	Protective Gloves (PF = 5)	Protective Gloves (PF = 10)	Protective Gloves (Industrial uses, PF = 20)
Manufacture	Bin 1	1.0	1.2 (CT) 3.5(HE)	0.2 (CT) 0.7 (HE)	0.1 (CT) 0.4 (HE)	5.9E-2 (CT) 0.2 (HE)
Import/Repackaging						
Processing as a Reactant						
Incorporation into Formulation, Mixture, or Reaction Product						
Industrial Processing Aid						
Other Industrial Uses						
Laboratory Chemicals						
Waste Handling, Disposal, Treatment, and Recycling						
Batch Open-Top Vapor Degreasing	Bin 2	1.0	1.2(CT) 3.5 (HE)	0.2 (CT) 0.7 (HE)	0.1 (CT) 0.4 (HE)	5.9E-2 (CT) 0.2 (HE)
Batch Closed-Loop Vapor Degreasing						
Conveyorized Vapor Degreasing						
Web Degreasing						
Cold Cleaning						
Maskant for Chemical Milling						
Aerosol Degreasing and Aerosol Lubricants	Bin 3	1.0	1.8 (CT) 5.3 (HE)	0.4 (CT) 1.1 (HE)	0.2 (CT) 0.5 (HE)	N/A

Dry Cleaning and Spot Cleaning	Bin 4	1.0	1.8 (CT) 5.4 (HE)	0.4 (CT) 1.1 (HE)	0.2 (CT) 0.5 (HE)	N/A
Wipe Cleaning and Metal/Stone Polishes	Bin 5	1.0	1.8 (CT) 5.4 (HE)	0.4 (CT) 1.1 (HE)	0.2 (CT) 0.5 (HE)	N/A
Other Spot Cleaning/Spot Remover						
Other Commercial Uses						
Metalworking Fluids	Bin 6	0.10	0.1 (CT) 0.4 (HE)	2.5E-2 (CT) 7.1E-2 (HE)	1.2E-2 (CT) 3.5E-2 (HE)	5.9E-3 (CT) 1.8E-2 (HE)
Adhesives, Sealants, Paints, and Coatings (Industrial)	Bin 7	0.80	0.9 (CT) 2.8 (HE)	0.2 (CT) 0.6 (HE)	9.4E-02 (CT) 0.3 (HE)	4.7E-2 (CT) 0.1 (HE)
Adhesives, Sealants, Paints, and Coatings (Commercial)		0.80	1.4 (CT) 4.3 (HE)	0.3 (CT) 0.9 (HE)	0.1 (CT) 0.4 (HE)	N/A

Yderm = Concentration of PCE in product formulation; CT = Central Tendency; HE = High-End

2.4.1.29 Key Assumptions and Uncertainties of the Occupational Exposure Assessment

EPA addressed variability in models by identifying key model parameters to apply a statistical distribution that mathematically defines the parameter's variability. EPA defined statistical distributions for parameters using documented statistical variations where available. Where the statistical variation is not known, assumptions are made to estimate the parameter distribution using available literature data. See the *Risk Evaluation for Perchloroethylene Supplemental Information: Assessment of Occupational Exposure and Environmental Releases for Perchloroethylene* (U.S. EPA, 2019a) for statistical distribution for each model input parameter. The following sections discuss uncertainties in the occupational exposure assessment.

One overarching uncertainty is that exposures to PCE from outside the workplaces are not included in the occupational assessment, which could lead to an underestimate of the overall exposures experienced by workers and ONUs. Another overarching uncertainty is that inhalation and dermal exposures were assessed separately, which could lead to an underestimation of occupational exposure. EPA considered the reasonably available information and used the best available science to determine whether to consider aggregate or sentinel exposures for PCE. There is low confidence in the result of aggregating the dermal and inhalation risks for PCE in case of using an additive approach, due to the uncertainty in the data. EPA does not have data that could be reliably modeled into the aggregate (see Section 4.3.2 for more details).

2.4.1.29.1 Number of Workers

There are a number of uncertainties surrounding the estimated number of workers potentially exposed to PCE, as outlined below. Most are unlikely to result in a systematic underestimate or overestimate but could result in an inaccurate estimate. A systematic under- or overestimate would be an inaccuracy/uncertainty in the methodology or underlying data that consistently resulted in EPA's estimate being biased in a single direction (*i.e.*, always higher or always lower than the true value). Although the uncertainties in the number of workers may cause a result to be inaccurate, all results are not expected to be subject to a single directional bias.

CDR data are used to estimate the number of workers associated with manufacturing. There are inherent limitations to the use of CDR data as they are reported by manufacturers and importers of PCE. Manufacturers and importers are only required to report if they manufactured or imported PCE in excess of 25,000 pounds at a single site during any calendar from 2012 to 2015; as such, CDR may not capture all sites and workers associated with any given chemical. Second, the estimate is based on information that is known or reasonably ascertainable to the submitter. CDR submitters (chemical manufacturers and importers) do not always have accurate information on the number of potentially exposed workers at downstream processing sites.

There are also uncertainties with BLS data, which are used to estimate the number of workers for the remaining conditions of use. First, BLS' OES employment data for each industry/occupation combination are only available at the 3-, 4-, or 5-digit NAICS level, rather than the full 6-digit NAICS level. This lack of granularity could result in an overestimate of the number of exposed workers if some 6-digit NAICS are included in the less granular BLS estimates but are not, in reality, likely to use PCE for the assessed conditions of use. EPA addressed this issue by refining the OES estimates using total employment data from the U.S. Census' SUSB. However, this

approach assumes that the distribution of occupation types (SOC codes) in each 6-digit NAICS is equal to the distribution of occupation types at the parent 5-digit NAICS level. If the distribution of workers in occupations with PCE exposure differs from the overall distribution of workers in each NAICS, then this approach will result in inaccuracy.

Second, EPA's judgments about which industries (represented by NAICS codes) and occupations (represented by SOC codes) are associated with the uses assessed in this report are based on EPA's understanding of how PCE is used in each industry. Designations of which industries and occupations have potential exposures is nevertheless subjective, and some industries/occupations with few exposures might erroneously be included, or some industries/occupations with exposures might erroneously be excluded. This would result in inaccuracy but would be unlikely to systematically either overestimate or underestimate the count of exposed workers**.**

2.4.1.29.2 Analysis of Exposure Monitoring Data

To analyze the exposure data, EPA categorized individual PBZ data points as either "worker" or "occupational non-user." The categorizations are based on descriptions of worker job activity as provided in literature and EPA's judgment. In general, samples for employees that are expected to have the highest exposure from direct handling of PCE are categorized as "worker" and samples for employees that are expected to have lower exposure and do not directly handle PCE are categorized as "occupational non-user."

Exposures for occupational non-users can vary substantially. Most data sources do not sufficiently describe the proximity of these employees to the PCE exposure source. As such, exposure levels for the "occupational non-user" category will have high variability depending on the specific work activity performed. It is possible that some employees categorized as "occupational non-user" have exposures similar to those in the "worker" category depending on their specific work activity pattern.

Some data sources may have a bias. For example, bias may be present if exposure monitoring was conducted to address concerns regarding adverse human health effects reported following exposures during use.

Some scenarios have limited exposure monitoring data in literature, if any. Where few data are available, the assessed exposure levels are unlikely to be representative of worker exposure across the entire job category or industry. In addition, exposure data for compliance safety and health officers may not be representative of typical exposure levels for occupational non-users.

In cases where there was no exposure monitoring data, EPA attempted to identify monitoring data from similar conditions of use as surrogate. While these conditions of use have similar worker activities contributing to exposures, it is unknown if the results will be fully representative of worker exposure across different conditions of use.

Where the sample data set contains six or more data points, the 50^{th} and 95^{th} percentile exposure concentrations were calculated from the sample to represent central tendency and high-end exposure levels. using available data. The underlying distribution of the data, and the representativeness of the available data, are not known. Where discrete data was not available,

EPA used reported statistics (*i.e.,* median, mean, 90th percentile, etc.). Since EPA could not verify these values, there is an added level of uncertainty.

2.4.1.29.3 Near-Field/Far-Field Model Framework

The near-field/far-field approach is used as a framework to model inhalation exposure for many conditions of use. The following describe uncertainties and simplifying assumptions generally associated with this modeling approach:

- There is some degree of uncertainty associated with each model input parameter. In general, the model inputs were determined based on review of available literature. Where the distribution of the input parameter is known, a distribution is assigned to capture uncertainty in the Monte Carlo analysis. Where the distribution is unknown, a uniform distribution is often used. The use of a uniform distribution will capture the low-end and high-end values but may not accurately reflect actual distribution of the input parameters.
- The model assumes the near-field and far-field are well mixed, such that each zone can be approximated by a single, average concentration.
- All emissions from the facility are assumed to enter the near-field zone. This assumption will overestimate exposures and risks in facilities where some emissions do not enter the airspaces relevant to worker exposure modeling.
- The exposure models estimate airborne concentrations. Exposures are calculated by assuming workers spend the entire activity duration in their respective exposure zones (*i.e.,* the worker in the near-field and the occupational non-user in the far-field). Since vapor degreasing and cold cleaning involve automated processes, a worker may actually walk away from the near-field during part of the process and return when it is time to unload the degreaser. As such, assuming the worker is exposed at the near-field concentration for the entire activity duration may overestimate exposure.
- For certain PCE applications (*e.g.,*vapor degreasing and cold cleaning), PCE vapor is assumed to emit continuously while the equipment operates (*i.e.,* constant vapor generation rate). Actual vapor generation rate may vary with time. However, small time variability in vapor generation is unlikely to have a large impact in the exposure estimates as exposures are calculated as a time-weighted average.
- The exposure models represent model workplace settings for each PCE condition of use. The models have not been regressed or fitted with monitoring data.

Each subsequent section below discusses uncertainties associated with the individual model.

2.4.1.29.4 Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model

For the other industrial uses and waste handling, disposal, treatment, and recycling conditions of use, the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* is used to estimate the airborne concentration associated with generic chemical loading scenarios at industrial facilities. Specific uncertainties associated with this model are described below:

- After each loading event, the model assumes saturated air containing PCE that remains in the transfer hose and/or loading arm is released to air. The model calculates the quantity of saturated air using design dimensions of loading systems published in the OPW Engineered Systems catalog and engineering judgment. These dimensions may not be

representative of the whole range of loading equipment used at industrial facilities handling PCE.

- The model estimates fugitive emissions from equipment leaks using total organic compound emission factors from EPA's *Protocol for Equipment Leak Emission Estimates* (U.S. EPA, 1995), and engineering judgment on the likely equipment type used for transfer (*e.g.*,number of valves, seals, lines, and connections). The applicability of these emission factors to PCE, and the accuracy of EPA's assumption on equipment type are not known.
- The model assumes the use of a vapor balance system to minimize fugitive emissions. Although most industrial facilities are likely to use a vapor balance system when loading/unloading volatile chemicals, EPA does not know whether these systems are used by all facilities that potentially handle PCE.

2.4.1.29.5 Vapor Degreasing and Cold Cleaning Models

The conveyorized vapor degreasing, web degreasing, and cold cleaning assessments use a near-field/far-field approach to model worker exposure. In addition to the uncertainties described above, the vapor degreasing and cold cleaning models have the following uncertainties:

- To estimate vapor generation rate for each equipment type, EPA used a distribution of the emission rates reported in the 2014 NEI for each degreasing/cold cleaning equipment type. NEI only contains information on major sources not area sources. Therefore, the emission rate distribution used in modeling may not be representative of degreasing/cold cleaning equipment emission rates at area sources.
- The emission rate for conveyorized vapor degreasing is based on equipment at a single site and the emission rates for web degreasing are based on equipment from two sites. It is uncertain how representative these data are of a "typical" site.
- EPA assumes workers and occupational non-users remove themselves from the contaminated near- and far-field zones at the conclusion of the task, such that they are no longer exposed to any residual PCE in air.

2.4.1.29.6 Brake Servicing Model

The aerosol degreasing assessment also uses a near-field/far-field approach to model worker exposure. Specific uncertainties associated with the aerosol degreasing scenario are presented below:

- The model references a CARB study (CARB, 2000) on brake servicing to estimate use rate and application frequency of the degreasing product. The brake servicing scenario may not be representative of the use rates for other aerosol applications involving PCE.
- The CARB study (CARB, 2000) presented 13 different aerosol degreasing formulations containing PCE. For each Monte Carlo iteration, the model determines the PCE concentration in product by selecting one of 13 possible formulations, assuming the distribution for each formulation is equal to that found in a survey of brake cleaning shops in California. It is uncertain if this distribution is representative of other geographic locations within the U.S.
- Some of the aerosol formulations presented in the CARB study (CARB, 2000) were provided as ranges. For each Monte Carlo iteration the model selects a PCE concentration within the range of concentrations using a uniform distribution. In reality, the PCE concentration in the formulation may be more consistent than the range provided.

2.4.1.29.7 Dry Cleaning Model

The multi-zone dry cleaning model also uses a near-field/far-field approach. Specific uncertainties associated with the dry cleaning scenario are presented below (see also Section 2.4.1.16):

- The model assumes each facility only has one dry cleaning machine, cleaning one to fourteen loads of garments per day. The number of machines is based on the 2010 King County, WA survey (Whittaker and Johanson, 2011) where 96 percent of 151 respondents reported having only one machine at their facility. It is uncertain if this distribution is representative of other geographic locations in the U.S. Larger facilities are likely to have more machines, which could result in additional PCE exposures.
- The model conservatively uses a hemispherical volume based on the dry cleaning machine door diameter as the near-field for machine unloading. The small near-field volume results in a large spike in concentration when the machine door is opened, where any residual PCE solvent is assumed to be instantaneously released into the near-field. In reality, the residual solvent will likely be released continuously over a period of time. In addition, the worker may move around while unloading the garments, such that the worker's breathing zone will not always be next to the machine door throughout the duration of this activity. Therefore, these assumptions may result in an overestimate of worker exposure during machine unloading.
- Many of the model input parameters were obtained from von Grote (2003), which is a German study. Aspects of the U.S. dry cleaning facilities may differ from German facilities. However, it is not known whether the use of German data will under- or over-estimate exposure.
- The model does not cover all potential worker activities at dry cleaners. For example, workers could be exposed to PCE emitted due to equipment leaks, when re-filling PCE solvent into dry cleaning machines, when interrupting a dry cleaning cycle, or when performing maintenance activities (*e.g.*, cleaning lint and button traps, raking out the still, changing solvent filter, and handling solvent waste) (OSHA, 2005). However, there is a lack of information on these activities in the literature, and the frequency of these activities is not well understood. The likelihood of equipment leaks is dependent on whether the machines are properly maintained. The frequency of solvent re-filling depends on a specific dry cleaner's workload and solvent consumption rate, which is also affected by the presence of leaks. Based on observations reported by NIOSH (2010) and Blando (2010), solvent charging is not performed every day. EPA was unable to develop a modeling approach for these exposure activities due to the lack of available information.

2.4.1.29.8 Modeled Dermal Exposures

The *Dermal Exposure to Volatile Liquids Model* used to estimate dermal exposure to PCE in occupational settings. The model assumes a fixed fractional absorption of the applied dose; however, fractional absorption may be dependent on skin loading conditions. The model also assumes a single exposure event per day based on existing framework of the *EPA/OPPT 2-Hand Dermal Exposure to Liquids Model* and does not address variability in exposure duration and frequency.

2.4.2 Consumer Exposures

EPA evaluated PCE exposure resulting from the use of relevant consumer products and consumer articles. EPA gathered and evaluated consumer exposure information according to the process described in the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018b). PCE concentrations measured in residential air or personal breathing zone samples are reported in Section 2.4.2.1. Monitoring and/or controlled laboratory data were available for a limited number of consumer use scenarios. To fill data gaps, EPA utilized a modeling approach to estimate PCE exposure via use of consumer products and articles (Section 2.4.2.3 and Section 2.4.2.4, respectively).

2.4.2.1 Overview and Literature Summary

Concentrations of volatile organic compounds, such as PCE, are often higher in indoor air than outdoor air due to their presence in consumer products and articles (Lehmann et al., 2002; Fishbein, 1992; Thomas et al., 1991). In developed counties, people generally spend 90% of their time indoors (de Blas et al., 2012; Fishbein, 1992), and indoor air quality can be greatly compromised due to volatile emissions from cleaning agents, dry-cleaned clothes, adhesives, paints and other commercial and consumer products (Canada, 2017; de Blas et al., 2012; D'Souza et al., 2009; Lehmann et al., 2002; Thomas et al., 1991).

Systematic review was conducted to identify consumer specific exposure data for PCE containing products and articles (data evaluation tables are available in the Risk Evaluation for PCE Systematic Review Supplemental File Data Quality Evaluation of Consumer Exposure Studies). The literature review returned limited information about chemical-specific consumer monitoring. Most results from the systematic review pertained to indoor air and personal breathing zone concentrations of PCE in residential and consumer settings. Monitoring sites included the United States, Canada, Mexico, Sweden, Finland, Estonia, Lithuania, Belgium, United Kingdom, France, Austria, Germany, Poland, Slovakia, Czech Republic, Hungary, Romania, Bulgaria, Serbia, Bosnia and Herzegovina, Italy, Portugal, Malta, Greece, Cyprus, Albania, Netherlands, China, Japan, Saudi Arabia and Hong Kong.

EPA identified 19 acceptable studies from the United States and Canada deemed to be in the scope of this risk evaluation, which monitored residential or commercial indoor air for PCE concentrations, for a total of 3172 measured samples. Identified studies were conducted between the years 1980 and 2013. The detection frequency of PCE in the identified studies ranged from 30% to 100% detection, with a median of 95% detection (with 4 studies not reporting detection frequency). Measured PCE concentrations in indoor air ranged from non-detects (detection limits varied) 94985 ug/m^3, with reported central tendency (mean) values ranging from 0.2 ug/m^3 to 58348 ug/m^3. The maximum air concentration of PCE was measured in a do-it-yourself laundry facility with coin-operated dry cleaning machines (Howie, 1981). Full data extraction details for residential indoor air samples conducted in schools and commercial establishments in the US and Canada is provided in the Risk Evaluation for PCE Data Extraction for Consumer and General Population Exposure Monitoring Studies.

Of the identified studies, 11 pertained to air concentrations of PCE limited to residential homes in the United States and Canada (Table 2-64). Residential indoor air monitoring studies were conducted between 1986 and 2010, with roughly 1,900 samples collected across eleven US states (CA, CO, IL, IN, MA, MI, MN, NJ, NY, OH, and TX) and Canada (exact location not reported).

Concentrations ranged from non-detect (limits varied) to 171 µg/m^3. The highest concentration was from the Canadian study (Chan et al., 1990), which sampled air concentration in Canadian residences. The next highest concentration was 78 µg/m^3, collected from inner-city homes in New York, New York (Sax et al., 2004). Maximum concentrations of approximately 30 µg/m^3 were detected in garages in Boston, Massachusetts (Dodson et al., 2008) and in living areas of industrial, urban, and suburban homes in Michigan (Jia et al., 2008a). All other maximum reported concentrations were less than 14 µg/m^3. Measures of central tendency (average or median) across all datasets were less than 7 µg/m^3, except for the Canadian study at 28.1 µg/m^3.

Table 2-64. Residential Indoor Air Concentrations (µg/m^3) of PCE in the United States and Canada

Study Info	Site Description	Detection Limit	Min.	Mean	GM	Median	Max.	Variance	Data Quality Rating
(Chin et al., 2014); US, 2009-2010 (n = 126; DF = 0.91)	Detroit, MI area; Homes (n=126) with asthmatic children, sampled in living rooms and bedroom	0.091	ND	0.71	--	0.26	13.7	1.66 (SD)	High
(Batterman et al., 2007); US, 2005 (n = 15; DF = 0.73)	Southeast MI; Homes (n = 15) sampled in various locations in the home (upstairs, downstairs)	0.069	--	0.6	--	--	4.4	1.2 (SD)	High
(Batterman et al., 2007); US, 2005 (n = 15; DF = 0.33)	Southeast MI; Garages of residences (n = 15)	0.069	--	0.3	--	--	1.6	0.5 (SD)	High
(Jia et al., 2008a); US, 2004-2005 (n = 252; DF = 0.99)	Ann Arbor, Ypsilanti, and Dearborn MI; Homes (n=159) in industrial, urban, and suburban cities over two seasons	0.02	ND	0.93	--	0.39	27.84	--	Medium
(Dodson et al., 2008)[a]; US, 2004-2005 (n = 16; DF = 0.81)	Boston, MA; Garage of residences	0.07-0.17	ND	2.8	--	0.3	31 (95th)	7.8 (SD)	High
(Dodson et al., 2008)[a]; US, 2004-2005 (n = 10; DF = 0.9)	Boston, MA; Apartment hallway of residences	0.07-0.17	ND	1.9	--	0.8	11 (95th)	3.4 (SD)	High
(Dodson et al., 2008)[a]; US, 2004-2005 (n = 52; DF = 0.98)	Boston, MA; Basement of residences	0.07-0.17	ND	1.7	--	0.5	1.7 (95th)	0.92 (SD)	High
(Dodson et al., 2008)[a]; US, 2004-2005 (n = 83; DF = 0.92)	Boston, MA; Interior room of residences	0.07-0.17	ND	1.9	--	0.6	8.6 (95th)	3.1 (SD)	High
(Adgate et al., 2004); US, 2000 (n = 113; DF = 0.949)	Minneapolis, MN in spring; Sampling from room where child spent the most time.	--	ND (10^{th} 0.02)	--	--	0.4	1 (90th)	--	Medium
(Adgate et al., 2004); US, 2000 (n=113; DF = 0.98)	Minneapolis, MN in winter; Sampling from room where child spent the most time.	--	ND (10^{th} 0.02)	--	--	0.5	1.3 (90th)	--	Medium
(Sax et al., 2004); US, 2000 (n = 32; DF = 1)	Los Angeles, CA in fall; Homes in inner-city neighborhood	0.15	0.6	1.8	--	1.3	6.8	1.4 (SD)	High

Study Info	Site Description	Detection Limit	Min.	Mean	GM	Median	Max.	Variance	Data Quality Rating
(Sax et al., 2004); US, 2000 (n = 40; DF = 1)	Los Angeles, CA in winter; Homes in inner-city neighborhood	0.15	0.7	2.3	--	1.9	11	1.9 (SD)	High
(Sax et al., 2004); US, 1999 (n = 30; DF = 0.78)	New York, NY in summer; Homes in inner-city neighborhood.	0.15	ND	5.3	--	2	43	8.7 (SD)	High
(Sax et al., 2004); US, 1999 (n = 36; DF = 1)	New York, NY in winter; Homes in inner-city neighborhood.	0.15	0.8	6.7	--	3.5	78	13.1 (SD)	High
(Clayton et al., 1999); US, 1995-1997 (n = 402; DF = 0.571)	IL, IN, OH, MI, MN, WI (Great Lakes Region); Non-institutionalized persons	--	ND	5.82	--	1.89	6.83 (90th)	--	High
(Su et al., 2013)[b]; US, 1999-2001 (n = 539; DF = NR)	Elizabeth, NJ; Houston, TX; and Los Angeles, CA; Non-smoking households (n=310)	0.21	--	1.85	--	0.82	6.03 (95th)	4.53 (SD)	Medium
(Van Winkle and Scheff, 2001); US, 1994-1995 (n = 48; DF = 1)	Southeast Chicago, IL; Urban homes (n=10) sampled over a 10-month period from the kitchen in the breathing zone.	--	0.54	2.61	--	2.17	4.74 (90th)	2.15 (SD)	High
(Lindstrom et al., 1995); US, 1994 (n = 9; DF = 0.89)	Denver, CO; Homes, occupied (n=9)	0.14	ND	0.66	--	0.33	1.99	--	Medium
(Chan et al., 1990); CA, 1987 (n = 6; DF = 1)	Homes (n=6), main floor	--	2	6.2	--	--	18	--	Medium
(Chan et al., 1990); CA, 1986 (n = 12; DF = 1)	Homes (n=12), main floor	--	1	28.1	--	--	171	--	Medium

Study Info: The information provided includes the HERO ID and citation; country and year samples collected; number of samples and detection frequency.
Abbreviations: If a value was not reported, it is shown in this table as "--." ND = not detected at the reported detection limit. GM = geometric mean. DF = detection frequency. NR = Not reported. US = United States. CA = Canada
Parameters: All statistics are shown as reported in the study. Some reported statistics may be less than the detection limit; the method of handling non-detects varied by study. All minimum values determined to be less than the detection limit are shown in this table as "ND." If a maximum value was not provided, the highest percentile available is shown (as indicated in parentheses); if a minimum value was not provided, the lowest percentile available is shown (as indicated in parentheses).
[a] Samples from this study (Dodson et al., 2008) were collected as part of the BEAMS study.
[b] Samples from this study (Su et al., 2013) were collected as part of the RIOPA study.

EPA identified 20 acceptable studies conducted outside of North America (Mexico, and the previously listed countries in Europe, Asia and the Middle East), for a total of 4369 measured samples. Identified studies were conducted between the years 1981 and 2015. The detection frequency of PCE in the identified foreign studies ranged from 30% to 100% detection, with a median of 100% detection (with 12 studies not reporting detection frequency). Measured PCE concentrations in indoor air ranged from non-detects (detection limits varied) to $9.63x10^4$ ug/m^3, with reported central tendency (mean) values ranging from 0.46 ug/m^3 to $4.95x10^3$ ug/m^3. The maximum air concentration of $9.63x10^4$ ug/m^3 was measured near a photocopy shop (Kiurski et al., 2016). The next highest reported concentration was $2.48x10^4$ ug/m^3 in a vehicle exposed to dry-cleaned articles (Gulyas and Hemmerling, 1990). The highest PCE concentration measured in residential air was 245 ug/m^3 measured in urban homes in Paris, France (Roda et al., 2013). Full data extraction details for indoor residential air samples, from studies conducted within and outside of North America, is provided in the Risk Evaluation for PCE Data Extraction for Consumer and General Population Exposure Monitoring Studies.

2.4.2.1.1 Personal Breathing Zone

Concentrations of PCE in personal breathing zone measurements are reported in Table 2-65 for seven US studies. Overall, the measured concentration dataset contains approximately 3,000 samples that were collected between 1981 and 2001, and represents time spent in various microenvironments (*i.e.*, home, school, work, transit) during the monitoring period (48- to 72-hr periods in four studies, and 3-hr, 12-hr, and/or 6-day periods for the remainder). Only the 3-hr samples from Heavner (1995) represent time inside the home only. Concentrations ranged from non-detects (detections limits varied) to 659 µg/m^3. The highest concentration was observed in NHANES survey data from 1999-2000 (Jia et al., 2008a). The study notes that two participants had exposure to highly elevated levels of PCE; one participant spent more time than usual at work/school and the other participant worked with paint thinners, brush cleaners, or strippers as well as glues, adhesives, hobbies or crafts, and also reported having new carpet installed in the past 6 months. The 95th percentile concentration for the NHANES study was 18.5 µg/m^3. Maximum reported concentrations in other studies were less than 11 µg/m^3 (including the 90^{th} or 95^{th} percentile if a maximum was not provided). Median values ranged from 0.4 to 2 µg/m^3; whereas, average values were higher, reaching a maximum of approximately 30 µg/m^3 (Sexton et al., 2007; Clayton et al., 1999). Full data extraction details for personal breathing zone samples, from studies conducted within and outside of North America, is provided in the Risk Evaluation for PCE Data Extraction for Consumer and General Population Exposure Monitoring Studies.

Table 2-65. Personal Breathing Zone Air Concentrations (µg/m3) for PCE in the United States (General/Residential).

Study Info	Type	Site/Population Description	Detection Limit	Min.	Mean	GM	Median	Max.	Variance	Data Eval. Score
(Su et al., 2013)[a] US, 1999-2001 (n=544; DF = NR)	48-hr	Elizabeth, NJ; Houston, TX; and Los Angeles, CA; Adults (n=309) and children (n=118) from 310 non-smoking households.	0.21	--	7.17	--	0.89	6.82 (95th)	112.35 (SD)	Medium
(Jia et al., 2008b)[b] US, 1999-2000 (n=665; DF = 0.69)	48- to 72-hr	Nation-wide; Adults (ages 20–59 years) in NHANES study	0.42	ND (0.1)	5.2	1.0	0.7	659.1 (18.5 - 95th)	31.2 (SD); 4.1 (GSD)	Medium
(Adgate et al., 2004) US, 2000 (n=113; DF = 1)	48-hr	Minneapolis, MN in winter; children ages 6-10 yrs	--	0.2 (10th)		--	0.4	1.3 (90th)	--	Medium
(Adgate et al., 2004) US, 2000 (n=113; DF = 0.966)	48-hr	Minneapolis, MN in spring; children ages 6-10 yrs	--	ND (0.2 10th)		--	0.4	0.9 (90th)	--	Medium
(Sexton et al., 2007) US, 1999 (n=333; DF = 0.997)	48-hr	Minneapolis -St. Paul, MN; Adults, non-smoking (n=70) living in three neighborhoods: (inner-city, blue-collar/near manufacturing plants, and affluent)	--	ND (0.3 10th)	27.8	--	0.9	6.4 (90th)	--	High
(Clayton et al., 1999)[c] US, 1995-1997 (n=386; DF = 0.613)	6-day	IL, IN, OH, MI, MN, WI (Great Lakes Region); Non-institutionalized persons	--	ND	31.92	--	1.98	10.78 (90th)	--	High
(Heavner et al., 1995)[d] US, 1991 (n=25; DF = NR)	3-hrs (in home only)	Columbus, OH; Non-smoking (n=25) women with smoking husbands	--	ND	0.89	--	0.68	3.78	0.96 (SD)	Medium
(Heavner et al., 1995)[d] US, 1991 (n=24; DF = NR)	3-hrs (in home only)	Columbus, OH; Non-smoking women (n=24) with non-smoking husbands	--	ND	1.24	--	0.7	5.13	1.46 (SD)	Medium
(Wallace, 1987)[e] US, 1981-1984 (n=772; DF = 0-0.97)	12-hrs	Elizabeth and Bayonne, NJ, Los Angeles, CA, and Contra Costa, CA; Adults s in industrial/chemical manufacturing and /or petroleum refining regions of the US.	--	--	5.6 to 45	--	--			High

Abbreviations: If a value was not reported, it is shown in this table as "--." ND = not detected at the reported detection limit. GM = geometric mean. GSD = geometric standard deviation. DF = detection frequency. NR = Not reported. US = United States.
Parameters: All statistics are shown as reported in the study. Some reported statistics may be less than the detection limit; the method of handling non-detects varied by study. All minimum values determined to be less than the detection limit are shown in this table as "ND." If a maximum value was not provided, the highest percentile available is shown (as indicated in parentheses); if a minimum value was not provided, the lowest percentile available is shown (as indicated in parentheses).
[a] Samples from this study (Su et al., 2013) were collected as part of the RIOPA study. The study notes that PCE exposures increased by visiting a drycleaner.
[b] Samples from this study (Jia et al., 2008b) were collected as part of the NHANES 1999-2000. Two measurements with high values (659 and 490 μg /m^3) were more than five times higher than the next measurement. These two participants did not report dry cleaning exposure, breathing fumes from or using dry cleaning fluid or spot remover. One participant spent an unusually large amount of time at work/school and another subject worked with paint thinners, brush cleaners, or strippers as well as glues, adhesives, hobbies or crafts, and also reported having new carpet installed in the past 6 months.
[c] Samples from this study (Clayton et al., 1999) were collected as part of the NHEXAS Phase 1 field study.
[d] In Heavner (1995), elevated concentrations of PCE were associated with wearing dry-cleaned clothes ($p \leq 0.05$) when all homes were combined, but not for smoking and non-smoking separately. Statistical power was low since only 2 of 49 participants wore dry-cleaned clothes within the previous week.
[e] Samples from this study (Wallace, 1987) were collected as part of the TEAMS study.

2.4.2.2 Consumer Exposure Approach and Methodology

Consumer exposures to PCE are expected via inhalation and dermal routes based on physical-chemical properties and identified consumer uses. PCE can be found in consumer and/or commercial products that are readily available for public purchase at common retailers ((U.S. EPA, 2017f), Sections 3-5) and can therefore result in exposures to consumers and bystanders (non-product users that are incidentally exposed to the product). The magnitude of exposure depends upon the concentration of PCE products, use patterns (including frequency, duration, amount of product used, room of use) and application methods. Several consumer product use scenarios were analyzed based on identified PCE products and articles available to consumers, including solvents for cleaning and degreasing, lubricants and greases, adhesives and sealant chemicals, paints and coatings, mold release products, metal and stone polishes, and exposure to recently dry-cleaned articles. Consumer exposure to elevated indoor air concentrations of PCE due to the use of coin-operated dry cleaning machines and retail print-shops was summarized based on available literature.

Consumer product application activities include using aerosol and liquid products for spraying, wiping, immersive cleaning and painting. Other activities include pouring and applying various types of liquids and pastes. Information regarding use patterns and application methods was obtained from national solvent usage surveys (Westat, 1987), as well as EPA's Consumer Exposure Model (CEM) Version 2.1 (see CEM 2.1 User Guide (U.S. EPA, 2019b)). PCE weight fractions and product densities of PCE containing products were compiled from publicly available product MSDS or SDS documents (Material Safety Data Sheet or Safety Data Sheet, see EPAs Preliminary Information on Manufacturing, Processing, Distribution, use and Disposal: Tetrachloroethylene (2017f)). If product densities were not reported, the product density was estimated based on reported mass percent composition of the product relative to constituent densities. Other physical-chemical parameters for PCE are referenced in the Scoping and Problem Formulation documents.

EPA does not expect exposure to consumers from disposal of consumer products. It is anticipated that most products will be disposed of in original containers, particularly those products that are purchased as aerosol cans.

2.4.2.2.1 Routes of Exposure

Inhalation

Consumer and bystander inhalation exposure to PCE-containing products and articles primarily include direct inhalation of vapors, mists and aerosols (*e.g.*, aerosols from spray applications) and indirect inhalation exposures after application. EPA assumed mists are absorbed via inhalation, rather than ingestion, due to deposition of vapors and mists in the upper respiratory tract. The magnitude of inhalation exposure depends upon the concentration of PCE in products, use patterns (including frequency, duration, amount of product used, room of use) and application methods.

Dermal

Consumer dermal exposure to PCE-containing products occurs via vapor or mist deposition onto the skin, or via direct contact with liquids during product use, or direct contact with treated articles (U.S. EPA, 2012e). PCE is expected to evaporate rapidly from skin based on physical

chemical properties of PCE but some PCE is absorbed dermally. The magnitude of dermal exposure depends on exposure characteristics such as skin surface area, product volume, chemical loading and weight fraction, and exposure duration. PCE is a volatile solvent expected to evaporate from skin, however, there are certain consumer use scenarios for which PCE evaporation may be limited, for example due to immersion of hands into a reservoir of cleaning solvent (reasonable given that consumers are not assumed to use PPE, as well as the nature of PCE containing products and uses), the wearing of recently dry-cleaned fabrics, or handling/wiping using a solvent soaked rag.

Ingestion

Consumers may be exposed to PCE via transfer of chemical from hand to mouth. However, this exposure pathway is expected to be limited by a combination of dermal absorption and high volatilization of PCE. Due to the expected very low magnitude of accidental hand to mouth exposure, EPA did not further assess this pathway.

2.4.2.2.2 Modeling Approach

EPA estimated consumer exposures for all currently known use scenarios for products containing PCE. A variety of sources were reviewed during the Systematic Review process to identify these products and/or articles, including Safety Data Sheets (SDS), National Institutes of Health (NIH) Household Products Database, the Chemical and Products (CPCat) Database, Peer-reviewed and gray literature and the Kirk-Othmer Encyclopedia of Chemical Technology.

Consumer exposures were assessed for all PCE containing products identified as available for consumer purchase, as described in EPAs Preliminary Information on Manufacturing, Processing, Distribution, use and Disposal: Tetrachloroethylene (2017f). No chemical-specific personal monitoring data was identified during Systematic Review, except in the case of exposure to PCE from recently dry-cleaned articles, and indoor air concentrations from coin-operated laundry and printshop proximity. Due to the lack of consumer monitoring data, a modeling approach was used to estimate potential consumer exposures. EPA's Consumer Exposure Model (U.S. EPA, 2017a) was selected as the most appropriate model for PCE consumer product use scenarios, as described below and in the Risk Evaluation for PCE Supplemental Information on Consumer Exposure. CEM was used to estimate indoor air concentrations of PCE and dermal exposure to PCE in certain scenarios, generated from the use of consumer products. Consumer exposure to recently dry-cleaned fabrics was also estimated, based on reasonably available monitoring data. Inhalation exposure due to off-gassing from recently dry-cleaned articles was assessed using EPA's Multi-Chamber Concentration and Exposure Model (MCCEM, (U.S. EPA, 2019e)), and dermal exposure due to wearing dry-cleaned articles was assessed using CEM, as described in the *Risk Evaluation for Perchloroethylene Supplemental Information on Consumer Exposure* (U.S. EPA, 2020f).

EPA's Consumer Exposure Model was chosen based on model relevance to consumer use scenarios, the in-model database of consumer relevant default parameters, and model flexibility to modify parameters when chemical-specific information is available. CEM was also preferred because it does not require chemical- and/or product-specific emission data, as is required to run more complex indoor/consumer models. CEM is a deterministic model utilizing user provided input parameters and/or assumptions to generate exposure estimates. A full discussion of CEM

features and general parameterization can be found in the *Risk Evaluation for Perchloroethylene Supplemental Information on Consumer Exposure* (U.S. EPA, 2020f).

Model parameters were determined based on physical chemical properties and product information (*e.g.*, product density, water solubility, vapor pressure, etc.), use-specific consumer survey data (Westat (1987); *e.g.*, duration of use, frequency of use, mass of product used per event, etc.), and where applicable, model scenario defaults (*e.g.*, room of use, activity patterns, air exchange rates, environment volume). A negligible background concentration of PCE was assumed for all scenarios. Room of use was selected based on either CEM scenario default room of use or a Westat survey category room of use (often in agreement with one another), based on professional judgment. The CEM model does not currently accommodate outdoor scenarios. For products that are intended to be used outdoors, modifications to the CEM inputs were made to simulate an outdoor scenario by adjusting Zone 1 parameters (which represents the room of use or use environment). In modeling caulk and column adhesives, the garage was selected as the room of use, but the room volume was changed to 16 m^3 to represent a half-dome chemical cloud around the person using the product. Additionally, the air exchange rate for Zone 1 was set to 100 to reflect the high rate between the cloud and the rest of outside. The interzonal ventilation rate was set to 0, which effectively blocks the exchange of air between Zone 1 and the rest of the house. Thus, the concentrations users are exposed to inside the home after product use is zero. In the outside scenario, bystanders in the home are assumed to have zero exposures. However, bystanders in the outdoor environment were not modeled, but could potentially be exposed to similar levels as the user.

While inhalation exposure can be acute or chronic in nature, EPA does not expect consumer exposure to be chronic in nature because product use patterns tend to be infrequent with relatively short durations of use. As a result, we only present the acute consumer results in this risk evaluation. Acute exposures were defined as those occurring within a single day; whereas chronic exposures were defined as exposures comprising 10% or more of a lifetime (U.S. EPA, 2011a). In addition to exposure doses, indoor air concentrations were estimated and reported as maximum 24-hour time-weighted-averages (24 hr TWA).

Sixteen distinct product categories were identified for consumer modeling. Product categories were assigned based on the physical form of the product (aerosol, liquid, wipe, etc.) and intended use. See Table 2-66 and Table 2-67 for groupings and the corresponding CEM parameters for each scenario.

To characterize the potential range of consumer exposures, modeling for each scenario was conducted by varying three key parameters while keeping all other input parameters constant, resulting in a range of "user intensities" for each COU. The key parameters included duration of use per event (minutes/use), amount of chemical in the product or article (weight fraction), and mass of product or article used per event (gram/use). Duration of use and mass of product used were assigned to each use category based on the Westat (1987) survey of consumer behavior patterns. Each scenario was evaluated at a low, medium, and high value (10^{th}, 50^{th}, and 95^{th} percentiles) for duration of use and mass of product used, based on the most representative product use category. Product weight fractions were determined from review of product Safety Data Sheets and any other information identified during Systematic Review. This input

parameter was varied using minimum, mean and maximum values, unless only a single product was identified for a given use scenario. Input parameters for PCE containing consumer product scenarios modeled in CEM are given in Table 2-66 and Table 2-67. For full parametrization details see the *Risk Evaluation for Perchloroethylene Supplemental Information on Consumer Exposure* (U.S. EPA, 2020f).

Inhalation Exposure Estimation

Inhalation exposure to PCE containing products was estimated using CEM, which predicts indoor air concentrations by implementing a deterministic, mass-balance calculation selected by the user (see CEM 2.1 User Guide (U.S. EPA, 2019b) and *Risk Evaluation for Perchloroethylene Supplemental Information on Consumer Exposure* (U.S. EPA, 2020f)). The model uses a two-zone representation of the building of use, with Zone 1 representing the room where the consumer product is used and Zone 2 being the remainder of the building. Product users and bystanders follow prescribed activity patterns and inhale airborne concentrations determined by the activity zone. All PCE scenarios were assessed using the near-field/far-field model option to capture the potentially higher concentration in the breathing zone of a product user during use. Inhalation exposure to PCE as a result of proximity to recently dry-cleaned articles was estimated using MCCEM (U.S. EPA, 2019e), which utilizes chemical- and article-specific emission parameters to predict indoor air concentrations (see Section 2.4.2.2.2 for further details).

Dermal Exposure Estimation

EPA used the CEM (Fraction Absorbed, P_DER2a) model to evaluate dermal exposure for product COUs where evaporation is expected to be uninhibited and no direct immersion of body parts into a product occurs during use. The fraction absorbed method (P_DER2a) is based on the volume of chemical absorbed across the skin barrier. The model calculates the competing process of evaporation of the chemical from the skin surface and penetration of chemical deeper into the skin. The fraction absorbed is estimated for PCE based on Frasch and Bunge (2015) and described in full within the CEM User's Guide (U.S. EPA, 2017a). This model assumes the skin surface layer is "filled" once during product use to an input thickness with subsequent absorption over an estimated absorption time. Consumer uses assessed for dermal exposure based on fraction absorbed include adhesives; aerosol coatings and primers; caulk, column adhesives and sealants; outdoor water sealant; rust primers and sealants; livestock grooming adhesives; metallic overglaze; spray lubricants and penetrating oils; mold cleaner and weld splatter protectants.

EPA used the CEM (Permeability, P_DER2b) model to evaluate dermal exposure for product COUs where there is the possibility of a continuous supply of chemical against the skin with inhibited or prohibited evaporation potential due to a barrier or direct immersion of body parts into a product during use. The permeability method (P_DER2b) is based on the ability of a chemical to penetrate the skin layer once contact occurs. The model assumes a constant supply of chemical, directly in contact with the skin, throughout the exposure duration. A chemical-specific skin permeability coefficient for neat[19] PCE was used (4.23E-04, (Kezic et al., 2001).

[19] The permeability coefficient has been updated since the release of the Draft Risk Evaluation for Perchloroethylene. In the draft Risk Evaluation, an aqueous Kp value was applied to dermal exposure calculations. However, PCE-containing consumer products frequently have majority PCE weight fractions. The dermal exposure

Consumer product uses analyzed for dermal exposure based on permeability include degreasers; break cleaners; cutting fluids; marble polish and stone cleaners; immersive parts cleaners; vandalism mark and stain remover.

Dermal exposure to PCE from recently dry-cleaned fabrics was estimated using CEM's direct-contact article model (A_DER2). This model estimates dermal exposure based on the migration rate of a chemical from an article to the skin, which is governed by the solid phase diffusion coefficient, in combination with age-specific activity patterns to estimate potential loading on the skin.

Exposure Receptors

Consumer use scenarios were assessed for adults (age 21+) and two youth age-groups (16-20 years and 11-15 years) as product users. All other individuals were considered as non-users (treated as bystanders). CEM was parameterized based on characteristics of exposed populations and receptor factors (such as age-specific body weight, skin surface area, inhalation rates, etc. all based on Exposure Factors Handbook (U.S. EPA, 2011a)); user and bystander activity patterns; building volumes and air exchange rates; and product use considerations.

results were recalculated using a neat Kp for PCE (Kezic et al., 2001) which is two orders of magnitude smaller than the aqueous Kp previous reported from (Nakai et al. 1999) ($4.23x10^{-4}$ vs. $1.8x10^{-2}$ cm/hr).

Table 2-66. CEM Consumer Product Modeling Scenarios and Key Product Parameters

Consumer Conditions of Use	Form	No. of Products Identified[1]	Range of Weight Fractions Identified (% PCE)[2]	Weight Fractions Selected for Use in Modeling (% PCE)			Selected Product Density (g/cm^3)[3]	Selected CEM 2.1 Modeling Scenario[4]	Emission Model Applied[5]	Dermal Exposure Model Applied[6]	Dermal SA/BW[7]
				Min	Mean	Max					
Solvent; Cleaner; Marine cleaner; Degreaser; Coil cleaner; Electric motor cleaner ; Parts cleaner; Cable cleaner; Stainless Steel Polish; Electrical/Energized Cleaner; Wire and ignition demoisturants; Electric motor cleaner	Aerosol	15	10-100	10	80	100	1.62	Degreasers	E3	P_DER2b	Inside of one hand
Parts cleaner	Liquid	1	50-60	50	60	---	1.34	Generic	E5	P_DER2b	Both hands
Brake Cleaner	Aerosol	14	40-100	40	91	100	1.32	Degreasers	E3	P_DER2b	Inside of one hand
Mold Cleaner; Weld Splatter Protectant	Aerosol	4	5-100	5	40	100	1.62	All Purpose Spray Cleaner	E3	P_DER2a	10% of hand
Vandalism Mark & Stain Remover	Aerosol	1	10-20	10	20	---	1.21	All Purpose Spray Cleaner	E3	P_DER2b	Inside of one hand
Marble Polish, Stone Cleaner	Liquid	3	10-100	10	85	100	1.62	All Purpose Liquid Cleaner	E1	P_DER2b	Inside of both hands[8]
Cutting Fluid	Liquid	1	10	10	---	---	7.72	Non-Spray Lubricant	E1	P_DER2b	Inside of both hands
Spray Lubricant; Penetrating Oil	Aerosol	9	5-100	5	54	100	1.62	Spray Lubricant	E3	P_DER2a	10% of hand
Industrial adhesive; Adhesive; Arts and crafts adhesive; Gun ammunition sealant	Liquid	15	30-100	30	89	100	1.31	Glues and Adhesives (small scale)	E1	P_DER2a	Inside of one hand
Livestock Grooming Adhesive	Aerosol	1	15	15	---	---	1.45	Spray Fixative and Finishing Spray Coatings	E3	P_DER2a	10% of hand
Column Adhesive; Caulk; Sealant	Gel/ Liquid	16	5-75	5	48	75	1.19	Caulk	E1	P_DER2a	Inside of one hand

Consumer Conditions of Use	Form	No. of Products Identified[1]	Range of Weight Fractions Identified (% PCE)[2]	Weight Fractions Selected for Use in Modeling (% PCE)			Selected Product Density (g/cm^3)[3]	Selected CEM 2.1 Modeling Scenario[4]	Emission Model Applied[5]	Dermal Exposure Model Applied[6]	Dermal SA/BW[7]
				Min	Mean	Max					
Coatings and Primers	Aerosol	10	9-14	9	10	14	1.3952	Aerosol Spray Paints	E3	P_DER2a	Inside of one hand
Rust primer; Sealant	Liquid	9	9-11	9	10	11	1.3952	Solvent-Based Wall Paint	E2	P_DER2a	Face, hands and arms
Sealant (Water Shield)	Liquid	1	45	45	---	---	1.28	Solvent-Based Wall Paint	E2	P_DER2a	Face, hands and arms
Metallic Overglaze (for ceramics)	Liquid	1	20-30	20	30	---	1	Lacquers and Stains	E2	P_DER2a	Inside of one hand
Marble Polish, Stone Cleaner	Liquid Wax	1	85-100	85	95	100	1.4	All Purpose Waxes and Polishes	E1	P_DER2b	Inside of both hands

[1] The number of products identified is based on the product lists in EPA's 2017 *Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: Tetrachloroethylene (PCE)* (2017f). It is possible that specific products and/or formulations identified in those reports and used herein to select appropriate weight fractions, formulation types, and formulation densities for use in modeling no longer contain PCE or are no longer readily available to consumers for purchase; however, they were still considered for sourcing such information since they were identified as in these recent EPA publications and therefore represent reasonably-foreseen uses. *See Risk Evaluation for Perchloroethylene Supplemental Information for Consumer Exposure* (U.S. EPA, 2020f) for the full product list utilized.

[2] The range in weight fractions is reflective of the identified products containing PCE and not reflective of hypothetical levels or theoretical functionality-based limits. Weight fractions were sourced from product Safety Data Sheets (SDSs) or Material Safety Data Sheets (MSDSs).

[3] Product densities were identified from product SDSs or MSDSs. When density was not reported in product MSDS or SDSs, products with high PCE weight fractions (>90% PCE) were assumed to have the density of pure PCE (1.62 g/cm^3), otherwise the product density was calculated based on the percent contribution of each ingredient per the MSDS ingredient list. See *Risk Evaluation for Perchloroethylene Supplemental Information for Consumer Exposure* (U.S. EPA, 2020f) for the full product list utilized.

[4] The listed CEM 2.1 modeling scenario reflects the default product options within the model, which are prepopulated with certain default parameters. However, due to EPA choosing to select and vary many key inputs, the specific model scenario matters less than the associated emission and dermal exposure models (*e.g.*, E1, E3, P_DER2a).

[5] Emission models used for PCE include E1 – Emission from Product Applied to a Surface Indoors Incremental Source Model, E2 – Emission from Product Applied to a Surface Indoors Double Exponential Model, E3 – Emission from Product Sprayed, and E5 – Emission from Product Placed in Environment.

[6] All product scenarios utilized the P_DER1b model for dermal exposure – Dermal Dose from Product Applied to Skin, Permeability Model.

7Suface Area to Body Weight (SA/BW) ratios are default parameters for the selected CEM use scenarios, values are based on central tendency (mean) values (Exposure Factors Handbook (U.S. EPA, 2011a), CEM 2.1 User Guide (U.S. EPA, 2019b))

[8]CEM default dermal SABW ratio for the All-Purpose Liquid Cleaner category is one hand, however both hands were modeled for consistency between wax vs. liquid stone polish use categories.

Table 2-67. Consumer Product Modeling Scenarios and Key Westat Product Use Parameters

Consumer Conditions of Use	Form	Selected Westat (1987) Survey Scenario[1]	Room of Use[2]	Duration of Use (Percentile) (min)			Mass of Product Used (Percentile) (g)[4]		
				(10th)[3]	50th	95th	10th	50th	95th
Solvent; Cleaner; Marine cleaner; Degreaser; Coil cleaner; Electric motor cleaner ; Parts cleaner; Cable cleaner; Stainless Steel Polish; Electrical/Energized Cleaner; Wire and ignition demoisturants; Electric motor cleaner	Aerosol	Solvent-Type Cleaning Fluids or Degreasers	Utility Room	2	15	120	26.83	155.69	1532.91
Parts cleaner	Liquid	Spot Remover	Utility Room	0.5 (0.25)	5	30	9.91	52.70	441.01
Brake Cleaner	Aerosol	Brake Quieters/ Cleaners	Garage	1	15	120	39.03	156.13	624.52
Mold Cleaner; Weld Splatter Protectant	Aerosol	Solvent-Type Cleaning Fluids or Degreasers	Utility Room	2	15	120	26.83	155.69	1532.91
Vandalism Mark & Stain Remover	Aerosol	Solvent-Type Cleaning Fluids or Degreasers	Utility Room	2	15	120	26.83	155.69	1532.91
Marble and Stone Polish	Liquid	Solvent-Type Cleaning Fluids or Degreasers	Utility Room	2	15	120	26.83	155.69	1532.91
Cutting Fluid	Liquid	Other Lubricants (Excluding Automotive)	Utility Room	0.5 (0.08)	2	30	26.83	155.69	1532.91
Spray Lubricant; Penetrating Oil	Aerosol	Other Lubricants (Excluding Automotive)	Utility Room	0.5 (0.08)	2	30	4.79	26.35	239.51
Industrial adhesive; Adhesive; Arts and crafts adhesive; Gun ammunition sealant	Liquid	Contact Cement, Super Glues, and Spray Adhesives	Utility Room	0.5 (0.33)	4.25	60	1.16	9.68	167.34

Consumer Conditions of Use	Form	Selected Westat (1987) Survey Scenario[1]	Room of Use[2]	Duration of Use (Percentile) (min)			Mass of Product Used (Percentile) (g)[4]		
				(10th)[3]	50th	95th	10th	50th	95th
Livestock Grooming Adhesive	Aerosol	Contact Cement, Super Glues, and Spray Adhesives	Utility Room	0.5 (0.33)	4.25	60	1.29	10.72	185.23
Column Adhesive; Caulk; Sealant	Gel/ Liquid	Primers and Special Primers (excluding automotive)	Garage	5	30	360	45.39	387.07	8121.46
Coatings and Primers	Aerosol	Aerosol Spray Paint	Utility Room	5	20	120	61.88	330.05	1608.99
Rust primer; Sealant	Liquid	Primers and Special Primers (excluding automotive)	Garage	5	30	360	53.22	453.82	9521.90
Sealant (Water Shield)	Liquid	Outdoor Water Repellent	Garage	15	60	300	302.8	2422.37	24223.74
Metallic Overglaze (for ceramics)	Liquid	Contact Cement, Super Glues, and Spray Adhesives	Utility Room	0.5 (0.33)	4.25	60	0.89	7.39	127.74
Marble and Stone Polish	Wax	Solvent-Type Cleaning Fluids or Degreasers	Utility Room	2	15	120	23.18	134.54	1324.74

[1] (Westat, 1987)
[2] Room of use is either default scenario option within CEM or based on Westat survey data for the specific product use category.
[3] CEM has a minimum timestep of 0.5 min. If the 10th percentile duration of use was less than 0.5 min, then the actual 10th percentile is reported in parentheses.
[4] Westat Survey scenario data for mass of product used is reported in ounces. The product density was used to convert percentile results from ounces to grams for use in CEM. As a result, mass of product used will be different for product categories with the same identified Westat Survey use scenario, but different product densities.

2.4.2.3 Consumer Product Exposure Scenarios

Consumer products were assessed for human user and bystander inhalation exposure, and for user dermal exposure when it was reasonable to assume that use characteristics would limit product evaporation from skin. The results of modeled consumer scenarios are presented below, in order of the consumer product Categories of Use (COUs) identified in Table 2-14 (Crosswalk of Subcategories of Use).

2.4.2.3.1 Degreasers

PCE containing aerosol-based degreasers were identified as available for consumer use. Two sub-categories of degreasers were identified, general aerosol degreasers and brake cleaners, based on the most appropriate use scenario.

Aerosol Cleaners for Motors, Coils, Electrical Parts, Cables, Stainless Steel and Marine Equipment, and Wire and Ignition Demoisturants

Aerosol-based degreasers for motors, coils, electrical parts, cables, stainless steel and marine equipment, and wire and ignition demoisturants were identified as available for consumer use, with reported PCE weight fractions of 10% to 100%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated bystanders, for three use scenarios (Table 2-68 and Table 2-69). Dermal exposures were evaluated using the CEM Permeability sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 1.5 to 869 mg/m^3 for users, and 0.3 to 216 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 6.6E-03 to 4.3 mg/kg/day, across all user age groups.

Table 2-68. Consumer inhalation exposure to PCE during use in degreasers for motors, coils, electrical parts, cables, stainless steel and marine equipment, and wire and ignition demoisturants

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (2)	Min (10)	10th (26.83)	User Bystander	1.5 0.3
Moderate Intensity User	50th (15)	Mean (80)	50th (155.69)	User Bystander	74 14
High Intensity User[1]	95th (120)	Max (100)	95th (1532.91)	User Bystander	869 216

[1]The maximum 24 hr TWA air concentration for the User was the 50th percentile duration -maximum weight fraction-50th percentile mass used iteration, with a PCE air concentration of 904 mg/m^3.

Table 2-69. Consumer dermal exposure to PCE during use in degreasers for motors, coils, electrical parts, cables, stainless steel and marine equipment, and wire and ignition demoisturants

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
Low Intensity User	10th (2)	Min (10)	10th (26.83)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	7.7E-03 6.6E-03 7.2E-03

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
Moderate Intensity User	50th (15)	Mean (80)	50th (155.69)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.4 0.4 0.4
High Intensity User	95th (120)	Max (100)	95th (1532.91)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	4.2 4.0 4.3

Confidence in the selected inhalation model and default parameters is high for the aerosol degreasing COU. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use is high due to a good match in the Westat survey data, which received a high- quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the aerosol degreaser inhalation exposure estimations is high. The overall confidence in the aerosol degreaser dermal exposure estimations is low.

Aerosol Brake Cleaners

Aerosol-based degreasers in the form of brake cleaners were identified as available for consumer use, with reported PCE weight fractions of 40% to 100%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-70 and Table 2-71). Dermal exposures were evaluated using the CEM Permeability sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 5.7 to 250 mg/m^3 for users, and 1.6 to 73 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 1.1E-02 to 3.5 mg/kg/day for the permeability method and across all user age groups.

Table 2-70. Consumer inhalation exposure to PCE during use in brake cleaner

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (1)	Min (40)	10th (39.03)	User Bystander	5.7 1.6
Moderate Intensity User	50th (15)	Mean (91)	50th (156.13)	User Bystander	59 15
High Intensity User[1]	95th (120)	Max (100)	95th (624.52)	User Bystander	250 73

[1]The maximum 24 hr TWI air concentration for the User was the 50th percentile duration -maximum weight fraction-95th percentile mass used iteration, with a PCE concentration of 259 mg/m^3.

Table 2-71. Consumer dermal exposure to PCE during use in brake cleaner

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
Low Intensity User	10th (1)	Min (40)	10th (39.03)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	1.2E-02 1.1E-02 1.2E-02
Moderate Intensity User	50th (15)	Mean (91)	50th (156.13)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.4 0.4 0.4
High Intensity User	95th (120)	Max (100)	95th (624.52)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	3.5 3.2 3.5

Confidence in the selected model and default parameters is high for inhalation exposure during brake cleaning. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high- quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the brake cleaner inhalation exposure estimations is high. The overall confidence in the brake cleaner dermal exposure estimations is low.

2.4.2.3.2 Parts Cleaners

Liquid-based parts cleaner (wipe or immersive) was identified as available for consumer use, with reported PCE weight fraction of 50% to 60%. Inhalation and dermal exposures were evaluated for consumers, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-72 and Table 2-73). Dermal exposures were evaluated using the CEM Permeability sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 0.4 to 161 mg/m^3 for users, and 6.5E-02 to 29 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 2.7E-02 to 2.2 mg/kg/day across all user age groups.

Table 2-72. Consumer inhalation exposure to PCE during use in parts cleaners

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (0.25)[2]	Min (50)	10th (9.91)	User Bystander	0.3 6.5E-02
Moderate Intensity User	50th (5)	Max (60)[1]	50th (52.70)	User Bystander	19 3.5
	95th	Max	95th	User	161

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
High Intensity User	(30)	(60)	(441.01)	Bystander	29

[1]A single product was identified for immersive and/or wipe cleaning, with a range given for the weight fraction. The weight fraction range was evaluated as minimum and maximum, with no average weight fraction used in modeling.
[2]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Table 2-73. Consumer dermal exposure to PCE during use in parts cleaners

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
Low Intensity User	10th (0.25)[2]	Min (50)	10th (9.91)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	2.9E-02 2.7E-02 3.0E-02
Moderate Intensity User	50th (5)	Max (60) [1]	50th (52.70)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.4 0.3 0.4
High Intensity User	95th (30)	Max (60)	95th (441.01)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	2.1 2.0 2.2

[1]A single product was identified for immersive and/or wipe cleaning, with a range given for the weight fraction. The weight fraction range was evaluated as minimum and maximum, with no average weight fraction used in modeling.
[2]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Confidence in the selected model and default parameters is high for inhalation exposure during immersive parts cleaning estimation, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high. A generic emission model (E5) was selected in CEM due to the lack of an existing scenario that would represent a good fit for immersive parts cleaning. However, the selected emission model is a good fit for this condition of use. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in the mass used and duration of use is medium. Lacking an exact match in the Westat survey for immersive parts cleaning, the spot remover scenario was selected to parameterize CEM. The spot remover scenario was of relatively short duration and low mass of product used, and thus the results may underestimate the inhalation exposure for immersive parts cleaning. The overall confidence in the immersive parts cleaner inhalation exposure estimations is medium, with possible underestimation of inhalation exposures. The overall confidence in the immersive parts cleaner dermal exposure estimations is low.

2.4.2.3.3 Mold Cleaners and Weld Splatter Protectants

Aerosol-based mold cleaners and weld splatter protectors were identified as available for consumer use, with reported PCE weight fractions of 5% to 100%. Inhalation and dermal exposures were evaluated for

users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-74 and Table 2-75). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 0.7 to 869 mg/m^3 for users, and 0.2 to 216 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 2.2E-02 to 6.8 mg/kg/day across all user age groups.

Table 2-74. Consumer inhalation exposure to PCE during use in mold cleaners and weld splatter protectants

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (2)	Min (5)	10th (26.83)	User Bystander	0.7 0.2
Moderate Intensity User	50th (15)	Mean (40)	50th (155.69)	User Bystander	37 7.2
High Intensity User	95th (120)	Max (100)	95th (1532.91)	User Bystander	869 216

Table 2-75. Consumer dermal exposure to PCE during use in mold cleaners and weld splatter protectants

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (2)[2]	Min (5)	10th (26.83)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	2.3E-02 2.2E-02 2.4E-02
Moderate Intensity User	50th (15)	Mean (40) [1]	50th (155.69)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	1.1 1.1 1.2
High Intensity User	95th (120)	Max (100)	95th (1532.91)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	6.6 6.2 6.8

Confidence in the selected model and default parameters is high for estimation of inhalation exposure during use of mold cleaners and weld splatter protectors, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the inhalation exposure estimation for use of mold cleaners and

weld splatter protectors is high. Overall confidence in the dermal exposure estimation for use of mold cleaners and weld splatter protectors is low.

2.4.2.3.4 Vandalism Mark and Stain Remover

An aerosol-based vandalism mark and stain remover was identified as available for consumer use, with reported PCE weight fraction of 10% to 20%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-76 and Table 2-77). Dermal exposures were evaluated using the CEM Permeability sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 1.5 to 174 mg/m^3 for users, and 0.3 to 43.2 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 4.9E-03 to 0.6 mg/kg/day across all user age groups.

Table 2-76. Consumer inhalation exposure to PCE during use in vandalism mark and stain removers

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (2)	Min (10)	10th (26.83)	User Bystander	1.5 0.3
Moderate Intensity User	50th (15)	Max (20)[1]	50th (155.69)	User Bystander	18.5 3.6
High Intensity User	95th (120)	Max (20)	95th (1532.91)	User Bystander	174 43.2

[1]A single product was identified for immersive and/or wipe cleaning, with a range given for the weight fraction. The weight fraction range was evaluated as minimum and maximum, with no average weight fraction used in modeling.

Table 2-77. Consumer dermal exposure to PCE during use in vandalism mark and stain removers

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
Low Intensity User	10th (2)	Min (10)	10th (26.83)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	5.3E-03 4.9E-03 5.4E-03
Moderate Intensity User	50th (15)	Max (20)[1]	50th (155.69)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	7.9E-02 7.4E-02 8.1E-02
High Intensity User	95th (120)	Max (20)	95th (1532.91)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.6 0.6 0.6

[1]A single product was identified for immersive and/or wipe cleaning, with a range given for the weight fraction. The weight fraction range was evaluated as minimum and maximum, with no average weight fraction used in modeling.

Confidence in the selected model and default parameters is high for estimation of inhalation exposure during use of vandalism mark and stain removers, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation

differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the inhalation exposure estimation for use of vandalism mark and stain removers is high. The overall confidence in the vandalism mark and stain remover dermal exposure estimations is low.

2.4.2.3.5 Liquid Marble and Stone Polish

A liquid-based stone polish was identified as available for consumer use, with reported PCE weight fraction of 10% to 100%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-78 and Table 2-79). Dermal exposures were evaluated using the CEM Permeability sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 1.5 to 868 mg/m^3 for users, and 0.3 to 216 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 1.3E-02 to 8.7 mg/kg/day across all user age groups.

Table 2-78. Consumer inhalation exposure to PCE during use in marble polish

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (2)	Min (10)	10th (26.83)	User Bystander	1.47 0.29
Moderate Intensity User	50th (15)	Mean (85)	50th (155.69)	User Bystander	60.8 17.3
High Intensity User	95th (120)	Max (100)	95th (1532.91)	User Bystander	868 216

Table 2-79. Consumer dermal exposure to PCE during use in marble polish

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
Low Intensity User	10th (2)	Min (10)	10th (26.83)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	1.4E-02 1.3E-02 1.5E-02
Moderate Intensity User	50th (15)	Mean (85)	50th (155.69)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.9 0.8 0.9

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
High Intensity User	95th (120)	Max (100)	95th (1532.91)	User, Adult (≥21 yr)	8.5
				User, Youth (16-20 yr)	7.9
				User, Youth (11-15 yr)	8.7

Confidence in the selected model and default parameters is high for inhalation exposure during marble polish use. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. The utility room was selected as the room of use for this scenario. While it is also reasonable to assume that marble polish may be used in the kitchen, the room volumes are similar and air exchange rates identical, resulting in similar user inhalation exposure. However, a difference may occur for the bystander inhalation exposure when considering utility room use versus kitchen use, based on bystander activity patterns. For example, amount of time the bystander spends in the kitchen is greater than time spent in the utility room, resulting in a lower bystander inhalation exposure for the utility room scenario. If the product was used in the kitchen, the bystander inhalation exposure would be greater than estimated, up to the air concentration experienced by the user. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the marble polish user inhalation exposure estimations is high, with possible underestimation of bystander inhalation exposures if the room of use changed. The overall confidence in the marble polish use dermal exposure estimations is low.

2.4.2.3.6 Cutting Fluid

Cutting fluid was identified as available for consumer use, with a reported PCE weight fraction of 10%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for user and bystanders, for three use scenarios (Table 2-80 and Table 2-81). Dermal exposures were evaluated using the CEM Permeability sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 1.4 to 91 mg/m^3 for users, and 0.3 to 19 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 1.6E-02 to 1.0 mg/kg/day across all user age groups.

Table 2-80. Consumer inhalation exposure to PCE during use in cutting fluids

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (0.08)[2]	Single (10)	10th (26.83)	User	1.4
				Bystander	0.3
Moderate Intensity User	50th (2)	Single (10)	50th (155.69)	User	8.5
				Bystander	1.7

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
High Intensity User	95th (30)	Single (10)	95th (1532.91)	User	91
				Bystander	19

[1]A single product was identified for cutting fluid, with a single weight fraction reported.
[2]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Table 2-81. Consumer dermal exposure to PCE during use in cutting fluids

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Permeability ADR (mg/kg/d)
Low Intensity User	10th (0.08) [2]	Single (10)	10th (26.83)	User, Adult (≥21 yr)	1.7E-02
				User, Youth (16-20 yr)	1.6E-02
				User, Youth (11-15 yr)	1.7E-02
Moderate Intensity User	50th (2)	Single (10)	50th (155.69)	User, Adult (≥21 yr)	6.7E-02
				User, Youth (16-20 yr)	6.3E-02
				User, Youth (11-15 yr)	6.9E-02
High Intensity User	95th (30)	Single (10)	95th (1532.91)	User, Adult (≥21 yr)	1.0
				User, Youth (16-20 yr)	0.9
				User, Youth (11-15 yr)	1.0

[1]A single product was identified for cutting fluid, with a single weight fraction reported.
[2]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Confidence in the selected model and default parameters is high for estimation of inhalation exposure during use of cutting fluids, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the inhalation exposure estimation during use of cutting fluids is high. The overall confidence in the cutting fluid use dermal exposure estimations is low.

2.4.2.3.7 Lubricants and Penetrating Oils (aerosol)

Aerosol-based lubricants and penetrating oils were identified as available for consumer use, with reported PCE weight fractions of 5% to 100%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-82 and Table 2-83). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Indoor

maximum 24-hour time weighted average (TWA) air concentrations ranged from 0.1 to 142 mg/m^3 for users, and 2.6E-02 to 29 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 8.9E-03 to 7.2 mg/kg/day across all user age groups.

Table 2-82. Consumer inhalation exposure to PCE during use in lubricating and penetrating oils

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (0.08)[1]	Min (5)	10th (4.79)	User Bystander	0.1 2.6E-02
Moderate Intensity User	50th (2)	Mean (54)	50th (26.35)	User Bystander	7.9 1.6
High Intensity User	95th (30)	Max (100)	95th (239.51)	User Bystander	142 29

[1]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Table 2-83. Consumer dermal exposure to PCE during use in lubricating and penetrating oils

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (0.08) [1]	Min (5)	10th (4.79)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	9.5E-03 8.9E-03 9.8E-03
Moderate Intensity User	50th (2)	Mean (54)	50th (26.35)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.4 0.4 0.4
High Intensity User	95th (30)	Max (100)	95th (239.51)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	7.0 6.6 7.2

[1]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Confidence in the selected model and default parameters is high for estimation of inhalation exposure during use of aerosol lubricants and penetrating oils, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the inhalation exposure estimation during use of aerosol lubricants and penetrating oils is high. The overall confidence in the dermal exposure estimation during use of aerosol lubricants and penetrating oils is low.

2.4.2.3.8 Adhesives

Industrial adhesives, arts and crafts adhesives, and gun ammunition sealant was identified as available for consumer use, with PCE weight fractions of 10% to 100%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-84 and Table 2-85). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 0.2 to 90 mg/m^3 for users, and 3.8E-02 to 23 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 3.4E-02 to 6.1 mg/kg/day across all user age groups.

Table 2-84. Consumer inhalation exposure to PCE during use in adhesives

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA[1] (mg/m^3)
Low Intensity User	10th (0.33)[2]	Min (30)	10th (1.16)	User Bystander	0.2 3.8E-02
Moderate Intensity User	50th (4.25)	Mean (89)	50th (9.68)	User Bystander	4.9 1.0
High Intensity User [1]	95th (60)	Max (100)	95th (167.34)	User Bystander	90 23

[1]The maximum 24 hr TWA air concentration for the User was the 50th percentile duration-maximum weight fraction-95th percentile mass used iteration, with a PCE concentration of 94 mg/m^3.
[2]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Table 2-85. Consumer dermal exposure to PCE during use in adhesives

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (0.33) [1]	Min (30)	10th (1.16)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	3.6E-02 3.4E-02 3.7E-02
Moderate Intensity User	50th (4.25)	Mean (89)	50th (9.68)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.9 0.8 0.9
High Intensity User	95th (60)	Max (100)	95th (167.34)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	6.0 5.6 6.1

[1]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Confidence in the selected model and default parameters is high for estimation of inhalation exposure during adhesive use, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is

high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the inhalation exposure estimation during use of adhesives is high. The overall confidence in the dermal exposure estimation during use of adhesives is low.

2.4.2.3.9 Livestock Grooming Adhesive (aerosol)

Livestock grooming adhesive spray was identified as available for consumer use, with a reported PCE weight fraction of 15%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-86 and Table 2-87). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Use was modeled indoors, as product may be used a or horse stable or other enclosed space. Indoor maximum 24-hour time weighted average (TWA) concentrations ranged from 0.1 to 15 mg/m^3 for users, and 2.1E-02 to 3.7 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 1.5E-02 to 0.8 mg/kg/day across all user age groups.

Table 2-86. Consumer inhalation exposure to PCE during use in livestock grooming adhesive

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA[2] (mg/m^3)
Low Intensity User	10th (0.33)[3]	Single (15)	10th (1.29)	User Bystander	0.1 2.1E-02
Moderate Intensity User	50th (4.25)	Single (15)	50th (10.72)	User Bystander	0.9 0.2
High Intensity User[2]	95th (60)	Single (15)	95th (185.23)	User Bystander	15 3.7

[1]A single product was identified for livestock grooming adhesive, with a single reported weight fraction.
[2]The maximum 24 hr TWA air concentration for the User was the 50th percentile duration -single weight fraction-95th percentile iteration, with a PCE concentration of 16 mg/m^3.
[3]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Table 2-87. Consumer dermal exposure to PCE during use in livestock grooming adhesive

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (0.33) [2]	Single (15)	10th (1.29)	User, Adult (≥21 yr)	1.6E-02
				User, Youth (16-20 yr)	1.5E-02
				User, Youth (11-15 yr)	1.7E-02
Moderate Intensity User	50th (4.25)	Single (15)	50th (10.72)	User, Adult (≥21 yr)	0.1
				User, Youth (16-20 yr)	0.1
				User, Youth (11-15 yr)	0.1
High Intensity User	95th (60)	Single (15)	95th (185.23)	User, Adult (≥21 yr)	0.8
				User, Youth (16-20 yr)	0.7
				User, Youth (11-15 yr)	0.8

[1]A single product was identified for livestock grooming adhesive, with a single reported weight fraction.
[2]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Confidence in the selected model and default parameters is high for estimation of inhalation exposure during livestock grooming adhesive use, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. The utility room was selected as the room of use for this scenario, assuming the product was used as a general spray fixative. If the product was used in a barn the inhalation exposure would be reduced. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the inhalation exposure estimation during use of livestock grooming adhesive is high, but overestimate exposures if the product is used in a barn rather than a utility room. The overall confidence in the dermal exposure estimation during use of livestock grooming adhesive is low. Dermal acute dose rate (ADR) ranged from mg/kg/day across all user age groups.

2.4.2.3.10 Caulks, Sealants and Column Adhesives

Caulks, sealants and column adhesives were identified as available for consumer use, with reported PCE weight fractions of 5% to 75%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-88 and Table 2-89). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Area of use was assumed to be outdoors, so bystander exposure was not estimated. A modified garage with a high air exchange rate was used to model outdoor use. Maximum 24-hour time weighted average (TWA) air concentrations ranged from 5.9E-02 to 159 mg/m^3 for users. Dermal acute dose rate (ADR) ranged from 0.1 to 9.4 mg/kg/day across all user age groups.

Table 2-88. Consumer inhalation exposure to PCE during use in caulks, sealants and column adhesives

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10^{th} (5)	Min (5)	10^{th} (45.39)	User	5.9E-02
Moderate Intensity User	50^{th} (30)	Mean (48)	50^{th} (387.07)	User	4.8
High Intensity User	95^{th} (360)	Max (75)	95^{th} (8121.46)	User	159

Table 2-89. Consumer inhalation exposure to PCE during use in caulks, sealants and column adhesives

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10^{th} (5)	Min (5)	10^{th} (45.39)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.1 0.1 0.1
Moderate Intensity User	50^{th} (30)	Mean (48)	50^{th} (378.07)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	3.9 3.7 4.0
High Intensity User	95^{th} (360)	Max (75)	95^{th} (8121.46)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	9.2 8.6 9.4

Confidence in the selected model and default parameters is high for estimation of inhalation exposure from caulks, sealants and column adhesives, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. A modified garage with a high air exchange rate was used to model outdoor use, resulting in no bystander exposure. Greater user and bystander inhalation exposure would be expected for use of caulk and column adhesive products indoors. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is medium as there was not an exact match in the Westat survey data. As such, the primers and special primers (non-automotive) scenario was selected. It may be that primers are used for longer periods and in larger quantities than caulks, sealants and column adhesives, and thus the selected scenario may overestimate inhalation exposure. The overall confidence in the inhalation exposure estimation from caulks, sealants and column adhesives is medium with the possibility of overestimation based on selected scenario mass used and duration of use parameters, and/or underestimation of exposures, particularly for bystanders, based on the assumption of outdoor product use. The overall confidence in the dermal exposure estimating from caulks, sealants, and column adhesives is low.

2.4.2.3.11 Outdoor Water Shield

Liquid-based outdoor water sealant was identified as available for consumer use, with a reported weight fraction of 45%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-90 and Table 2-91). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 1.5 to 127 mg/m^3 for users, and 0.4 to 33 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 12 to 31 mg/kg/day across all user age groups.

Table 2-90. Consumer inhalation exposure to PCE during use in outdoor water shield sealants

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User[2]	10th (15)	Single (45)	10th (302.8)	User Bystander	1.5 0.4
Moderate Intensity User	50th (60)	Single (45)	50th (2422.37)	User Bystander	10 3.4
High Intensity User[3]	95th (300)	Single (45)	95th (24223.74)	User Bystander	127 33

[1]A single product was identified for outdoor water shield, with a single reported weight fraction.
[2]The minimum 24 hr TWA air concentration for the User was the 50th percentile duration-single weight fraction-10th percentile mass used iteration, with a PCE concentration of 1.3 mg/m^3.
[3]The maximum 24 hr TWA air concentration for the Bystander was the 50th percentile duration-single weight fraction-95th percentile mass used iteration, with a PCE concentration of 34 mg/m^3.

Table 2-91. Consumer dermal exposure to PCE during use in outdoor water shield sealants

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (15)	Single (45)	10th (302.8)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	12 12 13
Moderate Intensity User	50th (60)	Single (45)	50th (2422.37)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	26 25 27
High Intensity User	95th (300)	Single (45)	95th (24223.74)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	30 28 31

[1]A single product was identified for outdoor water shield, with a single reported weight fraction.

Confidence in the selected model and default parameters is high for inhalation exposure during use of an outdoor water sealant. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. The garage was selected as the room of use for this scenario, assuming application of waterproofing sealant to an item that will later be installed outside. If the product were used outside inhalation exposures would be reduced. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation

differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in inhalation exposure estimations during use of an outdoor water sealant is high, but possibly overestimates inhalation exposure if the product were to be used outside, rather than inside a garage. The overall confidence in dermal exposure estimations during use of an outdoor water sealant is low.

2.4.2.3.12 Aerosol Coatings and Primers

Aerosol-based rust primers and battery reconditioners were identified as available for consumer use, with reported PCE weight fractions of 9% to 14%. Inhalation and dermal exposures were evaluated for users, and inhalation exposure was evaluated for bystanders, for three use scenarios (Table 2-92 and Table 2-93). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 2.2E-02 to 1.9 mg/m^3 for users, and 8.4E-04 to 5.4E-02 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 0.1 to 1.3 mg/kg/day across all user age groups.

Table 2-92. Consumer inhalation exposure to PCE during use in aerosol coatings and primers

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10th (5)	Min (9)	10th (61.88)	User Bystander	2.2E-02 8.4E-04
Moderate Intensity User	50th (20)	Mean (10)	50th (330.05)	User Bystander	0.2 5.3E-03
High Intensity User	95th (120)	Max (14)	95th (1608.99)	User Bystander	1.9 5.4E-02

Table 2-93. Consumer dermal exposure to PCE during use in aerosol coatings and primers

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (5)	Min (9)	10th (61.88)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.1 0.1 0.1
Moderate Intensity User	50th (20)	Mean (10)	50th (330.05)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.5 0.5 0.5
High Intensity User	95th (120)	Max (14)	95th (1608.99)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	1.3 1.2 1.3

Confidence in the selected model and default parameters is high for estimation of inhalation exposure from use of aerosol coatings and primers, as this model underwent peer review, was designed explicitly

for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high as there is a good match in the Westat survey data. The overall confidence in the inhalation exposure estimation from use of aerosol coatings and primers is high. The overall confidence in the dermal exposure estimation from use of aerosol coatins and primers is low.

2.4.2.3.13 Liquid Primers and Sealants

Liquid-based rust primer and sealant was identified as available for consumer use, with reported PCE weight fractions of 9% to 11%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-94 and Table 2-95). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Indoor use was assumed as a more conservative estimate of consumer exposure. Consumer exposure would likely be lower if the product was used outdoors. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 1.1E-03 to 0.3 mg/m^3 for users, and 8.8E-05 to 4.9E-02 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 1.1 to 8.2 mg/kg/day across all user age groups.

Table 2-94. Consumer inhalation exposure to PCE during use in rust primers and sealants

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User [1]	10th (5)	Min (9)	10th (53.22)	User Bystander	1.1E-03 8.8E-05
Moderate Intensity User	50th (30)	Mean (10)	50th (453.82)	User Bystander	9.7E-03 9.1E-04
High Intensity User	95th (360)	Max (11)	95th (9521.90)	User Bystander	0.3 4.9E-02

[1]The minimum 24 hr TWA air concentration for the User was the 50th percentile duration-minimum weight fraction-10th percentile mass used iteration, with a PCE concentration of 1.0E-03 mg/m^3.

Table 2-95. Consumer dermal exposure to PCE during use in rust primers and sealants

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (5)	Min (9)	10th (53.22)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	1.1 1.0 1.1
Moderate Intensity User	50th (30)	Mean (10)	50th (453.82)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	4.8 4.5 5.0
High Intensity User	95th (360)	Max (11)	95th (9521.90)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	7.9 7.5 8.2

Confidence in the selected model and default parameters is high for inhalation exposure during use of liquid rust primers. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high as there was a good match in CEM. Confidence in the selected model is medium for dermal exposure during use of liquid rust primers. CEM's permeability model assumes limited evaporation, which may be appropriate for liquid rust primers considering a large volume may be used with potential for coating of skin during use. However, if consumers used this product in such a way that evaporation was not impeded, or dermal exposure was limited, then the selected model would be an overestimate of dermal exposure. Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The product was assumed to be used indoors, which represents a reasonable, but likely more conservative, exposure estimate than if outdoor use had been assumed. The overall confidence in inhalation exposure estimations during use of liquid rust primers is high, however outdoor use would likely result in lower consumer inhalation exposure. The overall confidence in dermal exposure estimations during use liquid rust primers is low.

2.4.2.3.14 Metallic Overglaze

Metallic overglaze for ceramics was identified as available for consumer use, with a reported PCE weight fractions of 20 to 30%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-96 and Table 2-97). Dermal exposures were evaluated using the CEM Fraction Absorbed sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 2.6E-03 to 0.5 mg/m^3 for users, and 5.4E-04 to 0.1 mg/m^3 for bystanders. Dermal acute dose rate (ADR) ranged from 3.5E-02 to 2.8 mg/kg/day across all user age groups.

Table 2-96. Consumer inhalation exposure to PCE during use in metallic overglaze

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User [1]	10th (0.33)[4]	Min (20)	10th (0.89)	User Bystander	2.6E-03 5.4E-04
Moderate Intensity User [2]	50th (4.25)	Max (30)	50th (7.39)	User Bystander	3.4E-02 6.8E-03
High Intensity User [3]	95th (60)	Max (30)	95th (127.74)	User Bystander	0.5 0.1

[1]The minimum 24 hr TWA air concentration for the User was the 95th percentile duration-minimum weight fraction-10th percentile mass used iteration, with a PCE concentration of 2.5E-03 mg/m^3.
[2]A single product was identified for metallic overglaze, with a range given for the weight fraction. The weight fraction range was evaluated as minimum and maximum, with no average weight fraction used in modeling.
[3]The maximum 24 hr TWA air concentration for the User was the 50th percentile duration-maximum weight fraction-95th percentile mass used iteration, with a PCE concentration of 0.6 mg/m^3.
[4]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Table 2-97. Consumer dermal exposure to PCE during use in metallic overglaze

Scenario Description	Duration Percentile (min)	Weight Fraction[1] (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	Fraction Absorbed ADR (mg/kg/d)
Low Intensity User	10th (0.33)[2]	Min (20)	10th (0.89)	User, Adult (≥21 yr)	3.7E-02
				User, Youth (16-20 yr)	3.5E-02
				User, Youth (11-15 yr)	3.8E-02
Moderate Intensity User	50th (4.25)	Max (30)	50th (7.39)	User, Adult (≥21 yr)	0.4
				User, Youth (16-20 yr)	0.4
				User, Youth (11-15 yr)	0.5
High Intensity User	95th (60)	Max (30)	95th (127.74)	User, Adult (≥21 yr)	2.7
				User, Youth (16-20 yr)	2.6
				User, Youth (11-15 yr)	2.8

[1]A single product was identified for metallic overglaze, with a range given for the weight fraction. The weight fraction range was evaluated as minimum and maximum, with no average weight fraction used in modeling.
[2]CEM has a minimum timestep of 0.5 minutes. If the 10th percentile duration is less 0.5 min, then the minimum timestep was used for modeling, rather than the percentile.

Confidence in the selected model and default parameters is high for estimation of inhalation exposure from use of metallic overglaze, as this model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is medium as there was not an exact match in the Westat survey data. As such, the Contact Cement, Super Glues and Spray Adhesives scenario was selected. Metallic overglaze is sold in small quantities, and thus the 95th percentile mass used for the selected scenario is likely an overestimate for pottery glazing applications. The overall confidence in the inhalation exposure estimation from use of metallic overglaze is medium due to possible overestimation of inhalation exposure for the high intensity user. The overall confidence in the dermal exposure estimation from use of metallic overglaze is low.

2.4.2.3.15 Wax Marble and Stone Polish

Liquid wax-based polishes for metal and stone were identified as available for consumer use, with reported PCE weight fraction of 85% to 100%. Inhalation and dermal exposures were evaluated for users, and inhalation exposures were evaluated for bystanders, for three use scenarios (Table 2-98 and Table 2-99). Dermal exposures were evaluated using the CEM Permeability sub-model. Indoor maximum 24-hour time weighted average (TWA) air concentrations ranged from 11 to 750 mg/m3 for users, and 2.2 to 187 mg/m3 for bystanders. Dermal acute dose rate (ADR) ranged from 0.1 to 7.5 mg/kg/day across all user age groups.

Table 2-98. Consumer inhalation exposure to PCE during use in wax-based metal and stone polish

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor	24 hr Max TWA (mg/m^3)
Low Intensity User	10^{th} (2)	Min (85)	10^{th} (23.18)	User Bystander	11 2.2
Moderate Intensity User	50^{th} (15)	Mean (95)	50^{th} (134.54)	User Bystander	76 15
High Intensity User	95th (120)	Max (100)	95^{th} (1324.74)	User Bystander	750 187

Table 2-99. Consumer dermal exposure to PCE during use in wax-based metal and stone polish

Scenario Description	Duration Percentile (min)	Weight Fraction (%)	Mass Used Percentile (g)	Exposed Receptor (age group)	ADR (mg/kg/d)
Low Intensity User	10^{th} (2)	Min (85)	10^{th} (23.18)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.1 0.1 0.1
Moderate Intensity User	50^{th} (15)	Mean (95)	50^{th} (134.54)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	0.9 0.8 0.9
High Intensity User	95th (120)	Max (100)	95^{th} (1324.74)	User, Adult (≥21 yr) User, Youth (16-20 yr) User, Youth (11-15 yr)	7.3 6.9 7.5

Confidence in the selected model and default parameters is high for inhalation exposure during use of liquid wax polishes for metal and stone. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the selected inhalation emission scenario is high, as there was a good match in CEM. The utility room was selected as the room of use for this scenario. While it is also reasonable to assume that marble polish may be used in the kitchen, the room volumes are similar and air exchange rates identical, resulting in similar user inhalation exposure. However, a difference may occur for the bystander inhalation exposure when considering utility room use versus kitchen use, based on bystander activity patterns. For example, amount of time the bystander spends in the kitchen is greater than time spent in the utility room, resulting in a lower bystander inhalation exposure for the utility room scenario. If the product was used in the kitchen, the bystander inhalation exposure would be greater than estimated, up to the air concentration experienced by the user. Confidence in the selected dermal exposure sub-model is medium based on model assumptions and key calculation differences, discussed in detail later in this risk evaluation (Section 2.4.2.6). Confidence in dermal model default parameters is high due to the high quality of source data. Confidence in the weight fraction is high as this information was pulled directly from product safety data sheets (SDSs). Confidence in mass used and duration of use data is high due to a good match in the Westat survey data, which received a high-quality rating during data evaluation and has been applied in previous agency assessments. The overall confidence in the wax polishes for metal and stone user inhalation exposure estimations is high, with possible underestimation of bystander inhalation exposures if the room of use changed. The overall confidence in the wax polishes for metal and stone dermal exposure estimations is low.

2.4.2.3.16 Consumer Product Exposure Summary

Consumer exposure to PCE due to use of PCE-containing products was evaluated for 15 product scenarios. A modeling approach was taken, based heavily on empirical and survey data, to estimate dermal and inhalation exposures. Ideally, consumer product exposure estimates would be compared to monitoring data for product use, however such monitoring data was not available in the literature. Air monitoring data for PCE were collected as background indoor air concentrations, *i.e.*, not during product use. The North American residential background indoor maximum concentration was 0.17 mg/m^3, with central tendencies at or below 0.028 mg/m^3. Modeling estimates represent exposure during active product use and immediately after. The "moderate intensity user" estimates returned maximum 24-hour TWA indoor air concentrations for product users between 0.0097 and 166 mg/m^3 and bystander maximum 24-hour TWA indoor air concentrations between 0.009 and 32.2 mg/m^3. These estimated central values are in some instances below monitored central tendency background levels of PCE in residential air. Estimated central values for users and bystanders exceed the maximum monitored background concentration by three and two orders of magnitude, respectively, which is reasonable for direct product contact.

2.4.2.4 Consumer Article Exposure Scenarios

2.4.2.4.1 Literature Summary and Modeling Approach

PCE is a common dry-cleaning solvent used to clean a wide variety of clothing and fabrics. Residual solvent is emitted from cleaned fabrics during transportation, storage and wear; and the introduction of dry-cleaned articles into residences has been shown to increase indoor PCE. EPA identified concentrations of PCE in residential indoor air, personal air, and exhaled breath due to the controlled and monitored introduction of freshly dry-cleaned garments in residential homes and apartments (results summarized in Table 2-100). These studies were conducted in the United States, China, and Japan, between 1980 and 1996. In all studies, the dry-cleaned garments were placed in the bedroom closet, hall closet, or dresser drawer. Following introduction of the dry-cleaned clothes, reported concentrations of PCE in the indoor air (excluding the storage closet or drawer) ranged from 0.93 to 692 µg/m^3. The maximum concentration was from a US study ((Howie, 1981), conducted in a rural residential area outside of Washington DC) in which samples were collected from a closed bedroom after freshly dry-cleaned garments were placed in the bedroom closet. Two other US studies reported slightly lower maximum concentrations, including 297 µg/m^3 in an experiment conducted in nine homes in NJ by Thomas (1991) and 195 µg/m^3 in a series of experiments conducted in one test house by Tichenor (1990). The data in Thomas (1991) showed that PCE levels can increase after bringing freshly dry-cleaned clothes into the home (seven of the nine test homes showed PCE concentrations increases). This study includes a calculated source strength at four homes and determined that sources of PCE outside the house were not responsible for observed concentration increases after introduction of dry-cleaned clothing. Personal air concentrations of PCE were higher when test subjects spent more time in the home, and wearing dry-cleaned garments was a less important predictor of personal air concentration than the number of garments per home volume and number of hours spent in the home. The Tichenor (1990) study investigated concentrations over a seven-day period for multiple scenarios: storing clothes with and without a plastic bag cover, and "airing out" the clothes before bringing them inside. A wide variation of concentrations was observed in this study. All the experiments, however, showed that PCE concentrations increased with the introduction of dry-cleaned clothes, and levels dropped to near or below the detection limit after the clothes were removed. The authors also concluded that "airing out" of the clothing for short time periods does not reduce emissions. Concurrent to measuring concentrations in a test house, a chamber study was conducted, and modeled concentrations were calculated based on empirical data. Modeled concentrations were similar to measured concentration, reaching a maximum of

approximately 100 µg/m^3. In the storage location within the homes, the maximum concentration (daily average) observed in this dataset was 2,900 µg/m^3, as reported by Tichenor (1990).

In addition to homes, a German study (Gulyas and Hemmerling, 1990) investigated the concentration of PCE in a car after driving with a freshly dry-cleaned down jacket placed in the car. Prior to introduction, the concentration inside the car was the same as background ambient concentrations (1 to 2 µg/m^3). Concentrations increased to a maximum 24,800 µg/m^3 at 108 minutes after article introduction. Another study, Park (1998), predicted PCE concentration in a car containing freshly dry-cleaned clothes, using the EPA Indoor Air Quality model set to simulate driving a car. The model used emission data from Tichenor (1990) (initial emission rate of 1.2 mg·m^2·hr^{-1} and first order rate constant of 3.3 x 10^{-2} hr^{-1}) combined with air exchange rates experimentally determined in the study (1 per hour while stopped or 10 per hour while driving). Concentrations peaked at 2,300 µg/m^3 which occurred at the end of a 30-minute stopped/parking period.

Table 2-100. Concentrations (µg/m3) of PCE in indoor air, personal breathing zones, and breath from exposure studies with dry-cleaned textiles placed in the home or automobile

Study Info	Media Type	Site Description	Detection Limit	Sample Size	DF	Min.	Mean	Max.	Data Evaluation Score
Residential Homes									
(Chao et al., 1999)[a] CN, 1996	24-hr (indoor air)	Hong Kong, CN; Residential Home (Site A) with dry-cleaned clothes in closet. Four tests (each 7 days) in urban 5th floor apartment bedroom. Windows open and no AC unit.	--	28	1	4.6	--	76	Medium
		Hong Kong, CN; Residential Home (Site B) with dry-cleaned clothes in closet. Four tests (each 7 days) in suburban 2nd floor apartment bedroom. Windows never opened and AC occasionally on.	--	28	1	21	--	494	Medium
		Hong Kong, CN; Residential Home (Site C) with dry-cleaned clothes in closet. Four tests (each 7 days) in urban 10th floor apartment bedroom. Windows closed when AC on and windows open when AC off.	--	28	1	0.93	--	100	Medium
(Thomas et al., 1991)[b] US	12-hr (indoor air)	Bayonne and Elizabeth, NJ; Living rooms and bedrooms of nine homes. Six to ten 12-hr sampling periods per home. Two to ten sets of dry-cleaned clothes were brought into the homes during the third monitoring period and stored based on the participants normal procedures. A resident wore a set of dry-cleaned clothes during a later period. Number of maximum observations = 18.	--	--	--	--	--	8 - 297 (mean of max = 96±88)	High
	12-hr (personal air)	Bayonne and Elizabeth, NJ; Six to ten 12-hr sampling periods per home. Two to ten sets of dry-cleaned clothes were brought into the homes during the third monitoring period and stored based on the participants normal procedures. The resident monitored wore a set of dry-cleaned clothes during a later period. Number of maximum observations = 7.	1	--	--	--	--	8 - 303 (mean of max = 127±108)	High
	n/a (exhaled breath)	Bayonne and Elizabeth, NJ; Six to ten 12-hr sampling periods per home. Two to ten sets of dry-cleaned clothes were brought into the homes during the third monitoring period and stored	--	--	--	--	--	9 - 61 (mean of max = 27±20)	High

Study Info	Media Type	Site Description	Detection Limit	Sample Size	DF	Min.	Mean	Max.	Data Evaluation Score
		based on the participants normal procedures. A breath sample was collected at end of each 12-hr monitoring period. The resident monitored wore a set of dry-cleaned clothes during a later period. Number of maximum observations = 9.							
(Tichenor et al., 1990)[c] US	-- (indoor air)	Single story residential house with dry cleaning placed in closet. Closet door was closed and all other doors were open. HVAC fan operated. Samples collected from the closet.	1	--	--	--	100-2,900 (daily avg.) [model est. = 200-1,000]	--	High
		Single story residential house with dry cleaning placed in closet. Closet door was closed and all other doors were open. HVAC fan operated. Samples collected from the bedroom.	1	--	--	--	20-195 (daily avg.) [model est. = 30-100]	--	High
		Single story residential house with dry cleaning placed in closet. Closet door was closed and all other doors were open. HVAC fan operated. Samples collected from the den.	1	--	--	--	10-80 (daily avg.) [model est. = 15-50]	--	High
(Kawauchi and Nishiyama, 1989)[d] JP	2-hr (indoor air)	Consumer homes in Japan (n=4). Dry-cleaned clothes placed in chest of drawers. Samples collected from 2 to 4 pm during the weekday inside chest of drawers.	--	9	1	2.9	--	326.6	Medium
		Consumer homes in Japan (n=4). Dry-cleaned clothes placed in chest of drawers. Room air samples collected from 2 to 4 pm during the weekday in same room as chest of drawers.	--	6	1	1.3	--	7.4	Medium
(Howie, 1981)[e] US, 1980	24-hr (indoor air)	Washington, D.C., in late summer; Private home in rural residential area. Samples collected over 7 days after placing dry-cleaned clothing in the house.	--	7	1	42.0	--	692	High
Automobiles									
(Gulyas and Hemmerling, 1990) Germany, 1990		Vehicle with a dry-cleaned down jacket placed in the car.	--	3	1	9,300	--	24,800	
(Park et al., 1998)	n/a	Modeled air concentration in vehicle with dry-cleaned jacket. Assumptions: Volume = 3.24 m^3; surface area of jacket = 3.32 $m^{2;}$ initial emission rate of 1.2 mg/m^2/hr and first order rate constant of 3.3 x 10-2/hr (from Tichenor et al., 1990);	n/a	n/a	n/a	--	--	2,300	High

Study Info	Media Type	Site Description	Detection Limit	Sample Size	DF	Min.	Mean	Max.	Data Evaluation Score
		AER of 1/hr while stopped or 10/hr while driving							

Study Info: The information provided includes the HERO ID and citation; country and year samples collected.
Abbreviations: If a value was not reported, it is shown in this table as "--." ND = not detected at the reported detection limit. DF = detection frequency. NR = Not reported. CN = China. US = United States. JP = Japan. AC = air -conditioning.
Parameters: All statistics are shown as reported in the study.
[a] Results from this study (Chao et al., 1999) represent four tests at each of three test sites. Test 1: male clothes kept inside dry cleaner's original plastic bags. Test 2: male clothes kept outside dry cleaner's plastic bag. Test 3: male and female clothes kept inside drycleaner's plastic bags. Test 4: male and female clothes kept outside dry cleaner's plastic bags. Site A: min from Test 2 Day 7 and max from Test 4 Day 2. Site B: min from Test 1 Day 7 and max from Test 4 Day 1. Site C: min from Test 1 Day 2 and max from Test 4 Day 1.
[b] Results from this study (Thomas et al., 1991) represent a summary of the maximum indoor air, personal air, and breath concentrations measured at nine homes after introduction of dry-cleaned clothes. Individual concentration values were not reported in the study. Indoor air (living area/bedroom): min from bedroom and max from living room. Concentrations before introduction of dry-cleaned clothes were also measured for two 12-hr periods. Maximum concentrations ranged from 5 to 64 µg/m^3 in living room or bedroom, 8 to 35 µg/m^3 in personal air, and 3 to 30 µg/m^3 in breath.
[c] Results from this study (Tichenor et al., 1990)[c] represent a summary of daily average indoor air concentrations from a closet (with dry-cleaned clothes), bedroom and den inside a residential home over seven days. The study provided the results (in graph form) for four tests performed during each day of sampling: (1) bag off; (2) bag on; (3) aired out; and (4) repeat of bag off. Closet: min from Test 1 Day 7 and max from Test 3 Day 1. Bedroom: min from Test 1 Day 7 and max from Test 3 Day 1. Den: min from Test 1 Day 7 and max from Test 3 Day 2. Model estimates were calculated using a source term based on small chamber data
[d] Results from this study (Kawauchi and Nishiyama, 1989) represent indoor air concentrations from a chest of drawers and a bedroom in four homes.
[e] Results from this study (Howie, 1981) represent measured indoor air concentrations over a 7 day period (24-hr samples).

Inhalation exposure to PCE in indoor air due to emissions from storage of dry-cleaned articles was assessed for consumer users and bystanders, using measurements of PCE emissions from fabrics cleaned with older dry-cleaning technologies (2nd and 3rd generation) as a worst-case emission scenario. Dermal exposure due to direct skin contact with recently dry-cleaned fabrics during article wear was assessed for consumer users, for older and more modern dry-cleaning technologies (2nd and 5th generation). Dry cleaning consumer exposures could be cumulative for the user, including inhalation exposure during transport of dry-cleaned articles in an automobile, inhalation exposure from dry-cleaned articles stored in the home, and inhalation and dermal exposure from wearing dry-cleaned articles.

Modeling Approach

Dermal exposure to PCE resulting from direct skin contact with recently dry-cleaned articles, *i.e.*, wearing dry-cleaned clothing, was modeled with CEM. Inhalation exposure to PCE emitted from recently dry-cleaned articles stored in a home was modeled using EPA's Multi-Chamber Concentration and Exposure Model (MCCEM). MCCEM is a higher tier model and utilizes chemical-specific emissions data to estimate air concentrations and inhalation exposure.

2.4.2.4.2 Dermal Exposure to Recently Dry-Cleaned Articles

EPA's CEM 2.1 dermal sub-model A_DER2: Dermal Dose from Skin Contact with Article, as presented in the CEM user guide (U.S. EPA, 2019b) was used to model dermal exposure to PCE from direct contact with recently dry-cleaned articles. This model calculates dermal exposure due to migration of a chemical within an article to the skin via direct article contact.

Residual Mass

Residual mass of PCE remaining in recently in dry-cleaned articles can be thought of as the chemical "pool", or the amount of chemical potentially available for dermal exposure. Residual PCE mass was calculated from two sources (see Section 2.4.2.4.2) The first data source, based on Tichenor (1990) applies to 1st, 2nd and 3rd generation dry cleaning machines, due to the date the study was conducted[20]. Tichenor (1990) conducted chamber tests and test house studies to measure emission rates and emission half-lives of PCE from various commercially dry-cleaned fabrics. Residual PCE was calculated using a simple exponential model based on measured PCE emissions. The second data source, based on Sherlach (2011), likely applies to 4th and 5th generation dry cleaning machines, due to the date the study was conducted. Sherlach (2011) extracted perchloroethylene residues from commercially dry-cleaned fabrics after a single cleaning event, multiple cleaning events, and after one week of storage. Cotton, Polyester and wool fabric were shown to accumulate PCE with subsequent dry cleaning cycles. Multiple dry cleaning cycle estimates were included to model a high-end user (albeit using more modern commercial dry cleaners) who has their wool suit dry-cleaned weekly, such that residual PCE concentrations become saturated in the fabric (Sherlach (2011) showed that wool continued to accumulate PCE for at least 6 cleaning cycles). Residual PCE was calculated using reported residual concentration data and a simple emission model. Residual mass of PCE in dry-cleaned fabrics was

[20] Perchloroethylene related NESHAPs from 1993 and 2006 banned 1st generation machine and required more modern technologies for new dry cleaning machines but allowed certain 2nd and 3rd generation machines to continue to be used. Given the age of 2nd generation dry cleaning technology, it is likely that only a very small number of these machines are still in use today, but EPA cannot definitively rule out the possibility of their continued use. Similarly, an unknown but likely small number of 3rd generation dry cleaning machines may still be in use.

calculated for the first three days after the dry cleaning event[21]. Details of the calculation can be found in the *Risk Evaluation for Perchloroethylene Supplemental Information for Consumer Exposure* (U.S. EPA, 2020f).

Table 2-101. Cumulative mass released for number of days post dry cleaning and number of hours the garment was worn (10 hr), based on Tichenor (1990) and Sherlach (2011). Values were used as modeling inputs for the residual pool of PCE available for exposure.

Data Source (est. machine generation)	Fabric Type	Dry cleaning events	Average Residual Mass (mg) Time since article was dry cleaned		
			1 day	2 days	3 days
Tichenor (1990) (1st -3rd)	Polyester-wool blend	Single	105	81	63
Sherlach (2011)	Polyester[1]	Single	18	14	11
Sherlach (2011)	Wool[2]	Repeat[3]	58	45	35

[1] Based on average maximum measured PCE concentration in polyester fabric samples after single cleaning event
[2] Based on average maximum measured PCE concentration in wool fabric samples after multiple cleaning events
[3] Residual value used to parameterize model is based on 6th cycle data for wool from Sherlach (2011))

Factors affecting the value of residual mass include fabric type, number and proximity of dry cleaning events, total number of dry-cleaned articles, total article surface area, the type (generation) of dry cleaning machine used and number of days elapsed since the fabric was dry-cleaned. Different fabrics retain different amounts of PCE, the values estimated here are based on measured emissions from a variety of fabrics reported in Tichenor (1990) and Sherlach (2011).

Dry-cleaned Article Parameters

An article with a surface area of $1m^2$ and $1.5m^2$ was assumed to calculate residual mass, with a wearer donning the garment(s) 1 to 3 days after dry cleaning, for a total duration of 10 hours (assumption of 8-hour workday, plus commute). An average fabric thickness of 0.1 cm was assumed based on the fabrics used in the Tichenor (1990) and Sherlach (2011) studies and thickness measurements of various types of fabrics (based on Küçük and Korkmaz (2012); Marolleau (2017); Van Amber (2010). Thickness of fabric is inversely proportional to dermal dose (as thinner fabrics require less diffusion distance to reach skin). A single, multi-hour contact per day was assumed for acute exposure.

CEM Dermal Results

Dermal exposure to PCE due to direct contact with recently dry-cleaned articles was evaluated for 1-3 days after dry cleaning, assuming different dry cleaning technologies and for four article thickness values, for both half-body (1 article) and full body (2 articles) exposure (Table 2-102). ADR results for

[21] Measured PCE emissions from recently dry-cleaned fabrics were fit to a simple exponential model to describe the rate of emission, and thus calculate the residual mass of PCE remaining in the fabric at a certain time after the dry cleaning event. Residuals were calculated for days 1-3 post-cleaning, as 3 days was roughly one half-life in the fitted decay curve. A consumer that wore a garment more than three days after dry cleaning would have less potential dermal PCE exposure, although elevated air concentrations in the home and inhalation exposures would remain unchanged.

half-body exposure ranged from 5.1E-02 to 0.5 mg·kg^{-1}·day^{-1}. ADR results for full-body exposure ranged from 0.2 to 1.5 mg·kg^{-1}·day^{-1}.

Table 2-102. Dermal exposure results to recently dry-cleaned articles, based on CEM modeling

Assumed dry cleaning technology	Dry Cleaning Events	Days After Dry Cleaning	Half-body Dermal ADR (Surface Area 1 m^2, SABW 122.9) mg/kg-day	Full-body Dermal ADR (Surface Area 1.5 m^2, SABW 245.9) mg/kg-day
2nd and 3rd generation	Single	1	0.5	1.5
		2	0.3	1.1
		3	0.3	0.9
4th and 5th generation	Single	1	8.7E-02	0.3
		2	6.7E-02	0.2
		3	5.1E-02	0.2
4th and 5th generation	Repeat[1]	1	0.3	0.8
		2	0.2	0.6
		3	0.2	0.5

[1] Based on maximum average PCE concentration in wool after 6 dry cleaning cycles from Sherlach (2011); PCE concentration was still increasing in wool fabric after 6 cycles and had not yet reached saturation.

Confidence in the selected model and default parameters is medium to high for dermal exposure due to wearing recently dry-cleaned articles. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in dermal model default parameters is high due to the high quality of source data. Residual PCE remaining in dry-cleaned clothing was determined from high quality test chamber emission data from early generation dry cleaning machines (dates from 1990), and high-quality analytical data on PCE residuals from more modern dry cleaning technologies, which leave less residual PCE in dry-cleaned fabrics. CEM's article diffusion model is sensitive to the thickness of material selected. An effort was made to best match the fabric type and assumed article thickness of the Tichenor (1990) and Sherlach (2011) test swatches to minimize over- or underestimating residual PCE. The quantity of residual PCE in articles varies based on fabric type and how much time has elapsed between subsequent dry-cleaning events. Dermal exposure results may differ for other types of fabrics. The overall confidence in dermal exposure estimations due to wearing recently dry-cleaned articles is medium to high with possible overestimation or underestimation based on differences in PCE retention in various fabric types and frequency of dry cleaning events.

2.4.2.4.3 Inhalation Exposure to Recently Dry-cleaned Articles

MCCEM Modeling Approach

Inhalation exposure due to emissions of PCE from recently dry-cleaned clothing was modeled using EPA's Multi-Chamber Concentration and Exposure Model (MCCEM, (U.S. EPA, 2019e)) single-exponential emission model and emissions data available in published literature.

Tichenor (1990) measured PCE air concentrations due to emissions from recently dry-cleaned articles in a test house (EPA's Air and Energy Engineering Research Laboratory, Indoor Air Quality test home). It

is assumed, given the date of the study, that results likely reflect commercial cleaners using 2nd or 3rd generation dry cleaning machines. Newer technologies are presumed to result in lower residual PCE concentrations in dry-cleaned fabrics, but EPA cannot definitely say that older model machines have been completely replaced with 4th generation (or later) technologies. As such, Tichenor (1990) was used for model parameterization as a high end estimate, and based on risk results (see Section 4.2.4.17), further modeling for 4th and 5th generation technologies was not done. Test house measurements were conducted by placing freshly dry-cleaned garments (wool skirt, two polyester/rayon blouses and a two-piece wool-blend suit) in a bedroom closet. Indoor air samples were collected at three locations (closet, bedroom, and den), four times a day.

EPA used this data as a modeling basis to parameterize the MCCEM indoor air model for a generic residential house (Table 2-103). The EPA/Tichenor test house layout, along with reported house volume and whole-house air exchange rate (Chang et al., 1998; Tichenor et al., 1990) were used as the basis for a generic home. EPA assumed the zone of use to be a bedroom closet containing dry-cleaned articles, defined as the near-field volume. The bedroom containing the closet was defined as the far-field volume. The third zone was termed the "rest of the house" (ROH) and included all areas outside of the bedroom. A user in this scenario was assumed to be a person who places dry-cleaned articles in their bedroom closet and spends some short amount of time dressing in that closet, twice per day. The CEM activity pattern for a stay-at-home adult was selected as the basis for an MCCEM adult "user" pattern, with an addition of 5 minutes spent in the closet (near-field) in the morning and in the evening. A bystander in this scenario was considered to be a youth or child that remained in the rest of the house. PCE air concentrations were modeled over a ten-day period. Further details of the MCCEM model parameterization are given in the *Risk Evaluation for Perchloroethylene Supplemental Information for Consumer Exposure* (U.S. EPA, 2020f).

Table 2-103. Emission parameters for MCCEM modeling of PCE emissions from recently dry-cleaned clothing.

Parameter Name	Value	Source
First order decay rate	0.011 hr^{-1}	Scaled from Tichenor (Tichenor et al., 1990)
Emission rate	7.38 mg/hr	Scaled from Tichenor (Tichenor et al., 1990)
Article surface area[1]	12.6 m^2	Scaled from Tichenor (Tichenor et al., 1990)
MCCEM model house volume	446 m^3	Scaled from Chang (1998)
Closet volume (near-field)	5 m^3	Scaled from Chang, (1998)
Near-field: far-field air flow rate	8 m^3/hr	Scaled from Chang, (1998)
Whole house air exchange rate	0.45 hr^{-1}	CEM v2.1 default[2]
Length of run	240 hr (10 days)	EPA choice
Background concentration	0 mg/m^3	EPA choice

[1]An article surface area of 12.6 m^2 corresponds to roughly seven articles of adult clothing
[2]EPA's Consumer Exposure Model version 2.0 (2017a)

MCCEM Inhalation Results

Peak PCE air concentrations and maximum 24-hour TWAs for the dry-cleaned article storage scenario are summarized in Table 2-104 and Table 2-105. Maximum PCE air concentrations occurred in the closet roughly 4 hours after placement of clothing ($9.67x10^{-1}$ mg/m^3). Air concentrations in the surrounding bedroom peaked roughly 7 hours after clothing placement ($8.72x10^{-2}$ mg/m^3), and 10 hours after placement for the rest of the house ($2.98x10^{-2}$ mg/m^3). The maximum 24-hour TWA PCE air concentrations were $7.24x10^{-2}$ mg/m^3 for the user and $2.33x10^{-2}$ mg/m^3 for the bystander. Indoor air concentrations of PCE remained elevated above pre-exposure levels for the duration of the 10-day modeling window.

Table 2-104. MCEEM calculated PCE air concentrations for storage of recently dry-cleaned articles in a generic house.

Zone	Maximum Concentration (mg/m^3)	Time Elapsed at Maximum (hr)	Hour 10 Concentration (mg/m^3)
Closet (near-field)	9.7E-01	3.85	7.3E-02
Bedroom (far-field)	8.7E-02	7.27	6.9E-03
ROH	3.0E-02	9.62	2.4E-03

Table 2-105. MCEEM calculated PCE maximum 24-hour TWAs for storage of recently dry-cleaned articles in a generic house.

Exposure Receptor	Maximum 24-hour TWA Concentration (mg/m^3)
User (stay-at-home adult)	7.2E-02
Bystander (stay-at-home child or youth)	2.3E-02

Confidence in the selected model and default parameters is medium to high for inhalation exposure during storage of recently dry-cleaned articles in a home closet. Estimated exposures represent a higher-end scenario where articles have been cleaned at a commercial dry cleaner still employing older technology. The selected model underwent peer review, was designed explicitly for the purpose of this type of estimation and applied in the manner intended. Confidence in the parameterization of the inhalation emission scenario is high, as there was a high-quality test chamber emission data and test house monitoring data available, however the total number of studies was limited. The master bedroom room was selected as the room of use for this scenario. This may underestimate bystander inhalation exposure, based on activity patterns, relative to storage of dry-cleaned articles in a common area of the house. Residual PCE remining in dry-cleaned clothing was determined from high quality test chamber emission data, using emissions parameters based on older (2nd and 3rd generation) dry cleaning technologies. More modern dry cleaning technologies presumably leave less residual PCE in dry-cleaned fabrics. Based on risk results (see Section 4.2.4.17), further modeling for more modern dry cleaning technologies was unnecessary. The quantity of residual PCE in articles varies based on fabric type and how much time has elapsed between subsequent dry cleaning events. Inhalation exposure results may differ for other types of fabrics, for more or less frequently dry-cleaned articles and based on the number of dry-cleaned items stored. The overall confidence in inhalation exposure estimations due to storage of recently dry-cleaned articles in a home is medium to high with possible overestimation

based on the availability of more modern dry cleaning technologies, and possible overestimation or underestimation based on differences in PCE retention in various fabric types, frequency of dry cleaning events and number of dry-cleaned items stored.

2.4.2.4.4 Consumer Article Exposure Summary

Consumer exposure to PCE due to off-gassing from recently dry-cleaned articles was evaluated for two scenarios, direct dermal contact with clothing, and inhalation exposure from article storage in a home closet. A modeling approach was taken, based heavily on empirical data, to estimate dermal and inhalation exposures. No direct measurements were found for consumer dermal exposure to PCE from dry-cleaned fabrics. Dermal exposure estimates ranged from 5.1E-02 to 1.5 mg/kg/day. Measurements of PCE concentrations in indoor air from storage of recently dry-cleaned articles are in good agreement with modeling results. Elevated PCE concentrations measured in bedroom air, shortly after dry-cleaned articles were stored in a dresser or closet, were reported as between 9.3E-03 and 0.7 mg/m^3, with modeling estimates for maximum PCE air concentration in the bedroom after article storage of 8.7E-02 mg/m^3. Dry cleaning consumer exposures could be cumulative for the user, including inhalation exposure during transport of dry-cleaned articles in an automobile, inhalation exposure from dry-cleaned articles stored in the home, and inhalation and dermal exposure from wearing dry-cleaned articles.

2.4.2.5 Other Consumer Uses

Additional potential consumer exposures to PCE were identified, including off-gassing from new clothing and apparel, due to use of PCE in the textile industry; use of coin operated dry cleaning machines; and emissions from photocopy and printing equipment. Available data is summarized below. Due to limited available information on these conditions of use, risk for these scenarios will not be further assessed.

2.4.2.5.1 New Clothing/Textile Industry

PCE is used to remove spinning oils, lubricants and naturally occurring dirt and oils from yarn and fabric used in clothing manufacturing, and as a carrier solvent for dyes in the textile industry (Morrison and Murphy, 2013). While a high percentage of PCE applied to textiles during manufacturing is expected volatize, there is potential for consumer exposure due to off-gassing from new textiles and fabrics. Chan (2014) measured PCE in indoor air in apparel stores, with a detection frequency of 30% (120 samples), and reported mean air concentration of 0.2 $\mu g/m^3$.

2.4.2.5.2 Coin Operated Dry Cleaners

Howie (1981) measured indoor air PCE concentrations in coin-operated dry cleaning facilities in the United States (6 facilities). PCE was detected in 100% of collected samples, with air concentration range from 508 to 94984 $\mu g/m^3$. EPA was not able to determine if coin operated dry cleaning machines were still in use in the United States.

2.4.2.5.3 Print Shops

Stefaniak (2000) measured PCE in area and personal breathing zone air samples, in three commercial print shops in Baltimore, MD. A total of 17 area samples and 4 personal breathing zone samples were collected, with detection frequencies of 94% and 100%, respectively. PCE concentrations in personal breathing zone samples ranged from 0.7 to 3.4 $\mu g/m^3$, and in area samples from non-detection to 21 $\mu g/m^3$.

Ryan (2002) measured PCE in indoor air in a printmaking art studio in a university building in the United States. 18 samples were collected, with reported PCE concentration mean of 0.4 $\mu g/m^3$.

Kiurski (2016) measured elevated PCE levels in a small commercial photocopy shop in Serbia, containing two copiers and a printer. PCE concentrations were attributed to the usage of photocopying equipment. A total of 225 samples were collected, with a PCE detection frequency of 64%, and measured concentration rage of 6.8 to 96341 µg/m^3.

Kowalska and Gierczak (2013) measured volatile emissions from disintegrated office equipment (11 items). PCE was detected most frequently in office equipment samples, with 68.7% detection.

2.4.2.6 Consumer Exposure Assumptions and Key Sources of Uncertainty

Modeling was used to evaluate consumer exposure concentrations under the conditions of use. Where high quality chemical- and/or product-specific data was available it was used to parameterize consumer models. In the absence of available data, this modeling relied on certain default data values and certain assumptions. As with any risk evaluation, there are uncertainties associated with the data, assumptions and approaches. An overall review of these factors can help develop a qualitative description of the confidence associated with these factors and results obtained.

In addressing consumer exposures, EPA assumed that a consumer product was only used once per day, for a single day. There is a medium to low uncertainty associated with this assumption. Based on the COUs evaluated, EPA felt it was unlikely that two PCE-containing products would be used within the same exposure time frame, by the same user. If a consumer user was to use multiple PCE-containing products in a single day, their exposure would be greater than is captured in this risk evaluation. EPA also assumed that the frequency of consumer product use would not meet benchmarks for chronic exposure. Information found during EPA's systematic review process supports infrequent use and short durations of use (Westat, 1987). However, there is a sub-set of consumer users, the "do-it-yourself" hobbyist, that may use PCE-containing products more frequently than the general population, which may result in greater exposures than are captured in this risk evaluation. However, since reasonably available information was not identified to inform these and other parameters (such as whether high-frequency exposures are likely to be consecutive or intermittent), and the absence of data leaves it uncertain how to develop a credible worst-case scenario, chronic exposures from consumer product use and storage of consumer products were not evaluated in this Risk Evaluation.

Two peer reviewed EPA models were used to estimate inhalation exposure to the consumer user or bystander (CEM and MCCEM). These models were selected as fit-for-purpose models, with pre-defined exposure scenarios applicable to the identified PCE COUs. Overall, there is medium to high or high confidence in the consumer inhalation exposure modeling approach and results. This is based on the strength of the model employed, as well as the quality and relevance of the default, user-selected and varied modeling inputs. CEM 2.1 (U.S. EPA, 2019b) is a peer reviewed, publicly available model that was designed to estimate inhalation and dermal exposures from household products and articles. One overarching uncertainty is that the consumer risks may be underestimated, because background exposures were not incorporated to the risk estimations for each COU. While there are documented background exposures of PCE in residential or consumer environments (Section 2.4.2.1), those concentrations were not attributable to a specific condition of use and, therefore, not included in our evaluation. In other words, EPA assumed a PCE background air concentration of zero for consumer exposure estimates. General background concentration of PCE in indoor air measured at residential sites in the U.S. is summarized in Section 2.4.2.1. CEM uses central-tendency default values for sensitive inputs such as building and room volumes, interzonal ventilation rate, and air exchange rates. These parameters were not varied by EPA due to EPA having greater confidence in the central tendency inputs for such factors that are outside of a user's control (unlike, *e.g.*, mass of product used or use duration). These central tendency defaults are sourced from EPA's Exposure Factors Handbook (U.S. EPA,

2011a). The confidence in the user-selected varied inputs (*i.e.*, mass used, use duration, and weight fraction) are medium to high, depending on the condition of use. The sources of these data are U.S. EPA (1987) (high-quality) and company-generated SDSs (see EPAs Preliminary Information on Manufacturing, Processing, Distribution, use and Disposal: Tetrachloroethylene (2017f)). Weight fractions reported in SDSs may vary per chemical product. However, what typically reduces confidence for particular conditions of use is the relevance or similarity of the U.S. EPA (1987) survey product category for the modeled condition of use. For instance, the evaluated brake cleaner scenario had surveyed information directly about this condition of use within U.S. EPA (1987), resulting in a high confidence in model default values. In contrast, the parts cleaner scenario did not have an exact match within U.S. EPA (1987), resulting in use of a surrogate scenario selected by professional judgment that most closely approximates the use amount and duration associated with this condition of use. Additionally, in some cases, professional judgment or surveyed information from U.S. EPA (1987) was used in selection of room of use, which sets the volume for modeling zone 1.

EPA evaluated dermal exposure to consumer users with the CEM Fraction Absorbed and Permeability sub-models for consumer product analysis, and the Skin Contact with an Article sub-model for consumer article analysis. EPA evaluated each model, the inputs and outputs associated with each model, the applicability of each model to the expected consumer dermal exposure scenarios for each condition of use and applied a fit-for-purpose approach to selecting the final models used to estimate consumer dermal exposures. The CEM Fraction Absorbed sub-model was selected for those COUs where evaporation is uninhibited during use. The sub-model is a mass limited model which considers evaporation from the skin and calculates a fraction absorbed portion of the total exposure occurring during product use. To minimize uncertainty, this model was run utilizing the assumption that the entire mass of chemical in the thin film enters the stratum corneum. Additionally, while the estimated absorption coefficient (Kp) within the model is based on an aqueous vehicle, a Kp for neat PCE was obtained from literature and incorporated into the model. The use of the neat Kp is more representative of the product COUs, with PCE weight fractions up to 100 percent and/or non-aqueous co-solvent formulations. The CEM Permeability sub-model was selected for those COUs where evaporation is inhibited/prohibited or where full immersion of body parts is expected during use. The sub-model assumes a constant supply of product against the skin during the entire duration of use. As with the fraction absorbed sub-model, the permeability sub-model permeability coefficient (Kp) is based on an aqueous vehicle. As discussed above, the permeability sub-model was run utilizing a neat Kp to minimalize uncertainty as this is more representative of the product COUs.

EPA has an overall high confidence in the CEM dermal models themselves, but medium confidence in the assignment of a sub-model to each COU. This is because the dermal sub-models calculate dermal exposure differently, beyond the issue of limited versus unlimited volatilization, particularly how each model deals with mass of product available for absorption and the duration of use term. The Permeability sub-model calculates the mass absorbed based on the permeability coefficient, dilution factor, duration of exposure, density, surface area of skin, and weight fraction. The dilution factor is assumed to be 1 in all modeling scenarios (no dilution). The product of these terms gives the mass of the chemical of concern absorbed by the body from exposure to the modeled product(s). The Permeability sub-model assumes an unlimited supply of the product is present against the skin for the entire duration period and does not consider losses due to evaporation or rinsing. The Fraction Absorbed sub-model calculates the mass available for absorption based on the amount retained on skin (the mathematical product of film thickness and product density), the surface area of skin, and weight fraction. The product of these terms multiplied by the absorption fraction gives the total absorbed mass. This assumes that the product or chemical is applied once to the skin's surface in a thin film and then absorbed based on the

absorption fraction. What this model doesn't consider is the mass of the product or chemical that may enter the skin continuously during the use of the product or chemical. The duration of product use was assumed equal to the exposure time for all dermal modeling. The basic relationship between the duration of use or exposure time to the acute dose rate is quite distinct for each of the dermal sub-models. The Permeability sub-model maintains a strong positive correlation between duration of use and ADR, with ADR increasing by the same factor of the duration of use. The exact slopes of these lines are influenced differently by other factors, such as weight fraction. The Fraction Absorbed sub-model maintains a logarithmic relationship between duration of use and ADR, hitting a horizontal asymptote after a certain duration (that duration varies by chemical). These outlined factors make the selection of a dermal sub-model, only based on how/if the model assesses volatilization, a challenging process and increases modeling uncertainties. However sub-model results for Permeability and Absorption Fraction, for identical COU consumer exposure scenarios, are generally within an order of magnitude of one another.

A comparison and sensitivity analysis of CEM models is provided in *Risk Evaluation for Perchloroethylene Supplemental Information on Consumer Exposure* (U.S. EPA, 2020f).

2.4.3 Biomonitoring Data

EPA identified blood biomonitoring measurements from multiple sources. The most comprehensive source is the National Health and Nutrition Examination Survey (NHANES) conducted by CDC's National Center for Health Statistics (NCHS). The survey is "a complex, stratified, multistage, probability-cluster design survey" designed to collect data on the health and nutrition of a representative sample of the U.S. population. For the purposes of chemical risk evaluation, NHANES data is used to quantify chemical concentrations in food, drinking water and environmental media, and exposures to consumers, workers, and general population, when applicable. NHANES measured PCE in whole blood of males and females ages 12+ years. In the Fourth Report on Human Exposure to Environmental Chemicals (CDC, 2017), statistics were reported for the 50th, 75th, 90th, and 95th percentiles for 2-year cycles starting in 2001 through 2008. Sample sizes ranged from 978 (2001-2002) to 2,940 (2005-2006). The concentrations in all samples were less than the limit of detection (0.048 ng/mL) at the 50th percentile for all years. At the 95th percentile, concentrations ranged from 9.4E-02 µg/L (2007-2008) to 1.9E-01 µg/L (2001-2002).

For 1999-2004 (n=2577), the mean sample concentration was 8.1E-02 µg/L, and the median sample concentration was 3.4E-02 µg/L. This study also reported regression statistics, coefficients, and trends over time for each chemical reported. Another source (Sexton et al., 2005), measured concentrations of PCE in whole blood from 150 children from two poor, minority neighborhoods in Minneapolis, Minnesota in four periods during 2000-2001. These samples were collected as part of the School Health Initiative: Environment, Learning, Disease (SHIELD) study. PCE was detected in 37 to 63% of the samples, with concentrations ranging from 2.0E-02 – 3.0E-02 ng/mL (10th percentile) to 0.1-0.8 ng/mL (99th percentile). The limit of detection was 2.2E-02 ng/mL. The SHIELD study also collected 2-day, integrated personal air samples. Blood samples were also collected as part of the National Human Exposure Assessment Survey (NHEXAS) Phase I conducted by EPA (Clayton et al., 1999). Samples were collected from 147 people in six states (IL, IN, OH, MI, MN, and WI) in 1995-1997. PCE was detected in 37% of the samples, with a mean of 0.2 ng/mL, a 50th percentile of 5.0E-02 ng/mL, and a 90th percentile of 0.1 ng/mL. NHEXAS Phase I also collected indoor air and personal air samples. PCE concentrations in blood were similar between the NHANES, SHIELD, and NHEXAS surveys conducted between 1995 and 2016.

In addition to blood samples, NHANES also collected urine samples for the PCE metabolite N-Acetyl-S-(trichlorovinyl)-L-cysteine. Samples were collected for males and females ages 6+ years. Statistics

were reported for both uncorrected urine concentrations and creatine corrected urine concentrations. Data were reported for the survey years 2011-2012, and all samples measured (n=2,464-2,466) were below the detection limit of 3.0 µg/L. The NHANES urine metabolite data for PCE was also used in a 2015 study analyzing the reported data to develop means and other descriptive statistics (Jain, 2015). In that paper, the urinary metabolite TCVMA was reported in measurements of male (n=203) and female children (n=214) in 2011 and 2012. The mean concentration for male children was reported as 6.9 ng/mL and 6.4 ng/mL for female children. The 95% confidence interval around the mean was reported as 5.8 to 8.4 ng/mL for male children and 5.2 to 8.0 ng/mL for female children.

Breath samples were also collected as part of the Total Exposure Assessment Methodology (TEAM) Study (Wallace, 1987), which also collected concurrent personal inhalation monitoring samples and outdoor air samples. In Phase II and III of the study conducted between 1981 and 1984, samples were collected from adults conducting normal daily activities in industrial/chemical manufacturing and /or petroleum refining regions of the US, including Elizabeth and Bayonne, NJ, Los Angeles, CA, and Contra Costa, CA (n= 660). Arithmetic means ranged from 8.3 to 13 µg/m^3, with detection in 58 to 100% of samples.

2.4.4 Potentially Exposed or Susceptible Subpopulations

TSCA Section 6(b)(4)(A) requires EPA to conduct risk evaluations to "determine whether a chemical substance presents an unreasonable risk of injury to health or the environment, without consideration of cost or other non-risk factors, including an unreasonable risk to a potentially exposed or susceptible subpopulation identified as relevant to the risk evaluation by the Administrator, under the conditions of use." TSCA § 3(12) states that "the term 'potentially exposed or susceptible subpopulation' means a group of individuals within the general population identified by the Administrator who, due to either greater susceptibility or greater exposure, may be at greater risk than the general population of adverse health effects from exposure to a chemical substance or mixture, such as infants, children, pregnant women, workers, or the elderly."

During Problem Formulation (U.S. EPA, 2018d), EPA identified potentially exposed or susceptible subpopulations for further analysis during the development and refinement of the life cycle, conceptual models, exposure scenarios, and analysis plan. In this section, EPA addresses the potentially exposed or susceptible subpopulations identified as relevant based on *greater exposure*. EPA addresses the subpopulations identified as relevant based on *greater susceptibility* in Section 3.2.5.2.

In developing the risk evaluation, the EPA analyzed the reasonably available information to ascertain whether some human receptor groups may have greater exposure than the general population to the hazard posed by PCE. Exposures of PCE would be expected to be higher amongst groups living near industrial facilities, groups with PCE containing products in their homes, workers who use PCE as part of typical processes, and groups who have higher age and route specific intake rates compared to the general population.

Of the human receptors identified in the previous sections, EPA identifies several potentially exposed or susceptible subpopulations due to their greater exposure to PCE and considered them in the risk evaluation.

2.4.4.1 Workers and Occupational Non-Users (ONUs)

EPA reviewed monitoring data found in published literature including both personal exposure monitoring data (direct exposure) and area monitoring data (indirect exposures) and identified data sources that contain measured monitoring data and or/estimated data for the various conditions of use

(including import and processing of PCE). Exposure estimates were developed for users (males and female workers of reproductive age) exposed to PCE as well as non-users or workers exposed to PCE indirectly by being in the same work area of the building. Adolescents and female workers of reproductive age (>16 to less than 50 years old) were also considered as a potentially exposed or susceptible subpopulations. Additionally, children of employees present at dry cleaners are a PESS group that may be exposed to air concentrations equal to that of ONUs (Section 2.4.1.16).

For occupational exposures, EPA assessed exposures to workers and ONUs from all PCE conditions of use (Section 2.4.1). Table 2-106 presents the percentage of employed workers and ONUs whom may experience either greater exposure or biological susceptibility within select industry sectors relevant to PCE conditions of use. The percentages were calculated using Current Population Survey (CPS) data for 2017 (U.S. BLS, 2017). CPS is a monthly survey of households conducted by the Bureau of Census for the Bureau of Labor Statistics and provides a comprehensive body of data on the labor force characteristics. Statistics for the following subpopulations of workers and ONUs are provided: adolescents, men and women of reproductive age, and the elderly. For the purpose of this assessment, EPA considers "reproductive age" as age >16 to less than 50 years old.

As shown in Table 2-106, men make up the majority of the workforce in manufacturing sectors. In other sectors, women (including those of reproductive age and elderly women) make up nearly half of the workforce. Adolescents are generally a small part of the total workforce. Table 2-107 presents further breakdown on the percentage of employed adolescents by industry subsectors. As shown in the tables, they comprise only 1.2% percent of the manufacturing workforce, and only as high as 3.7% for other services such as dry cleaning that fall under a COU for PCE.

Table 2-106. Percentage of Employed Persons by Age, Sex, and Industry Sector

Age group	Sex	Manufacturing	Wholesale and Retail Trade	Professional and Business Services	Other Services
Adolescent (16-19 years)	Male	0.8%	3.0%	0.7%	1.4%
	Female	0.4%	3.2%	0.5%	1.7%
Reproductive age[a] (16-54 years)	Male	52.9%	42.8%	44.4%	35.2%
	Female	22.2%	35.4%	32.8%	38.4%
Elderly (55+)	Male	17.5%	12.3%	13.4%	13.1%
	Female	7.3%	9.6%	9.4%	13.3%

[a] The World Health Organization defines women of reproductive age as ages 15-49 (WHO, 2006b)While statistics on pregnant women are not reasonably available, Labor Force Statistics from the Current Population Survey provides data on the number of employed female workers by age group, which allows for determination of the number of employed women of reproductive age. The Bureau of Labor Statistics breaks apart age groups such that age 15 is combined with children, and ages 44-54 are clustered (U.S. BLS, 2017). Percentages were calculated using CPS Table 14, "Employed persons in nonagricultural industries by age, sex, race, and Hispanic or Latino ethnicity", for ages 16-64.

Table 2-107. Percentage of Employed Adolescent by Detailed Industry Sector

Sector	Subsector	Adolescent (16-19 years)
Manufacturing	All	1.2%
Wholesale and retail trade	Wholesale trade	1.4%
Professional and business services	Waste management and remediation services	0.9%
Other services	Repair and maintenance	3.1%
	Dry cleaning and laundry services	3.7%

Source: (U.S. BLS, 2017). Percentage of adolescent calculated using CPS table 18b, "Employed persons by detailed industry and age."

The CPS uses 2012 Census industry classification, which was derived from the 2012 NAICS. The Census classification uses the same basic structure as NAICS but is generally less detailed. PCE conditions of use fall under the following Census industry sectors:

2.4.4.2 Manufacturing

The Manufacturing sector comprises establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products. Establishments in the sector are often described as plants, factories, or mills. For PCE, this sector covers most conditions of use that occur in an industrial setting, including: Manufacturing, Processing as a Reactant, Formulation of Aerosol and Non-Aerosol Products, the vast majority of facilities likely engaged in Vapor Degreasing (all degreaser types), Cold Cleaning, Metalworking Fluids, Adhesives, Sealants, Paints and Coatings, Other Industrial Uses, Industrial Processing Aids and Printing and Copying. This sector also covers cement manufacturing facilities that may burn waste containing PCE for energy recovery. Also Printing and Copying worker information may also be captured under the Information sector (see below).

2.4.4.3 Wholesale and Retail Trade

The wholesale trade sector comprises establishments engaged in wholesaling merchandise, generally without transformation, and rendering services incidental to the sale of merchandise. Wholesalers normally operate from a warehouse or office. This sector likely covers facilities that are engaged in the repackaging PCE or products and formulations containing PCE. The retail trade sector comprises establishments engaged in retailing merchandise and rendering services incidental to the sale of merchandise.

2.4.4.4 Professional and Business Services

This sector comprises establishments that specialize in a wide range of services. This sector covers waste management and remediation services, which includes establishments that may handle, dispose, treat, and recycle wastes containing PCE.

2.4.4.5 Other Services

This sector comprises establishments engaged in providing services not specifically provided for elsewhere in the classification system. For PCE, this sector covers the vast majority of commercial repair and maintenance facilities that are likely to use PCE for Aerosol Applications (spray degreasing). The sector also covers the use of PCE in dry cleaning.

2.4.4.6 Consumers/Product Users and Bystanders Associated with Consumer Use

PCE has been identified as being used in products available to consumers. Section 2.4.2.2 provides an overview of exposure pathways considered for the consumer assessment. Furthermore, EPA identified consumers and bystanders associated with use of PCE containing consumer products as a potentially exposed and susceptible subpopulation due to greater exposure. For example, higher-intensity users (*i.e.*, those using consumer products for longer durations and in greater amounts) were considered and evaluated. In addition, consumers are considered to include children and adults over age 11, but bystanders in the home exposed via inhalation are considered to include any age group, from infant to adult, including pregnant women and/or women of reproductive age. However, only some individuals within the general population may use these products. Therefore, those who do use these products are a potentially exposed or susceptible subpopulation due to greater exposure. Exposures for these subpopulations are considered and/or evaluated in Section 2.4.2.2.

In developing dermal exposure scenarios, EPA quantified age and sex-specific differences. For PCE, exposure scenarios that involve potentially exposed or susceptible subpopulations considered age-specific behaviors, activity patterns, and exposure factors unique to those subpopulations. EPA used the Exposure Factors Handbook (U.S. EPA, 2011a) to inform body weights, intake rates, and body surface areas for children and adults. Distinct dermal exposure estimates are provided for are provided for adults (including women of reproductive age) and children (Section 2.4).

The EPA IRIS Assessment for PCE (U.S. EPA, 2012c) also identified the developing fetus as potentially exposed, as well as infants consuming breastmilk, particularly for mothers with occupational exposure to PCE or exposure due to proximity to industrial or commercial sources (U.S. EPA, 2012c). For example, children who live or attend daycare or school above or adjacent to dry cleaners can also have elevated PCE exposures as noted in the 2012 IRIS PCE assessment (U.S. EPA, 2012c). Infants fed by formula may also experience increased PCE exposure if PCE is present in drinking water supplies (U.S. EPA, 2012c). However, because the drinking water exposure pathway for PCE is currently addressed in the NPDWR, EPA is not evaluating exposures to the infants from the drinking water exposure pathway in the risk evaluation for PCE under TSCA.

3 HAZARDS

3.1 Environmental Hazards

3.1.1 Approach and Methodology

During scoping and Problem Formulation (U.S. EPA, 2018e), EPA reviewed potential environmental health hazards associated with PCE. EPA identified the following sources of environmental hazard data for PCE: European Chemicals Bureau (ECB) EU Risk Assessment Report Tetrachloroethylene, Part 1 - environment (ECB, 2005) and World Health Organization (WHO) Concise International Chemical Assessment Document 68; Tetrachloroethylene WHO (WHO, 2006a).

EPA completed the review of environmental hazard data/information sources during risk evaluation using the data quality review evaluation metrics and the rating criteria described in the Application of Systematic Review in TSCA Risk Evaluations (U.S. EPA, 2018b). The data quality evaluation results indicated the quality of the studies is mostly 'high' and 'moderate', and these studies were used to characterize the environmental hazards of PCE. The data evaluation results for PCE environmental hazard are summarized in Table 3-1

3.1.2 Hazard Identification

3.1.2.1 Toxicity to Aquatic Organisms

EPA assigned an overall quality level of high, medium or low to 30 acceptable studies. These studies contained relevant aquatic toxicity data for fish, aquatic invertebrates, and aquatic plants. As shown in Table 3-1, EPA identified 12 aquatic toxicity studies as the most relevant for quantitative assessment. Four of the 12 studies were carried forward for characterizing the potential environmental risks from PCE. The rationale for selecting these studies is provided in Section 3.1.3.

Table 3-1. Ecological Hazard Characterization of PCE for Aquatic Organisms

Duration	Test organism	Endpoint	Hazard value[1] (mg/L)	Effect Endpoint	Geometric Mean[2] (mg/L)	References	Data Quality Evaluation Ratings
Acute	Fish	LC_{50}	4.82 – 28.1	Mortality	15.3	(Horne et al., 1983; Call et al., 1979; Spencer et al., 2002)	High
	Amphibians	EC_{50}[2]	7.8 - > 45	Developmental Deformities	9.63	(McDaniel et al., 2004)	High
	Aquatic invertebrates	EC_{50} (Midge)	7.0	Immobilization	NA	Call et al. 1979	High
		EC_{50} (Daphnia)	7.5	Immobilization	7.5	(Richter et al. 1983; Call et al. 1980; Call et al. 1983)	High
		LC_{50} (Daphnia)	9.1 - 15	Mortality	10.3	(Niederlehner et al., 1998; Richter et al. 1983; Call et al. 1980; Call et al. 1983)	High
Chronic	Fish	ChV	0.5-1.4	Mortality	0.84	(Ahmad et al., 1984)	High
	Aquatic invertebrates	NOEC LOEC (Daphnia)	0.5 1.1	Reproduction	0.7	(Call et al., 1983; Richter et al., 1983)	High
		ChV (Shrimp)	0.37 – 0.67	Growth	0.5	Hollister et al., 1968)	High
	Algae	EC_{50}	3.64 - > 500	Biomass	NA	(Brack and Rottler, 1994; Hollister et al., 1968)	High
		NOEC/ LOEC	0.01 - 0.02	Mortality	1.4E-2	(Labra et al., 2010)	Medium

[1] Values in the tables are presented as reported by the study authors
[2] Geometric mean of definitive values only (*i.e.*, > 45 mg/L) was not used in the calculation.

Aquatic Environmental Hazards from Acute Exposures to PCE

Fish

EPA assigned an overall data quality level of high for three acute (96-hour; flow-through) fish toxicity studies, which evaluated the median lethal concentrations (LC_{50}) of PCE. The acute 96-hour LC_{50} values for fish were 4.82 mg/L for rainbow trout (Call et al. 1979), 26.8 mg/L for Japanese medaka (Spencer et

al., 2002), and 28.1 for inland silverside (Horne et al. 1983). The LC_{50} study for rainbow trout did not report the statistical model used to calculate the LC_{50}. Whereas, Probit analysis was used for calculating both Japanese medaka and inland silverside LC_{50}s. The geometric mean of the LC_{50}s was used to account for this uncertainty while still incorporating the LC_{50} data for rainbow trout. As previously identified in the Problem Formulation document (U.S. EPA, 2018d), the acute 96-hour LC_{50} value of 4 mg/L (Smith et al., 1991) for flagfish (*Jordanella floridae*) was determined to be a reporting error from the study.

Amphibians
EPA assigned an overall data quality level of high to one acute (96-hour; static renewal) amphibian toxicity study (McDaniel et al., 2004), which evaluated developmental deformities (EC_{50}) in embryos of wood frogs (*Lithobates sylvatics*), green frog (*Lithobates clamitans*), American toad (*Anaxyrus americanus*). The same study also evaluated developmental deformities in the spotted salamander (*Ambystoma maculatum*), which was assigned an overall quality level of medium. The 96-hour EC_{50} values ranged from 7.8 mg/L (*L. sylvatics*) to > 45 mg/L (*Anaxyrus americanus*), and a geometric mean of definitive EC_{50} values for developmental effects was calculated at 9.63 mg/L.

Aquatic Invertebrates
Seven studies were assigned an overall quality level of high for acute toxicity to aquatic invertebrates that include mysid shrimp (*Mysidopsis bahia*), brine shrimp (*Artemia salina*), midge larvae (*Tanytarsus dissimilis*), *Ceriodaphnia dubia* and *Daphnia magna*. For *C. dubia*, the 48-hour LC_{50} toxicity was 15 mg/L (Niederlehner et al., 1998). For *D. magna*, three studies reported 48-hour EC_{50} concentrations based on immobilization of 7.5 mg/L and LC_{50} of 9.1 mg/L (Richter et al. 1983; Call et al. 1980; Call et al. 1983). The 48-hour acute toxicity to midge larvae show EC_{50} concentrations based on immobilization of 7.0 mg/L and LC_{50} of 31 mg/L (Call et al., 1979). Other salt water aquatic invertebrate toxicities range from 96-hour LC_{50} of 2.85 mg/L (Hollister et al., 1968) for mysid shrimp, to 24-hour LC_{50} of 23 mg/L (Sanchez-Fortun et al., 1997) for brine shrimp. However, the saltwater aquatic invertebrates are less representative of PCE exposure from releases than freshwater invertebrates.

Aquatic Environmental Hazards from Chronic Exposures to PCE
Fish
A single chronic 32-day toxicity study on exposure of *Pimphales promelas* (fathead minnow) to PCE was assigned an overall data quality level of high (Ahmad et al., 1984). The reported NOEL - LOEL values of 0.5 - 1.4 mg/L, respectively, based on growth and mortality of *P. promelas* exposure to PCE (Ahmad et al., 1984). The geometric mean was used to calculate the chronic toxicity value of 0.84 mg/L.

Aquatic Invertebrates
Three studies were assigned an overall data quality level of high for chronic (28-day) toxicity to aquatic invertebrates *Daphnia magna* (Richter et al., 1983; Call et al., 1980), *Americamysis bahia* (opossum shrimp) (Hollister et al., 1968) from exposure to PCE. The *D. magna* 28-day study reported a NOEC value of 0.5 mg/L using reproduction (Richter et al., 1983; Call et al., 1980) and a LOEC of 1.1 mg/L based on measured concentrations (Richter et al., 1983; Call et al., 1980). The 28-day *A. bahia* reported NOEC value of 0.4 mg/L and LOEC of 0.7 mg/L (Hollister et al., 1968). The geometric mean was calculated from the NOEC and LOEC values to derive the chronic toxicity value of 0.5 mg/L.

Aquatic Plants
Three studies were assigned an overall data quality level of high for EC_{50} endpoint (Brack and Rottler, 1994; Hollister et al., 1968) and medium for NOEC/LOEC (Labra et al., 2010) from exposure to PCE.

The algal toxicity 72-hr EC_{50} values were 3.6 mg/L for *Chlamydomonas reinhardtii* (Brack and Rottler 1994) to greater than 500 mg/L for 96-hr EC_{50} for saltwater algae (Hollister, 1968) based on biomass and abundance. The algal species in the Hollister study were not specified. The most conservative toxicity values were reported for *Pseudokirchneriella subcapitata* (green microalgae) 72-hour study using NOEC - 1.0E-2 mg/L and LOEC - 2.0E-2 mg/L based on mortality (Labra et al., 2010).

Terrestrial Plants and Animals
As noted in Section 1.4.2, the terrestrial pathway is out of scope for the risk evaluation. Problem Formulation

3.1.3 Weight of the Scientific Evidence

During the data integration stage of systematic review EPA analyzed, synthesized, and integrated the data/information into Table 3-1. This involved weighing scientific evidence for quality and relevance, using a weight of scientific evidence approach, as defined in 40 CFR 702.33, and noted in TSCA 26(i) (U.S. EPA, 2018b).

During data evaluation, EPA assigned studies an overall data quality level of high, medium, or low based on the TSCA criteria described in the Application of Systematic Review in TSCA Risk Evaluations (U.S. EPA, 2018b). While integrating environmental hazard data for PCE, EPA gave more weight to relevant data/information that were assigned an overall data quality level of high or medium. Only data/information that EPA assigned an overall quality level of high or medium was used for the environmental risk assessment. Data that EPA assigned an overall quality level of low was used to provide qualitative characterization of the effects of PCE exposures in aquatic organisms. Any information that EPA assigned an overall data quality of unacceptable was not used. EPA determined that data and information were relevant based on whether it had biological, physical/chemical, and environmental relevance (U.S. EPA, 1998):

- Biological relevance: correspondence among the taxa, life stages, and processes measured or observed and the assessment endpoint.
- Physical/chemical relevance: correspondence between the chemical or physical agent tested and the chemical or physical agent constituting the stressor of concern.
- Environmental relevance: correspondence between test conditions and conditions in the environment (U.S. EPA, 1998).

To calculate COCs, EPA derived geometric means for each trophic level that had comparable toxicity values (*e.g.*, multiple EC_{50} values measuring the same or comparable effects from various species within a trophic level). EPA did not use non-definitive toxicity values (*e.g.*, $EC_{50} > 48$ mg/L) to derive geometric means because these concentrations of PCE were not high enough to establish an effect on the test organism.

To assess aquatic toxicity from acute exposures, data for three taxonomic groups were available: fish, amphibians, and aquatic invertebrates. Aquatic invertebrates were also the most sensitive taxonomic group for acute exposures. The 48-hour acute EC_{50} = 7.0 mg/L was used to derive an acute COC as described in Section 3.1.4. This value is from a single study that EPA assigned an overall quality of high.

To assess aquatic toxicity from chronic exposures, data for two taxonomic groups were described in the acceptable literature: fish, and aquatic invertebrates. Aquatic invertebrates were also the most sensitive taxonomic group for chronic exposures. The chronic 72-hour NOEC = 0.01 mg/L and LOEC = 2.0E-2

mg/L values were used to derive a chronic COC in Section 3.1.4. This value was from two studies that EPA assigned an overall quality level of high.

To assess the toxicity of PCE to algae, data from three species were available from studies that EPA assigned an overall quality level of high and medium. EC_{50} values measuring biomass ranged from 3.6 mg/L to >500 mg/L. A NOEC = 1.0E-2 mg/L and LOEC = 2.0E-2 mg/L was also reported. The most protective endpoint was the NOEC/LOEC mortality endpoint from Labra et al. (2010). This study was rated medium for quality. The EC_{50} biomass endpoint from Brack et al. (1994), was rated high for quality. The Brack et al. (1994) study was also used in the risk evaluation for trichloroethylene with the same species (*C. reinhartdtii*). For the trichloroethylene risk evaluation, nine species of algae were available to perform a species sensitivity distribution (SSD) using EC_{50} values that included *C. reinhartdtii* from Brack et al. (1994). Because of the chemical similarities between these two chlorinated solvents, trichloroethylene and PCE, EPA expects the distribution of species sensitivities from exposure to either chemical to be similar. In the trichloroethylene SSD, *C. reinhartdtii* was below the calculated HC_{05} (Hazardous Concentration threshold for 5% of species). Therefore, EPA expects the EC_{50} from exposure of PCE to *C. reinhartdtii* to also be protective of 95% of algal species. The EC_{50} from one high quality algae study (Brack and Rottler 1994), was used to derive an algae COC in Section 3.1.4.

Based on the estimated bioconcentration factor and bioaccumulation potential described in Section 2.1, PCE does not bioaccumulate in biological organisms. Therefore, EPA did not assess hazards to aquatic species from trophic transfer and bioconcentration or accumulation of PCE.

3.1.4 Concentrations of Concern (COC)

EPA calculated the COCs for aquatic species based on the environmental hazard data for PCE, using the weight of the scientific evidence approach described above and EPA methods (U.S. EPA, 2013, 2012b). While there were data representing fish, amphibians, aquatic invertebrates, and aquatic plants, the data were not robust enough to conduct a more detailed SSD analysis. Therefore, EPA chose to establish COC as protective cut-off standards above which acute or chronic exposures to PCE are expected to cause effects for each taxonomic group in the aquatic environment. The COC is typically based on the most sensitive species or the species with the lowest toxicity value reported in that environment. For PCE, EPA derived an acute COC for aquatic invertebrates and a chronic COC for fish and aquatic invertebrates. Algae was assessed separately and not incorporated into acute or chronic COCs, because durations normally considered acute for other species (*e.g.*,48, 72 hours) can encompass several generations of algae.

After deriving the acute, chronic, and algal COCs, EPA applied an assessment factor (AF) according to EPA methods (U.S. EPA, 2013, 2012b), when possible. An AF is applied to the acute and chronic hazard endpoints for aquatic species to calculate a Concentration of Concern (COC) for use in the screening-level analysis of environmental hazards. The application of AFs provides a lower bound effect level that would likely encompass more sensitive species not specifically represented by the available experimental data. AFs can also account for differences in inter- and intra-species variability, as well as laboratory-to-field variability. These AFs are dependent on the availability of datasets that can be used to characterize relative sensitivities across multiple species within a given taxa or species group. They are often standardized in risk assessments conducted under TSCA, since the data available for most industrial chemicals are limited. For fish and aquatic invertebrates (*e.g.*, daphnia) the acute COC values are divided by an AF of 5. For chronic COCs, an AF of 10 is used. The COC for algae, where multiple generations can be present over the course of a standard toxicity test, an AF of 10 is used. The use of these assessment factors are consistent with EPA methodology for the screening and assessment of industrial chemicals (U.S. EPA, 2013, 2012b).

After applying AFs, EPA converts COC units from mg/L to µg/L (or ppb) in order to more easily compare COCs to surface water concentrations during risk characterization.

3.1.4.1 Acute COC

To derive an acute COC for PCE, EPA used the EC_{50} for aquatic invertebrates, which is the most sensitive acute value for aquatic species from the data integrated for PCE, from a single study EPA assigned overall quality rating of high (Call et al. 1979). The EC_{50} of 7.0 mg/L was divided by the AF of five for aquatic invertebrates and multiplied by 1,000 to convert from mg/L to µg/L, or ppb.

The acute COC = (7.0 mg/L) / AF of 5 = 1.4 mg/L x 1,000 = 1,400 µg/L or ppb.

- The acute COC for PCE is 1,400 ppb.

3.1.4.2 Chronic COC

EPA derived the chronic COC for aquatic invertebrate exposure to PCE from the lowest chronic toxicity value from the integrated data using the geometric mean of NOEC and LOEC for growth effects in opossum shrimp (Hollister et al., 1968). The geometric mean was then divided by an assessment factor of 10, and then multiplied by 1,000 to convert from mg/L to µg/L, or ppb.

The chronic COC = (0.5 mg/L) / AF of 10 = 5.0E-2 mg/L x 1,000 = 50 µg/L or ppb.

- The aquatic invertebrates chronic COC for PCE is 50 ppb.

EPA also derived a chronic COC for fish for comparison to the aquatic invertebrate chronic data. The chronic COC for fish exposed to PCE was derived from the most sensitive chronic toxicity value (ChV) from the integrated data using the geometric mean of NOEC and LOEC for measuring mortality in fathead minnow based on a study that EPA assigned a quality level of high (Ahmad et al., 1984). The ChV was then divided by an assessment factor of 10, and then multiplied by 1,000 to convert from mg/L to µg/L, or ppb.

The chronic COC = (0.84 mg/L) / AF of 10 = 0.084 mg/L x 1,000 = 84 µg/L or ppb.

- The fish chronic COC for PCE is 84 ppb.

3.1.4.3 Algal COC

The algal COC was derived from the integrated data using the EC_{50} value for algae biomass ((Labra et al., 2010). The algal toxicity value of 3.64 mg/L was then divided by an assessment factor of 10, and then multiplied by 1,000 to convert from mg/L to µg/L, or ppb.

The algal COC = (3.6 mg/L) / AF of 10 = 0.36 mg/L x 1000 = 360 µg/L or ppb.

- The algal COC is 360 ppb.

3.1.5 Summary of Environmental Hazard

3.1.5.1 Acute and Chronic Aquatic Toxicity

EPA concludes that PCE presents a hazard for acute exposure duration in aquatic invertebrates, with acute toxicity values as low as 2.85 mg/L, based on mortality in mysid shrimp (Niederlehner et al., 1998) to 31 mg/L in midge larvae (Call et al., 1979). Acute 96-hour exposures to PCE for fish based on mortality LC_{50} toxicity values for rainbow trout of 4.8 mg/L to inland silverside of 28 mg/L (resulting in a geometric mean of 15 mg/L). For chronic exposures to fish, PCE has a hazard value as low as 0.84 mg/L. For chronic exposure to aquatic invertebrates, PCE has a chronic toxicity value of 0.5 mg/L. In

algal species, where exposure durations are considered separate from chronic as they can encompass several generations of algae, PCE has an EC_{50} of 3.6 mg/L.

3.1.5.2 Concentrations of Concern

The acute and chronic COCs derived for aquatic organisms are summarized in Table 3-2. EPA calculated the acute COC for PCE exposures in aquatic invertebrates as 1,400 ppb, based on a single EC_{50} study that EPA assigned an overall data quality level of high (Niederlehner et al., 1998; Call et al., 1980). EPA calculated the chronic COC for PCE exposures in aquatic invertebrates as 50 ppb, based on the geometric mean of NOEC and LOEC for growth from a single study that EPA assigned an overall data quality level of high (Hollister et al., 1968).

For comparison with other trophic levels, EPA calculated the fish chronic COC for PCE of 84 ppb, based on the geometric mean of the NOEL and LOEL from a single study that EPA assigned an overall data quality level of high (Hollister et al., 1968). As noted previously, algal hazard values from exposures to PCE, for 96-hour durations, are considered separately from other aquatic species because algae can cycle through several generations in this time frame. The algal COC of 360 ppb is based on the geometric mean of the EC_{50} from a single study that EPA assigned an overall data quality level of high (Labra et al., 2010).

3.1.5.3 Confidence in COCs

Based on the data quality, weight of the scientific evidence, and uncertainties (see Section 4.1.5), confidence in acute and chronic COCs for fish and invertebrates are high. Additionally, algae species tend to vary widely in their sensitivity to chemical pollutants, and data were only available for three algal species and may not represent the most sensitive species at a given site. Therefore, confidence in algae COC is medium.

Table 3-2. COCs for Environmental Toxicity

Environmental Aquatic Toxicity	Hazard Value (µg/L)	Assessment Factor	COC (µg/L or ppb)
Toxicity to Aquatic Invertebrates from Acute Exposures	7,000	5	1,400
Toxicity to Aquatic Invertebrates from Chronic Exposures	500	10	50
Toxicity to Fish from Chronic Exposures	840	10	84
Algal Toxicity	3,600	10	360

3.2 Human Health Hazards

3.2.1 Approach and Methodology

EPA used the approach described in Section 1.5 to evaluate, extract and integrate PCE's human health hazard and dose-response information. The process is described below in Figure 3-1.

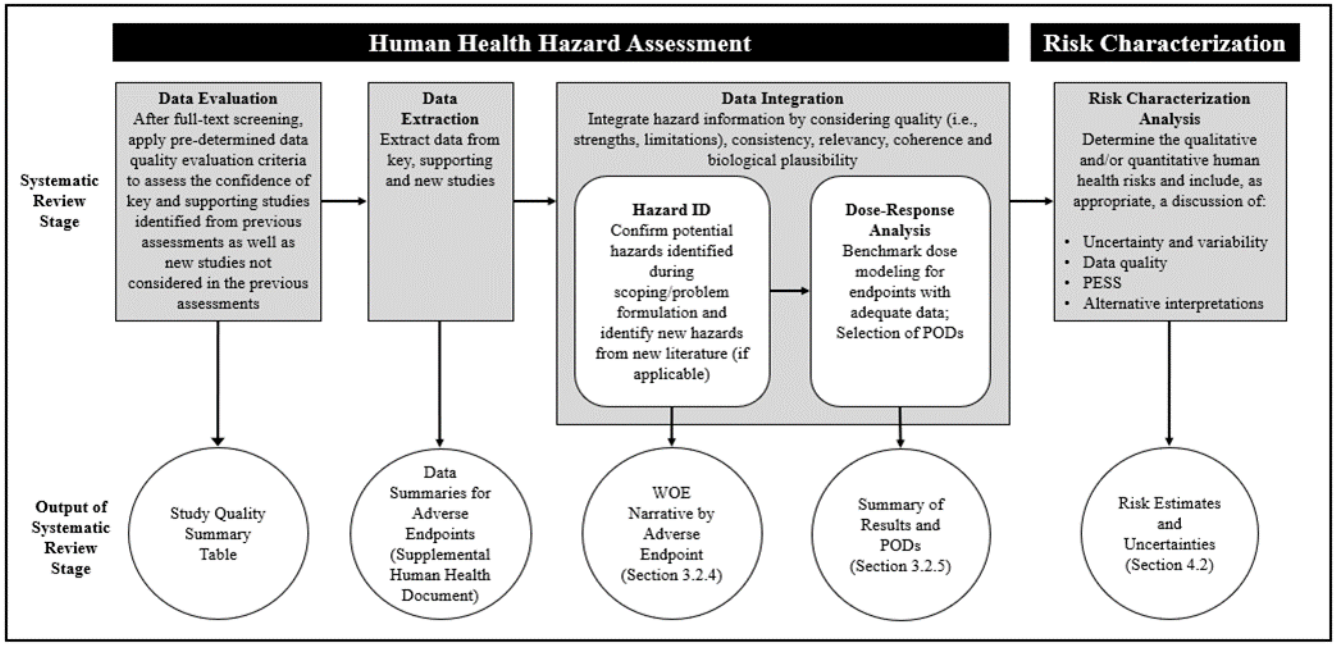


Figure 3-1. EPA Approach to Hazard Identification, Data Integration, and Dose-Response Analysis for PCE

Specifically, EPA reviewed key and supporting information from previous human health hazard assessments as well as the existing body of knowledge on PCE's human health hazards. These data sources included an existing EPA IRIS Assessment (U.S. EPA, 2012c) and an ATSDR Toxicological Profile (since finalized as (ATSDR, 2019)); hence, many of the human health hazards of PCE have been previously compiled and systematically reviewed. Key information evaluated from the IRIS assessment included studies considered for dose-response analysis and genotoxicity studies.

All human health hazards of PCE previously identified in these reviews were described and reviewed in this risk evaluation, including: acute toxicity, neurotoxicity, kidney toxicity, liver toxicity, reproductive/developmental toxicity, immune and hematological effects, irritation, and cancer. EPA relied heavily on the aforementioned existing reviews along with scientific support from the Office of Research and Development in preparing this risk evaluation. Development of the PCE hazard and dose-response assessments considered EPA and National Research Council (NRC) risk assessment guidance.

Any identified new literature published since these previous assessments was screened against inclusion criteria in the PECO statement and the relevant studies (*e.g.*, useful for dose-response)[22] were further evaluated using the data quality criteria for human, animal, and *in vitro* studies described in the

[22] Some of the studies that were excluded based on the PECO statement were considered later during the systematic review process as needed. For example, EPA reviewed mode of action information to qualitatively support the health hazard assessment.

Application of Systematic Review in TSCA Risk Evaluations document (U.S. EPA, 2018b). EPA skipped the screening step (for relevance to PCE) of the key and supporting studies identified in previous assessments and entered them directly into the data quality evaluation step based on their previously identified relevance to the chemical (U.S. EPA, 2018b).

EPA considered studies of low, medium, or high confidence for the weight of the scientific evidence (WOE) for hazard identification and dose-response analysis. Information from studies that were rated unacceptable were only discussed on a case-by-case basis for hazard ID and weight of the scientific evidence assessment but were not considered for dose-response analysis.

EPA has not developed data quality criteria for all types of hazard information. This is the case for toxicokinetics and many types of mechanistic data which EPA typically uses for qualitative support when synthesizing evidence. As appropriate, EPA evaluated and summarized these data to determine their utility with supporting the risk evaluation.

Following the data quality evaluation, EPA extracted the toxicological information from each relevant study. In the last step, the strengths and limitations of the data were evaluated for each endpoint and a weight of the scientific evidence narrative was developed. Data for each selected hazard endpoint underwent dose-response analysis. Finally, the results were summarized, and the uncertainties were presented. The WOE analysis integrated information from toxicokinetics and toxicodynamics in relation to the identified relevant hazard endpoints: toxicity from acute exposures, liver toxicity, kidney toxicity, neurotoxicity, immunotoxicity, reproductive toxicity, developmental toxicity, and cancer. EPA selected human health studies that were of high quality and relevance to move forward for dose-response analysis in order to quantitatively assess each key hazard endpoint.

Summaries for all studies considered for this risk evaluation, the no-observed- or lowest-observed-adverse-effect levels (NOAEL and LOAEL) for non-cancer health endpoints by target organ/system, the incidence for cancer endpoints, and the results of the data quality evaluation are provided in *Risk Evaluation for Perchloroethylene Data Quality Evaluation of Human Health Hazard Studies (Epidemiological Studies; Animal and In Vitro Studies*) (U.S. EPA, 2020k, l) and *Data Extraction for Human Health Hazard Studies.* (U.S. EPA, 2020g).

EPA considered points of departure (POD) from studies that were PECO relevant, scored acceptable in the data quality evaluation, and contained adequate dose-response information. The POD is a dose or concentration near the lower end of the observed range without significant extrapolation to lower doses. It is used as the starting point for subsequent dose-response (or concentration-response) extrapolations and analyses. PODs can be a no-observed-adverse-effect level (NOAEL), a lowest-observed-adverse-effect level (LOAEL) for an observed incidence, or change in level of response, or the lower confidence limit on the dose at the benchmark dose (BMDL)[23]. PODs were adjusted as appropriate to conform to the specific exposure scenarios evaluated. Section 3.2.5 describes the dose-response assessment guiding the selection of PODs for non-cancer endpoints.

3.2.2 Toxicokinetics

The toxicokinetics and PBPK modeling of PCE were thoroughly described in the 2012 EPA IRIS Assessment (U.S. EPA, 2012d). This discussion is summarized below.

[23] The benchmark dose (BMD) is a dose or concentration that produces a predetermined change in response range or rate of an adverse effect (called the benchmark response or BMR) compared to baseline.

3.2.2.1 Absorption/Distribution/Metabolism/Elimination (ADME)

3.2.2.1.1 Absorption

Inhalation

Inhalation is considered to be the major exposure route, and studies on both humans and animals confirm that PCE is both rapidly and readily absorbed via pulmonary uptake (with equilibrium occurring after several hours). A number of studies have evaluated PCE blood:gas partition coefficients and uptake following inhalation exposures (Dallas et al., 1994b; Dallas et al., 1994a; Opdam and Smolders, 1986; Monster et al., 1979; Pegg et al., 1979) and others). These data were incorporated into the PBPK model to account for any differences in the relative inhalation absorption for humans and rats. However, since the PBPK model does not include a dermal component, the external inhalation exposure concentrations had to be used to derive dermal PODs, and for this purpose EPA conservatively assumed 100% absorption through the lungs (assuming continuous exposure).

Oral

For oral exposures, studies in mice, rats, and dogs demonstrate that absorption of PCE through the gut is essentially complete (*i.e.*, 100%) (Dallas et al., 1995, 1994a; Frantz and Watanabe, 1983; Schumann et al., 1980; Pegg et al., 1979).

Dermal

Dermal exposure to PCE vapors is estimated to result in minimal dermal uptake compared to inhalation of the same vapors (only ~1% absorbed dermally compared to inhaled). However, studies indicate that dermal absorption may be significant for direct skin application of PCE. Complete (*i.e.*, 100%) absorption may be achieved in scenarios of impeded evaporation or complete immersion, and this risk evaluation assumes that up to 100% of the delivered dermal dose (*i.e.*, after accounting for evaporation or in scenarios with impeded evaporation) is absorbed. Volatilization from the skin is accounted for in the occupational exposure assessment by the *Dermal Exposure to Volatile Liquids Model* based on a theoretical framework provided by Kasting and Miller (2006). The amount of liquid on the skin is adjusted by the weight fraction of PCE in the liquid to which the worker is exposed. Specific details of the dermal occupational exposure assessment can be found in Section 2.4.1.28. For the consumer risk assessment, dermal exposure was assessed using the Consumer Exposure Model (CEM; (U.S. EPA, 2017a), Section 2.4.2.2.2). The permeability dermal sub-model (P_DER2b) was used for consumer COUs where evaporation is inhibited, or prohibited, or full immersion of a body part occurs during use based on the ability of a chemical to penetrate the skin layer once contact occurs. The CEM permeability model assumes a constant supply of chemical, directly in contact with the skin, throughout the exposure duration. The permeability method does NOT consider evaporation and is more representative of these COU types. EPA used the CEM (Fraction Absorbed, P_DER2a) model to evaluate dermal exposure for product COUs where evaporation is expected to be uninhibited and no direct immersion of body parts into a product occurs during use. The fraction absorbed method is based on the volume of chemical absorbed across the skin barrier.

3.2.2.1.2 Distribution

PCE is broadly distributed to all tissues and can cross both the blood:brain barrier and placenta. The highest concentrations are found in adipose tissues due to the lipophilicity of the chemical. Accordingly, PCE concentrations are higher in the brain and liver than many other tissues and it becomes concentrated in human breast milk. Breast milk is an exposure pathway specific to infants. Detectable levels of PCE were also found in seven of eight breast milk samples of mothers living in urban areas in the United States; however, concentrations were not provided (Pellizzari et al., 1982). Models have been developed to estimate the levels of PCE in breast milk of women exposed to PCE (Byczkowski and

Fisher, 1994; Schreiber, 1993). The PBPK model in Schreiber (1993) predicted that for women exposed under occupational conditions, breast milk concentrations would range from 857 to 8,440 µg/L. Skeletal muscle has been measured to contain the lowest concentration of any tissue. Long residence time in adipose tissue can result in increasing body burden with continuous or repeated exposures.

3.2.2.1.3 Metabolism

PCE is metabolized in laboratory animals and in humans through at least two distinct pathways as shown in Figure 3-2:

- Oxidative metabolism via the cytochrome P450 (CYP [also abbreviated as P450]); or
- Glutathione (GSH) conjugation followed by subsequent biotransformation to the cystine conjugate which can be cleaved by β-lyase or oxidized by flavin-containing monooxygenase 3 (FMO3) or CYPs to form metabolites that can rearrange to the reactive thiokene.

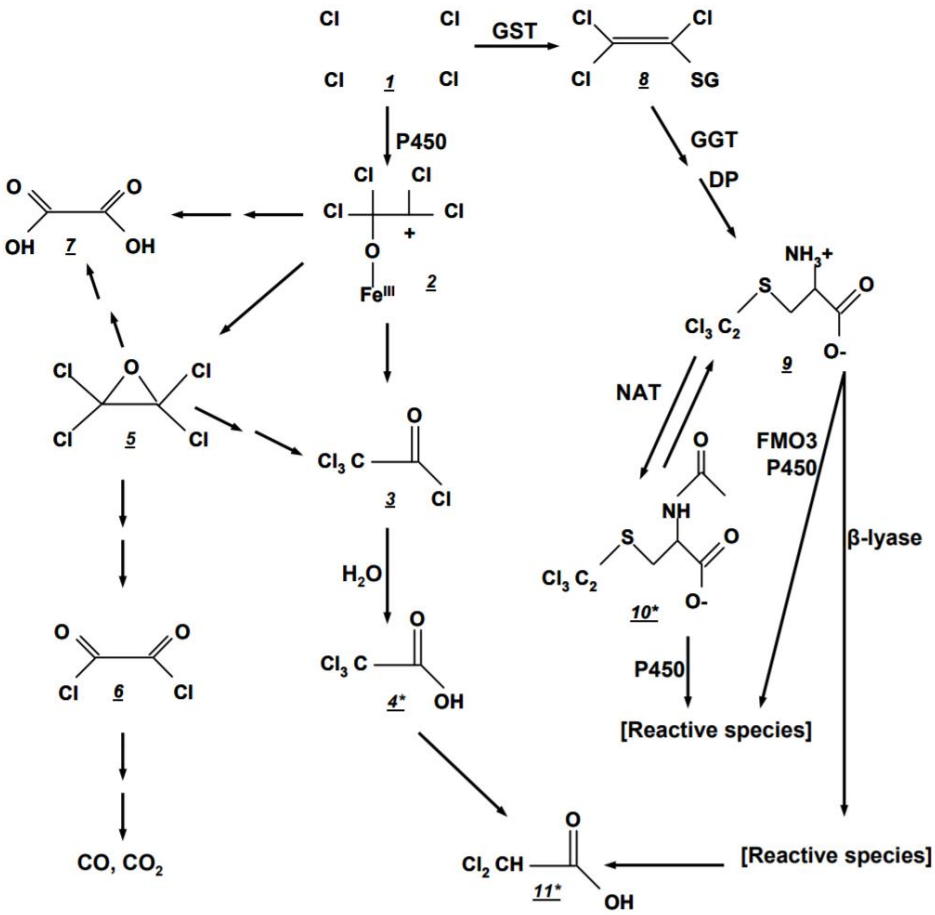


Figure 3-2. Scheme for the metabolism of tetrachloroethylene by the cytochrome P450 (P450) oxidative and glutathione S-transferase (GST)-mediated glutathione (GSH) conjugation pathways from (U.S. EPA, 2012d). PCE and identified (*) urinary metabolites: (1) PCE, (2) PCE-Fe-O intermediate, (3) trichloroacetyl chloride, (4) trichloroacetic acid, (5) PCE oxide, (6) ethandioyl dichloride, (7) oxalic acid, (8) S-(1,2,2-trichlorovinyl) glutathione (TCVG), (9) S-(1,2,2-trichlorovinyl)-Lcysteine (TCVC), (10) N-acetyl trichlorovinyl cysteine (NAcTCVC), (11) dichloroacetic acid.

Enzymes: cytochrome P450 (P450), GST, gamma-glutamyltransferase (GGT), dipeptidase (DP), β-lyase, flavin mono-oxygenase-3 (FMO3), N-acetyl transferase (NAT).

Studies in both animals and humans indicate that overall metabolism of PCE is relatively limited, particularly at higher exposures. Oxidative metabolism is the more dominant pathway in rodents, however the relative contribution of each pathway in humans has not been determined. The available data present a wide range of estimates for amount of PCE metabolized, depending on dose level and species, with a lower percent administered dose metabolized at higher doses and less metabolized in mice compared to rats. PBPK modeling results estimated that, at of 50 ppm, only 1.5-1.7% of inhaled PCE would be metabolized, while at air concentrations of only 0.001 ppm, the median estimate predicts that 36% of the inhaled dose would be metabolized (Bois et al., 1996).

Cytochrome P450-Dependent Oxidation

The oxidative metabolites are likely associated with PCE-induced liver toxicity. The major excreted oxidative metabolite is trichloroacetic acid (TCA), which has been detected in the urine of all species. TCA is postulated to be derived primarily from the upstream metabolite, trichloroacetyl chloride, which can be generated via epoxidation of PCE but the predominate pathway is thought to be from an intramolecular chlorine migration in the CYP-oxygenated PCE intermediate (Yoshioka et al., 2002). (Yoshioka et al., 2002).

Oxalic acid has been reported to be a major urinary metabolite in rats (Pegg et al., 1979). Oxalic acid has been reported to be a major urinary metabolite in rats (Pegg et al., 1979; Dmitrieva, 1967), and it may arise from action of microsomal epoxide hydrase on the epoxide intermediate or it may be a separate product from the initial Fe-O intermediate. The oxalate metabolite excretory product may also be derived from dichloroacetic acid (DCA) or monochloroacetic acid (Tong et al., 1998a, b; Dmitrieva, 1967), and it may arise from action of microsomal epoxide hydrase on the epoxide intermediate or it may be a separate product from the initial Fe-O intermediate. The oxalate metabolite excretory product may also be derived from dichloroacetic acid (DCA) or monochloroacetic acid (Tong et al., 1998a, b).

Dichloroacetic acid (DCA) has also been detected in urine and may be generated either from further metabolism of TCA or via bioactivation of the GSH conjugation metabolite. Studies on the biotransformation of radiolabeled TCA reported that up to 2% of the radioactivity recovered in urine was DCA with TCA excreted at a 25-fold higher concentration. Studies with PCE observed that DCA represented a larger proportion of urinary radioactivity, with TCA only being excreted at a 10-fold higher concentration than DCA. Therefore, it was concluded that the amount of DCA could not come from further metabolism of TCA alone, which suggests that DCA is predominantly derived from the GSH conjugation pathway (Völkel et al., 1998).

While trichloroethanol (TCOH) has been identified in the urine of workers, it has not been identified in all worker exposure studies (U.S. EPA, 2012c). Therefore, the current conclusion is that the detected TCOH is likely the result of simultaneous exposures to the closely related chemical, trichloroethylene, for which it is the major metabolite.

Irrespective of the route of administration, CYP-mediated oxidative metabolism occurs predominantly in the liver, but some oxidative metabolism does occur at other sites, for example CYP2E1 is expressed in the rat kidney. And CYP enzymes occur in other extrahepatic tissues as well. While there are too few studies on the relative roles of the CYP isoforms and the chemical-specific data are sparse, CYP2E1 is presumed to have an important role in tetrachloroethylene metabolism. Variability in CYP metabolic

capacity is generally believed to vary by approximately 10-fold among all humans, however, individual variations in *in vitro* CYP2E1 activity as high as 20- to 50-fold have also been reported. There is also large variability in CYP2E1 activity across different tissues. The PBPK model is expected to account for the majority of tissue variability via oral or inhalation routes.

Glutathione Conjugation Pathway

The metabolites of the glutathione pathway are associated with PCE nephrotoxicity (U.S. EPA, 2012c). For the glutathione conjugation pathway, PCE is first conjugated to GSH to form S-(1,2,2-trichlorovinyl) glutathione (TCVG). This reaction predominantly occurs in the liver (Lash and Parker, 2001). TCVG is then further metabolized via a two-step process by gamma-glutamyl transferase (GGT) and cysteinylglycine dipeptidase to generate the cysteine conjugate (TCVC) (Dekant et al., 1986).

In the kidney, β-lyase can cleave TCVC to produce 1,2,2-trichlorovinylthiol which rearranges spontaneously to form a highly reactive thioketene (Lash and Parker, 2001). TCVC may also be oxidized by flavin-containing monoxygenase 3 and cytochrome P450s to form TCVC sulfoxide (TCVCSO) (Lash and Parker, 2001), which has been shown to a more potent nephrotoxicant than TCVC (Elfarra and Krause, 2007). TCVSO can also rearrange to form a reactive thioketene (Lash and Parker, 2001), and therefore, this potent acylating agent can be generated through two pathways. It should be noted that the gene encoding renal β-lyase has been detected in other tissues (*e.g.*, brain) (Alberati-Giani et al., 1995), indicating the potential for local formation of the toxic metabolite; however, it has not yet been demonstrated whether or not TCVC can be a substrate for these other enzymes.

Alternatively, TCVC may be N-acetylated in the kidney to form the mercapturic acid, NAcTCVC (Luo et al., 2019), which is considered to be a detoxification reaction. Like TCVC, NAcTCVC can be oxidized to the corresponding sulfoxide, which may contribute to the nephrotoxic effects.

While the pathway was originally demonstrated only in rodents, it has since been confirmed to exist in humans, although the relative susceptibility of humans for TCVG production compared to rodents is unclear. There is also a lot of uncertainty regarding the contribution of the glutathione conjugation pathway to PCE metabolism, in part, due to the potential for the reactive metabolites of PCE to bind to cellular macromolecules (Cichocki et al., 2016). A more recent study by Luo et al. (2018a) found that, following equimolar treatment with TCE or PCE, the metabolic flux through the glutathione conjugation pathway in mice was 21-fold higher for PCE than for TCE, indicating that the glutathione conjugation pathway may be responsible for a greater proportion of metabolism for PCE compared to TCE. Overall, the importance of the glutathione conjugation pathway is uncertain.

Species Differences

Oxidative metabolism occurs at a faster rate and to a greater overall extent in rodents compared to humans. The half-life of these metabolites is significantly longer for humans (144 hrs in humans vs 10 hrs or less in rodents), which is thought the result of the long residence time in adipose tissue, with continued metabolic conversion of parent compound as it is released from adipose tissue.
which is an important information to consider when selecting dose metrics for PBPK modeling. TCA is the major oxidative metabolite produced in both rats and humans and is detected in urine. It is detected at much higher blood concentrations (3- to 8-fold) in rats with a much faster half-life (> 4-fold).

Species- and sex-related differences in the activities of β-lyase and other enzymes in the glutathione pathway may explain the sex- and species-specific renal carcinogenicity of PCE. As noted earlier, metabolic differences among strains resulted in at least 29-fold differences in AUC estimates for TCVG,

TCVC, and NAcTCVC in the kidneys of male mice of 45 strains exposed to PCE (Luo et al., 2019). There is also general positive epidemiological evidence (not kidney-specific) of genotoxicity from chronic PCE exposure in humans (Section 3.2.3.2.1).

Additional tissue and MOA-specific details on PCE metabolites are also provided in the Mode of Action section, Section 3.2.3.3

3.2.2.1.4 Elimination

PCE is primarily eliminated through pulmonary excretion of the parent compound independent of exposure route. Urinary excretion is the primary route for metabolites, although metabolites are also excreted through the lungs as a minor pathway. Half-life of PCE from blood-rich tissues, muscle, and adipose tissue is 12-16 hours, 30-40 hours, and 55-65 hours, respectively. In rodents, as body burden increases the percentage excreted as unchanged parent compound also increases (due to decreased metabolism, see Section 3.2.2.1.3). Pulmonary excretion rate is dose-independent, related instead to ventilation rate, cardiac output, and the relative solubility of PCE in blood and tissue. In contrast, contrast, urinary excretion of metabolites is dose-dependent and rate-limited.

3.2.2.2 Physiologically-Based Pharmacokinetic (PBPK) Modeling

Given the complicated metabolic profile of PCE, understanding the relationship between the external dose/concentration (*i.e.*, exposure) and internal dose at the target organ of interest is critical to quantifying potential risk(s) because internal dose is more closely associated with toxicity at the target tissue (U.S. EPA, 2006a). Predictions of internal dose in chemical risk assessments for a given external applied dose/concentration are achieved by employing physiologically based pharmacokinetic (PBPK) modeling.

PBPK models use a series of mathematical representations to describe the absorption, distribution, metabolism and excretion (ADME) of a chemical and its metabolites. Because PBPK modeling assumes that the toxic effects in the target tissue are closely related to the internal dose of the biologically active form of the chemical, knowledge about the chemical's mode of action guides the selection of the appropriate dose metric. Traditional risk estimates based on applied dose carry higher uncertainties than those based on PBPK-derived internal dose metrics because they do not account for the toxicokinetics of the chemical, which are both dose and time-dependent. This reduction in uncertainty and the versatility of PBPK approaches have resulted in a growing interest to use these models in risk assessment products (U.S. EPA, 2006a).

The 2012 EPA IRIS Assessment (U.S. EPA, 2012d) contains a PBPK model for PCE, which is based on the most recent analysis by Chiu and Ginsberg (2011a), an improvement on several earlier models. EPA has made the model code available for download through EPA's HERO database (Chiu and Ginsberg, 2011b), which also includes a link a zip file of all model files submitted as a public comment to the docket (https://www.regulations.gov/document?D=EPA-HQ-OPPT-2019-0502-0049). The model structure and parameters are shown in Figure 3-3. Full input parameters are provided in Appendix I.

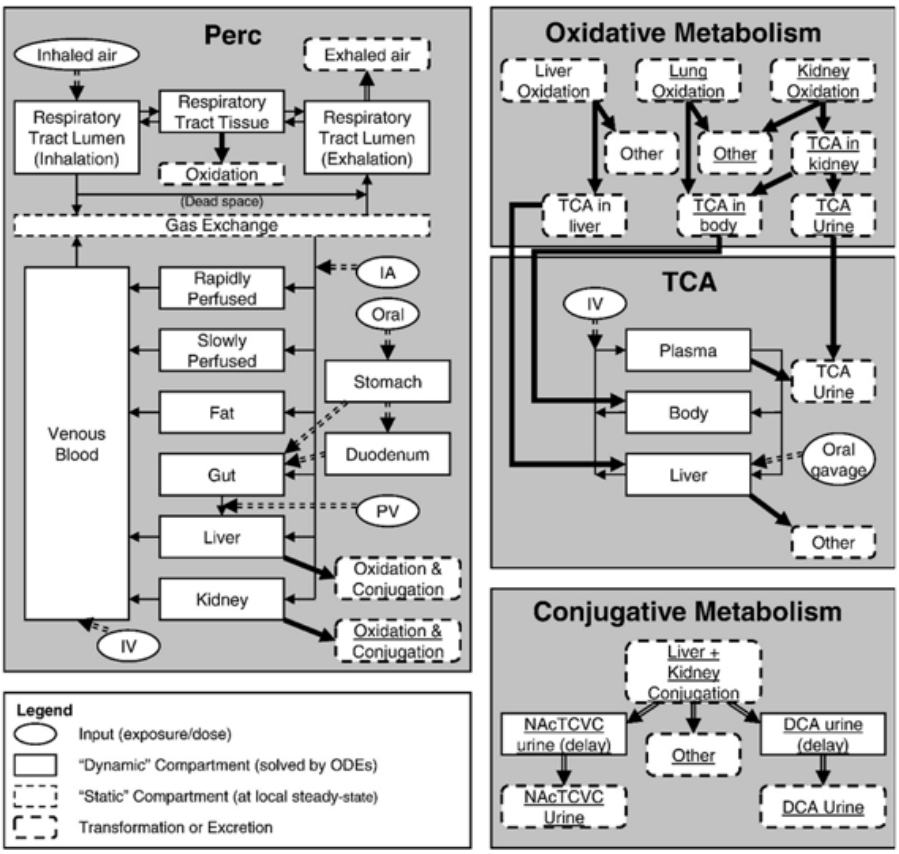


Figure 3-3. The structure of physiologically based pharmacokinetic (PBPK) model developed by Chiu and Ginsberg (2011a) for tetrachloroethylene and metabolites.

The model structure allowed it to be used to calculate internal dose metrics for inhaled and oral exposure to PCE for mice, rats, and humans (the model does not contain a dermal compartment). Thus, the analysis could be used for route-to-route extrapolation or interspecies extrapolation, comparison of parent and metabolite toxicity based on a common internal dose metric, and investigation of the shape of the dose-response curve. The following dose metrics were determined using this model based on continuous exposures (10 weeks for rodents, 100 weeks for humans) across several orders of magnitude of oral and inhalation doses/concentrations:

- Daily area-under-the-curve (AUC) of PCE in blood
- Fraction of PCE intake metabolized by oxidation (as fraction of intake)
- Fraction of PCE intake metabolized by GSH conjugation (as fraction of intake)
- Equivalent daily production of TCA per kg body weight.

Of note, a full Bayesian uncertainty/variability analysis was not performed, and instead Markov chain Monte Carlo (MCMC) was used as a stochastic optimization algorithm in a maximum likelihood estimation (MLE) context. Therefore, the model could not be used to represent the range of intraspecies human variability and was of limited utility for human studies not requiring route-to-route extrapolation. As stated in Chiu and Ginsberg (2011a), the analysis was intended as an intermediate approach that was considered better than the use of traditional optimization routines, which have difficulty with more than a few parameters being optimized simultaneously and which are no better at evaluating global versus local maxima. In lieu of a Bayesian analysis, the procedure for the PBPK model can be summarized as follows:

- Make an initial guess at the values of the unknown parameters

- Run an optimization algorithm (that is known to converge theoretically) to obtain the MLE of the unknown parameters
- Repeat steps 1-2 multiple times at different initial guesses for the unknown parameters
- Use the highest likelihood values in a deterministic setting, while keeping the other "local maxima" as a measure of uncertainty.

For this final Risk Evaluation, EPA re-ran multiple chains of the original human model for up to 80,000 iterations (as opposed to the 5,000 per chain in Chiu and Ginsberg (2011a)), and found that the resulting overall MLE parameters differed by 0.7%-28% and the dose metric predictions differed by 0%-3.9%, as compared to those obtained by Chiu and Ginsberg (2011a). Therefore, results of the model are reliable with minimal uncertainty around the dose metric estimates.

The dose metric with the highest confidence is AUC in blood, with the main source of uncertainty for the metric being the residual difference between model predictions and the calibration/validation data (about 2-fold for each species). The next highest confidence is for estimates of PCE oxidation and TCA formation, again with approximately a 2-fold residual difference between predictions and data. There is large interindividual variability in PCE oxidation that is not captured by the model in the absence of a Bayesian analysis. The model predicts decreasing oxidative metabolism from mice to rats to humans, meaning that humans are predicted to receive a smaller internal dose of oxidative metabolites and a larger internal dose of parent compound for the same applied dose compared to rodents, after accounting for body weight scaling. For cross-species extrapolation, the default assumption of equivalent air concentrations leading to equivalent internal doses appears correct based on AUC estimates (2011a).

There is greater uncertainty for estimates of GSH conjugation, especially in humans. The calibration data used by Chiu and Ginsberg (2011a) suggests an approximate 2-fold range of uncertainty in rats, however there is minimal available data in mice leading to a ~60-fold range in that species. The human estimates are extremely uncertain, with two local maxima in the model fits resulting in model predictions differing by up to 3,000-fold based on results of different optimization runs. Due to this very broad uncertainty range, the model can result in humans having either equal or greater GSH conjugation compared to rats, for which only ~1% of dosed PCE undergoes GSH metabolism (2011a).

Several steps were needed to derive the PBPK-derived HECs used in this assessment. First, the rodent PBPK model was run to estimate rodent internal doses (for rodent toxicity studies) for the applied doses in a study based on the selected dose metric. The internal dose POD is then obtained either directly from the internal dose corresponding to the applied dose LOAEL/NOAEL, or by BMD modeling of responses based on internal doses. Separately, the human PBPK model was run to establish the relationship between human exposure air levels and internal dose for the same dose-metric evaluated in the rodent PBPK model. This relationship was used to derive Human Equivalent Concentrations (HECs) and Human Equivalent Doses (HEDs) corresponding to the internal dose POD by interpolation.

3.2.3 Hazard Identification

3.2.3.1 Non-Cancer Hazards

The 2012 EPA IRIS Assessment (U.S. EPA, 2012c) evaluated the following non-cancer hazards that may be associated with PCE exposures: acute toxicity and irritation, central nervous system effects (neurotoxicity), kidney toxicity, liver toxicity, immune and hematological toxicity, reproductive toxicity, and developmental toxicity. In general, neurological effects were found across many studies to be associated with lower PCE inhalation exposures than those associated with other noncancer adverse

effects. According to the 2012 EPA IRIS Assessment (U.S. EPA, 2012c), support for an association with immune and blood effects were less well characterized. In their Toxicological Profile for PCE, ATSDR (2019) identified similar hazard concerns. The National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances (U.S. EPA, 2009) also identified irritation as a hazard concern. Since the EPA IRIS Assessment, 13 new studies were identified and evaluated during the systematic review process. These new studies add further evidence to support the conclusions established in the EPA IRIS (U.S. EPA, 2012c) and ATSDR assessments (ATSDR, 2019).

3.2.3.1.1 Acute Toxicity and Irritation

Data from acute exposure studies in animals and human incidents indicate that short term exposure to PCE may cause irritation and neurotoxicity and can impair cognitive function in humans (U.S. EPA, 2012c). An Acute Exposure Guidance Limit (AEGL) values, established by the National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances (U.S. EPA, 2009), has been developed based on irritation to humans (AEGL-1), ataxia in rodents (AEGL-2), and lethality in mice (AEGL-3) (U.S. EPA, 2009). Epidemiological studies since the EPA IRIS Assessment (U.S. EPA, 2012c) focused on chronic exposures.

There is sufficient evidence from controlled human exposure studies that acute-duration (≤ 24 hours) inhalation exposure to PCE induces symptoms of CNS depression and prolonged visual evoked potential latencies ((Stewart et al., 1977; Stewart et al., 1970; Stewart et al., 1961; Rowe et al., 1952; Carpenter, 1937) as cited in (ATSDR, 2019; U.S. EPA, 2012c, 2009; Altmann et al., 1990; Hake and Stewart, 1977)). While more limited, case reports show that CNS depression (including coma/ unconsciousness at sufficiently high doses) also occurs in humans after oral exposure to PCE ((Koppel et al., 1985; Haerer and Udelman, 1964; Sandground, 1941; Wright et al., 1937; Kendrick, 1929) as cited in (ATSDR, 2019)). Sufficient information in acute-duration studies in animals exposed by inhalation or oral gavage also shows CNS depression ((Moser et al., 1995; NTP, 1986; Dow Chem, 1984b, 1983c; Goldberg et al., 1964; Union Carbide, 1962) as cited in (ATSDR, 2019; U.S. EPA, 2009)) as well as reduced amplitude of visual evoked potentials, impaired sustained attention, prolongation of escape-directed behaviors after inhalation exposure ((Boyes et al., 2009; Oshiro et al., 2008; De Ceaurriz et al., 1983) as cited in (ATSDR, 2019; U.S. EPA, 2012c)) and reduce operant response behavior or increased seizure threshold ((Chen et al., 2002b; Warren et al., 1996) as cited in (ATSDR, 2019)) after oral exposure.

Human controlled-exposure studies and case reports demonstrated concentration-related increases in the incidence and severity of eye and upper respiratory tract irritation ((Rowe et al., 1952; Carpenter, 1937) as cited in (ATSDR, 2019; U.S. EPA, 2009)). There are also reports of greater excitement and struggling in beagle dogs exposed to PCE by facemask ((Reinhardt et al., 1973)as cited in (ATSDR, 2019)), however this is not adequate evidence to indicate an association with respiratory tract irritation in animals.

Data pertaining to hepatic effects in humans exposed acutely to PCE consist of only a single case report ((Bagnell and Ellenberger, 1977) as cited in (U.S. EPA, 2012c)). Dose-related hepatic effects following acute gavage administration to mice including increased serum ALT, fatty degeneration and necrosis, and cytoplasmic vacuolation ((Philip et al., 2007) as cited in (ATSDR, 2019)).

3.2.3.1.2 Neurotoxicity

The neurological effects of PCE in humans have been extensively studied. Findings in humans are supported by a more limited number of animal studies. The EPA IRIS Toxicological Review for PCE (U.S. EPA, 2012c) provides the basis for the information below from studies published up to that time;

more recent studies are also discussed. The review performed by EPA IRIS (U.S. EPA, 2012c) identified visual deficits in human studies, especially diminished color discrimination, as the most sensitive endpoint of PCE exposure. With one exception, newer human studies have not materially added to the database of PCE effects on visual function; instead, these studies have focused on symptoms of neurotoxicity (Lucas et al., 2015), risks of neurodegenerative diseases (Bove et al., 2014b; Goldman et al., 2012), risks of autism spectrum disorder (Aschengrau et al., 2016a; Aschengrau et al., 2011) or risky behaviors and head injuries (Aschengrau et al., 2016a; Aschengrau et al., 2011) after prenatal or early childhood exposure. One study published since the 2012 IRIS Assessment (U.S. EPA, 2012c) assessed visual function of a residential population exposed to PCE in contaminated drinking water (Getz et al., 2012). There have been no oral or inhalation repeated-exposure animal studies published after the IRIS Assessment (U.S. EPA, 2012c) that evaluated sensitive neurological endpoints.

Human Evidence

Visual Function

Human studies have documented an association between impairments in visual contrast sensitivity and color discrimination and PCE exposure in both occupational and residential settings ((Storm et al., 2011; Sharanjeet-Kaur et al., 2004; Schreiber et al., 2002; Gobba et al., 1998; Cavalleri et al., 1994; Nakatsuka et al., 1992) as cited in (U.S. EPA, 2012c)). Cavalleri et al. (1994) and Gobba et al. (1998), inform the relationship between impaired color discrimination and PCE exposure. Cavalleri et al. (1994) observed a significant positive correlation between time-weighted average concentrations of PCE and the Color Confusion Index (CCI) score on the Lanthony D-15 desaturated panel test among dry cleaning workers in Italy. The 35 workers made many more mistakes in the color vision test when compared with 35 unexposed factory workers, with most errors occurring in the blue-yellow range. Exposure to PCE was measured using passive personal air sampling, yielding a time-weighted (8-hour) average concentration of 6 ppm (41 mg/m^3) for the workers; the mean exposure duration was 8.8 years. Vision testing was performed at the same time of day for workers and controls by an investigator who was blinded to exposure status. When tested two years later, color visual impairment was again significantly associated with exposure concentration among the workers; furthermore, those workers whose exposure to PCE had increased in the two-year interim exhibited a decline in performance from the initial testing, while performance was unchanged among those whose exposure decreased (Gobba et al., 1998). Schreiber at al. (2002) reported diminished color discrimination or visual contrast sensitivity compared with unexposed referent groups among small groups of children and adults living or working in a building with a co-located dry cleaning establishment. EPA IRIS (U.S. EPA, 2012c) identified potential confounders in this study, including diagnoses of learning or developmental delays among some of the exposed children, and correlations between exposure and children's ages and races.

Only one study published after the EPA IRIS Toxicological Review (U.S. EPA, 2012c) examined visual function in humans exposed to PCE. Getz et al. (2012) measured color vision and visual contrast sensitivity among adult residents of Cape Cod, MA who were exposed prenatally and during early childhood to PCE-contaminated drinking water. Tests administered to the 25 exposed and 25 unexposed subjects included the Farnsworth D-15 and Lanthony D-15d for color discrimination, as well as tests of near acuity and near contrast sensitivity. The investigator who administered the tests was blinded to exposure status. A statistically significant difference in color discrimination was detected using the Farnsworth test (mean difference 0.05, 95% CI = 0.003, 0.10), but the difference observed in the Lanthony D-15d test was not statistically significant (mean difference 0.07, 95% CI = –0.02, 0.15). Contrast sensitivity at the highest spatial frequency test (18.0 cpd) was also diminished (mean difference –6.47; 95% CI = –12.33, –0.62).

Cognition

Several occupational studies of dry cleaning employees, as well as one study of individuals residing near dry cleaning facilities, have documented relationships between PCE exposure and adverse effects on visuospatial memory, attention, vigilance, and information processing speed ((Altmann et al., 1995; Echeverria et al., 1995; Echeverria et al., 1994; Seeber, 1989) as cited in (U.S. EPA, 2012c)). In one key study, a cohort of 65 dry cleaning workers in Michigan, high PCE exposure (TWA of 41 ppm or 278 mg/m^3) was associated with statistically significantly ($p<0.01$) reduced scores for pattern recognition, pattern memory, and visual reproduction tests (compared with low exposure workers whose mean exposure was 11 ppm or 75 mg/m^3 (Echeverria et al., 1995). The investigations by Echeverria et al. provided more robust evidence for the findings of Seeber et al. (1989), who reported dose-related, statistically significant effects on the threshold for perceptual speed test, digit reproduction, digit symbol, and cancellations among 101 German dry cleaning employees with low (8-hr TWA 12 ppm or 81 mg/m^3) or high (8-hr TWA 53 ppm or 359 mg/m^3) exposure to PCE (compared with 84 unexposed controls). Of note, EPA identified several shortcomings in this study, including lack of detail on methods used to select subjects, missing information related to testing procedures, differences in alcohol use between exposed and control subjects that were not accounted for in the models, and nonmonotonic dose-response relationships with some test scores. PCE exposure may also be associated with an increase in reaction time, as reported in a study of dry cleaners (Ferroni et al., 1992).

Neurodegenerative diseases

Goldman et al. (2012) examined the association between Parkinson's disease and exposure to solvents (including PCE) among discordant twin pairs. In the cohort of 99 twin pairs, each had only one twin diagnosed with the disease. The association between Parkinson's disease and self-reported PCE exposure (ever exposed) was not statistically significant and highly unstable (OR: 10.5; 95% CI = 0.97, 113). Evaluation of each twin's cumulative PCE exposure did not materially change the findings.

In a retrospective cohort mortality study, Bove et al. (2014b) reported a nonsignificant SMR for mortality due to ALS (Amyotrophic Lateral Sclerosis; SMR = 1.14; 95% CI = 0.70, 1.74) among PCE-exposed military personnel at Camp LeJeune (North Carolina) when compared with age, sex, race, and calendar period-specific national mortality rates. The hazard ratio for ALS mortality increased with cumulative PCE exposure category (HRs of 0.69, 1.58, and 1.96 for low [>1-155 ug/L-months], medium [>155 – 380 ug/L-months], and high [>380 ug/L-months] exposures, respectively) in analyses restricted to the Camp LeJeune cohort. A nonsignificant ($p=0.06$) association ($\beta = 0.00039$, 95% CI = -0.00002, 0.00080) was observed between cumulative PCE exposure (as a continuous variable) and ALS mortality in the cohort.

Neurodevelopment

Aschengrau et al. (2016a; 2011) conducted a series of studies examining neurological outcomes of early life (prenatal and early childhood) exposure to drinking water contaminated by PCE (cumulative exposures ranging from 11 to 4668 g). Individuals residing in Cape Cod, MA were exposed to PCE leaching from water distribution pipes; a model was used to estimate individual exposures to each residence from leaching. In analyses of 831 persons with prenatal and early childhood exposure compared with 547 unexposed subjects, any exposure to PCE was associated with statistically significant increased risks of engaging in risky behaviors (Aschengrau et al., 2016a). Analyses included adjustment for demographic characteristics, key risk factors for the behavioral and health outcomes under study, and non-drinking water sources of solvent exposure. Odds ratios for use of more than one major illicit drug (crack/cocaine, psychedelics, heroin, Ritalin without a prescription, and club/designer drugs) in the highest exposure groups were 1.6 (95% CI = 1.2, 2.2) for use during adolescence and 1.5

(95% CI = 1.2, 1.9) for use during adulthood. Early and heavy smoking, and frequent or heavy drinking behaviors were also increased among highly exposed subjects (ORs 1.3-1.6, with statistically significantly increased Ors for drinking, but not smoking patterns). In the same population, a significant increased risk was observed for development of bipolar disorder among highly exposed (≥ 67th percentile) subjects (RR = 2.7, 95% CI = 1.3, 5.6). Non-significant RRs were reported for post-traumatic stress disorder (1.7; 95% CI = 0.9, 3.2 for exposure ≥ 67th percentile) and schizophrenia (2.1; 95% CI = 0.2, 20.0) for any vs. no exposure, based on 3 cases; (Aschengrau et al., 2016a).

Neuropsychological findings in a subset of the Aschengrau et al. cohort (35 exposed and 28 unexposed adults, (Aschengrau et al., 2016a) who were willing to undergo testing showed nonsignificant mean differences of -0.2 or -0.3 in performance on tests for visuospatial function, learning and memory, mood alteration, and attention and executive function. The mean difference for motor functioning (measured in the finger tapping test) was -1.8, also not statistically significant. Other studies within the cohort evaluated whether PCE exposure was associated with altered brain MRI findings in a subset of the cohort (26 exposed and 16 unexposed adult subjects). There were no significant differences in MRI findings (*e.g.*, white and gray matter volumes and white matter hypointensities) between the groups. Postulating that neurological sequelae of early PCE exposure could increase the likelihood of unintentional head injuries, Aschengrau et al. (2016b) evaluated the frequency of self-reported head injuries among members of the cohort (828 exposed and 544 unexposed). No increase in the risk of head injuries was observed for any exposure, or in the highest exposure group (RRs 0.8-1.0).

Stingone et al. (2016) evaluated the relationship between standardized test scores in math and English language arts among 3rd graders in New York City schools and modeled air concentrations of PCE (median concentration 0.68 µg/m3) and diesel particulate matter from EPA's National Air Toxics Assessment (NATA) in 1996 (assessment closest to the children's birth years) to correspond with the mothers address at time of birth. In analyses of English language arts test results, prenatal PCE exposure was associated with decreased test scores only in the upper tail of the distribution of test scores (75th quantile and above); there was no association with failure to meet test standards. Due to the use of an exposure model based on census tract data and uncertainties surrounding the actual location of mothers during pregnancy, there was potential for exposure misclassification.

Four case-control studies of autism spectrum disorders (ASD) and prenatal exposure to hazardous air pollutants, including PCE, were identified in the literature searches (Talbott et al., 2015; von Ehrenstein et al., 2014; Roberts et al., 2013; Kalkbrenner et al., 2010). Three of the studies used modeled air concentrations of toxicants at the place of maternal or birth residence based on EPA's NATA, while von Ehrenstein et al. (2014) used measured air concentrations from monitoring stations within 5 km of the subjects' residences (Los Angeles County CA). Two studies (Roberts et al., 2013) and (von Ehrenstein et al., 2014) reported significant positive associations between the odds of ASD and PCE exposure. Roberts et al. (2013) reported an OR of 1.60 (95% CI = 1.07, 2.41) comparing the highest to lowest quintiles of PCE exposure in a case-control study nested within the Nurses' Health Study II. In the study by von Ehrenstein et al. (2014), significantly increased ORs were observed for an interquartile range increase in exposure concentration across pregnancy (OR = 1.40, 95% CI = 1.09, 1.80 for stations within 5 km of the residence and OR =1.61, 95% CI = 1.14, 2.26 for stations within 3.5 km). Stratification by ASD severity and by gender showed stronger associations for milder ASD and in males. Kalkbrenner et al. (2010) and Talbott et al. (2015) did not report significant associations between ASD and PCE exposure in case control studies in NC and WV or PA (respectively).

Clinical Signs of Neurotoxicity
Lucas et al. (2015) observed no significant differences ($p \geq 0.01$) in the prevalence of self-reported symptoms of neurotoxicity (*e.g.*, fatigue at end of day, difficulty sleeping) when comparing 50 dry cleaning workers with exposure to PCE with symptoms reported by 95 workers who were not exposed. The median airborne concentration of PCE was 7 ppm (47 mg/m^3) (range 0.22-33 ppm) in the dry cleaning establishments, and workers had blood levels of PCE ranging between 11.8 and 544 µg/L (median 73.6 µg/L).

Animal Evidence
Animal studies provide support for the effects seen in humans, but the database is much more limited. Effects recorded in studies of rats, mice, and gerbils include clinical signs of neurotoxicity, neurophysiological changes, and alterations in brain chemistry or brain weight ((Chen et al., 2002a; Jonker et al., 1996; Tinston, 1994; Kjellstrand et al., 1984) as cited in (ATSDR, 2019; U.S. EPA, 2012c)). Other studies reported decreases in brain fatty acid and DNA content, alterations in taurine and glutamine content, and decreased brain weight in gerbils and impaired nociception in rats ((Karlsson et al., 1987; Kyrklund et al., 1987; Briving et al., 1986; Rosengren et al., 1986; Kyrklund et al., 1984) as cited in (U.S. EPA, 2012c)).

Limited information is reasonably available on developmental neurotoxicity in animals exposed to PCE, however existing data suggests that gestational exposure can impair neurobehavior, motor performance, and neurotransmitter signaling ((Szakmáry et al., 1997; Tinston, 1994; Fredriksson et al., 1993; Nelson et al., 1979) as cited in (U.S. EPA, 2012c)).

No studies examining sensitive neurological endpoints in adult animals were published after the EPA IRIS Toxicological Review (U.S. EPA, 2012c). No clinical signs of neurotoxicity were noted in female Sprague-Dawley rats exposed to PCE concentrations up to 1000 ppm (6783 mg/m^3) for four weeks in a study focused on immunotoxicity (Boverhof et al., 2013).

3.2.3.1.3 Kidney Toxicity
Human Evidence
Most of the available epidemiological studies, conducted in populations of dry cleaning workers, examined markers of kidney toxicity without including standard tests for kidney function ((Trevisan et al., 2000; Verplanke et al., 1999; Solet and Robins, 1991; Vyskocil et al., 1990; Franchini et al., 1983; Lauwerys et al., 1983) as cited in (U.S. EPA, 2012c; Mutti et al., 1992)). Based on the observed increases in urinary RBP, β2-glucuronidase, lysozyme, and glutamine synthetase, EPA believes that PCE has its primary effect on the proximal tubules, as these are markers of proximal tubular injury. Other markers of tubular injury, including N-acetyl glucuronidase (NAG) and alanine aminopeptidase (AAP) were not associated with exposure (U.S. EPA, 2012c), however NAG is a relatively insensitive measure of tubular dysfunction, and AAP was assessed in only one study. One epidemiological study published after the EPA IRIS Toxicological Review (U.S. EPA, 2012c) examined non-cancer renal toxicity and found that PCE was not significantly associated with chronic renal diseases (Silver et al., 2014).

Animal Evidence
Animals exposed to PCE by inhalation exhibit renal effects such as increased kidney weights, and tubular histopathology (ATSDR, 2019; U.S. EPA, 2012c). Effects have been reported in both male and female rats and male and female mice. In a multigeneration study of Alpk:APfSD rats exposed for ~19 weeks, renal effects including minimal chronic progressive glomerulonephropathy and increased pleomorphism in proximal tubular nuclei were seen at 1,000 ppm (6,783 mg/m^3; the highest

concentration tested) (Tinston, 1994). With two years of exposure to 200 ppm (1,357 mg/m^3), male and female rats showed increased relative kidney weights and karyomegaly of the proximal tubules (Jisa, 1993; NTP, 1986b). In a four-week immunotoxicity study published after the EPA IRIS Toxicological Review (U.S. EPA, 2012c), no changes in kidney weight or histology were observed in female Sprague-Dawley rats exposed by whole-body inhalation to PCE concentrations up to 1,000 ppm (6,783 mg/m^3; (Boverhof et al., 2013)).

Mice exposed to 609 ppm (4,131 mg/m^3) for 13 weeks exhibited histopathology changes (not further described) in the proximal tubules; at 200 ppm (1,357 mg/m^3) for 13 weeks, karyomegaly of the renal tubular epithelial cells was observed (Jisa, 1993; NTP, 1986b). Chronic (2 years) inhalation exposure resulted in nephrosis (karyomegaly and cytomegaly of the proximal tubules) in both sexes of B6C3F1 mice exposed to 100 ppm (678 mg/m^3; the lowest concentration tested) (NTP, 1986b) and karyomegaly with atypical dilation of the proximal tubules in male and female hybrid mice exposed to 250 ppm (1,696 mg/m^3; (Jisa, 1993).

After 78 weeks of exposure to doses ≥ 386 mg/kg-day (mice) or ≥ 475 mg/kg-day (rats) administered by gavage in corn oil, both sexes of Osborne-Mendel rats and B6C3F1 mice exhibited toxic nephropathy, with higher incidences in rats than mice (Nci, 1977). Mixed evidence including both positive and negative findings for signs of kidney toxicity were observed in other mice studies ((Philip et al., 2007; Ebrahim et al., 2001; Ebrahim et al., 1996; Green et al., 1990) as cited in (U.S. EPA, 2012c)), while increased kidney weight, urinary markers of damage, and histopathology was reported in rats ((Jonker et al., 1996; Hayes et al., 1986) as cited in (U.S. EPA, 2012c)).

A group of studies in F344 rats showed accumulation of α2u-globulin and hyaline droplets in the proximal tubules of male rats exposed to PCE by gavage in corn oil for 10 days to four weeks ((Bergamaschi et al., 1992; Green et al., 1990; Goldsworthy et al., 1988; Goldsworthy and Popp, 1987) as cited in (U.S. EPA, 2012c)). These changes were correlated with cell proliferation, formation of granular tubular casts, and tubular cell regeneration, suggesting the involvement of male rat-specific α2u-globulin accumulation in the mode of action for some renal effects of PCE. However, the kidney effects seen in female rats and in mice of both sexes show that other mechanisms (*e.g.*, peroxisome proliferation and/or cytotoxicity mediated by reactive metabolites produced from glutathione conjugation in the kidney; see Section 3.2.3.3) also play a role in the renal toxicity of this compound.

3.2.3.1.4 Liver Toxicity

Human Evidence

There is limited information on the hepatic effects of PCE in humans, with conflicting evidence across several occupational studies of dry cleaning workers. Sonographic changes in the liver and alterations in hepatic enzyme levels in serum (compared with unexposed workers) were noted in two studies of dry cleaners with exposure to PCE; however other studies noted no differences in enzyme levels ((Brodkin et al., 1995; Gennari et al., 1992; Cai et al., 1991; Lauwerys et al., 1983) as cited in (U.S. EPA, 2012c)). Exposure levels in the negative studies were comparable to those in the ones reporting effects, but workers in the studies reporting effects had been exposed for much longer (12-20 yrs vs. 3-6 yrs in negative studies). In Silver et al. (2014), the only human study of PCE published after EPA IRIS (U.S. EPA, 2012c) that examined noncancer liver effects, there was a statistically significant deficit of cirrhosis and chronic liver disease in male workers at a microelectronics and business machine facility.

Animal Evidence

Liver toxicity (*i.e.*, necrosis, vacuolation, etc) has been reported in multiple animal species by inhalation and oral exposures to PCE, with the mouse typically being more sensitive than the rat. The liver effects

are characterized by increased liver weight, necrosis, inflammatory cell infiltration, triglyceride increases proliferation, cytoplasmic vacuolation (fatty changes), pigment in cells, oval cell hyperplasia and regenerative cellular foci (U.S. EPA, 2012c).

In mice exposed to PCE by oral gavage, increased serum ALT levels, increased liver weight, hepatocellular hypertrophy, fatty degeneration and necrosis, and regenerative repair/increased DNA synthesis were observed after exposure to doses of 20 – 2,000 mg/kg-day for 6 weeks ((Philip et al., 2007; Buben and O'Flaherty, 1985) as cited in (U.S. EPA, 2012c)). Rats exposed orally to 600 or 2,400 mg/kg-day PCE for 32 days showed increased relative liver weight as well (Jonker et al., 1996). In inhalation studies of PCE, both mice and rats exhibited hepatic effects, but mice appear to be more sensitive. Mice displayed increases in palmitoyl CoA, peroxisome proliferation, mitochondrial proliferation, increased relative weight, centrilobular lipid accumulation/fatty degeneration, and liver necrosis/degeneration ((Odum et al., 1988) as cited in (U.S. EPA, 2012c)). Effects observed in rats were limited to increased liver weight after subchronic exposure and spongiosis hepatis and hyperplasia following chronic exposure (U.S. EPA, 2012c). In rats, increased liver weight was observed after 90 days of continuous exposure, while spongiosis hepatis and hyperplasia were noted to occur at increased incidences after 110 weeks of exposure, while effects in mice after 110 weeks of exposure included increased incidences of angiectasis, central degeneration, and central and focal necrosis ((Kyrklund et al., 1990) as cited in (U.S. EPA, 2012c; Jisa, 1993)).

A four-week inhalation immunotoxicity study in rats (Boverhof et al., 2013) that was published after EPA IRIS (U.S. EPA, 2012c) also reported hepatic effects. Female Sprague-Dawley exposed whole-body to 1,000 ppm (6,783 mg/m^3) exhibited increased relative liver weights (in conjunction with decreased body weight at this exposure level) and an increased incidence of centrilobular hepatocellular hypertrophy. At lower exposure levels, no biologically significant hepatic effects were noted.

3.2.3.1.5 Immune System and Hematological Effects

Immune System Effects

Human evidence

Multiple studies in humans have examined the association between PCE exposure or work in the dry-cleaning industry and immunotoxicity endpoints. Of these, most studies investigated autoimmune diseases, two evaluated asthma in children and four evaluated changes in immune measures.

Autoimmunity. Several studies have identified ORs, RRs or SIRs of > 1 up to 4.07 for various autoimmune diseases and PCE exposure or surrogate measures. These diseases include Sjogren's, sclerosis (three studies), rheumatoid arthritis, undifferentiated connective tissue disease (UCTD) and anti-neutrophil cytoplasmic antibody (ANCA) related disease (Chaigne et al., 2015; Li et al., 2008; Beaudreuil et al., 2005; Garabrant et al., 2003; Lacey et al., 1999; Goldman, 1996; Lundberg et al., 1994). Associations for two studies were statistically significant, with an OR of 2.64 for Sjogren's syndrome associated with semi-quantitative measures of PCE exposure (Chaigne et al., 2015) and increased frequency of sclerosis associated both with self-reported PCE exposure and work in the dry cleaning industry ($p < 0.001$) (Goldman, 1996). Garabrant et al. (2003) evaluated sclerosis in females and identified non-significant ORs of 1.4 when using exposure measures of either dry cleaning employment or self-reported PCE; expert review of the self-reported PCE exposure resulted in an OR of 1.1. Zhao et al. (2016) conducted a meta-analysis of 14 case-control studies (6 with TCE and/or PCE exposure analysis) and identified an OR of 2.03 (not statistically significant) for the association between PCE exposure and systemic sclerosis. Lacey et al. (1999) identified an OR of 1.38 for UCTD for

females after adjustment for age and year of birth. Beaudreuil et al. (2005) calculated an OR of 2.0 for ANCA-related disease. Neither of these ORs were statistically significant.

In studies of rheumatoid arthritis, Li et al. (2008) did not find an association between increased hospitalizations for individuals working in laundering or dry-cleaning in *any* one of three census years (1960, 1970, 1980). In contrast, Lundberg et al. (1994) identified a positive OR (1.5) for females (OR for males: 0.8) working in laundering or dry cleaning for at least 10 years (*i.e.*, as indicated on both 1960 and 1970 censuses). Thus, even though Li et al. (2008) was a larger study, Lundberg et al. (1994) may have been more readily able to detect an effect because they limited the analysis to 10 or more years of exposure. U.S. EPA (2012c) notes that because both studies are based on hospitalization data, they are limited by inability to define the precise time of diagnosis.

Case reports have identified scleroderma and high antinuclear antibodies after PCE exposure or work in dry cleaning (U.S. EPA, 2012c).

Asthma and allergy. Two studies of asthma in children Delfino et al. (2003a); Delfino et al. (2003b) identified ORs from 1.07 to 1.94 based on various exposure measures and models. Delfino et al. (2003b) found that ambient PCE exposure was more positively associated with the outcome (OR: 1.94) than exhaled breath concentrations of PCE (OR: 1.07) in a model that controlled for respiratory infections and temperature. Delfino et al. (2003a) identified an OR of 1.37 [95% CI: 1.09, 1.71]) for asthma symptom score > 1 and PCE, although the association was reduced after adjustment for SO_2 or NO_2. The IRIS assessment also cites case reports of hypersensitivity pneumonitis and chemical sensitivity (U.S. EPA, 2012c).

Among 3-year old children at risk of atopy, Lehmann et al. (2001) identified ORs of 0.6 and 1.8 for PCE exposure (> 75th percentile compared with < 75th percentile PCE concentration in children's bedrooms) and egg white and milk sensitization, respectively. The OR for milk was not statistically significant.

Immune measures. Three of four human studies have identified changes in a variety of immune measures that include Th2 responsiveness/augmentation of allergic responses, phagocytic activity among others. Because autoimmunity can involve mechanisms that are the same as those for allergic reactions and may involve one or more mechanisms working simultaneously (Kaplan et al., 2018), some of these results may also support autoimmunity.

In a case-control study of male dry-cleaning workers in Egypt, Emara et al. (2010) found that workers exposed to PCE had increases in immunoglobulin E (IgE) when compared to a group of healthy males. The authors identified a significant increase in total white blood cell (WBC) counts, total lymphocyte counts, T lymphocytes (CD4+ and CD8+), natural killer (NK; CD3+CD16CD56+) cells, and B (CD19+) lymphocytes. Serum and lymphocytic interlukin-4 levels were significantly increased in PCE-exposed workers. The authors concluded that PCE exposure is associated with immunotoxicity and possible augmentation of allergic diseases or appearance of autoimmune reaction. In contrast, no differences were observed in eosinophils, monocytes, platelets, CD3+ lymphocyte subpopulations or interferon-gamma (IFN-y). No significant increases were observed for IgA, IgM or IgG (Emara et al., 2010).

Andrys et al. (1997) identified higher serum complement C3 and C4 and salivary IgA in female dry cleaners exposed to PCE in the Czech Republic compared with a control group of office workers at the dry-cleaning plant. Compared with the regional reference controls, dry cleaners had reduced T-lymphocytes, higher phagocytic activity and higher C3 levels. Results are difficult to interpret because

differences were also observed between the office workers and reference controls (*e.g.*, decreased T-lymphocytes in office workers). Also, the exposed group was older than the office workers (45.7 vs. 31.9 years), and there was a lack of information regarding the general population reference group (Andrys et al., 1997).

In a prospective cohort study, Lehmann et al. (2002) reported an OR of 2.9 for PCE's association with decreased percent of IFN-y producing type 1 T cells (Th1 cells), adjusted for confounding factors. Significant decreases in the Th1 cytokines IFN-y, tumor necrosis factor-alpha (TNF-alpha) and IL-2 (interleukin-2) were observed when comparing > 75th percentile to < 75th percentile of PCE exposure. There was no effect on IL-4 (Th2). Exposure was measured in the children's bedrooms for 4 weeks after birth, and immune cells and factors were measured in cord blood taken at birth. Reduced ability to produce IFN-y at birth has been associated with an increased risk of developing allergic manifestations later in childhood.

Among 3-year old children at risk of atopy, Lehmann et al. (2001) found no differences in either reduced IFN-y+CD8+T cells or in enhanced IL4+CD3+T cells between < 75th percentile and > 75th percentile PCE exposures, as measured in the children's bedrooms.

Animal evidence

Animal studies have evaluated the association between PCE exposure and autoimmunity, hypersensitivity, immunosuppression and general immune measures and have identified associations with PCE for each type of measure in some (but not all) studies.

Wang et al. (2017) investigated the ability of PCE to induce or exacerbate autoimmunity in female mice. Six-week old mice were treated with PCE for 12, 18 and 24 weeks at 0.5 mg/mL in drinking water, equivalent to approximately 96 mg/kg-bw/day. PCE exposure was associated with significant increases in serum anti-nuclear antibodies (ANA), anti-dsDNA and anti-scleroderma-70 (anti-Scl-70) antibodies at 18 weeks with a greater response at 24 weeks. The dose is equivalent to about 100 ppm in air, which is the PEL. Splenocytes from 18 and 24 weeks stimulated with MDS-mouse serum albumin resulted in increased Th17 cell proliferation and increased IL-17 production compared with controls. The authors also identified decreased antioxidants GSH (all weeks) and SOD (18 and 24 weeks). The authors concluded the PCE exposure exacerbated autoimmunity.

Aranyi et al. (1986) identified increased deaths from *Streptococcus zooepidemicus* challenge and decreased bacteriocidal activity of alveolar macrophages to *Klebsiella pneumonia* among female mice at 50 ppm in air for 1 or 5 exposures of 3 hours each. No effects were observed at 25 ppm in air (Boverhof et al., 2013).

Boverhof et al. (2013) did not observe immunotoxicity in female Sprague-Dawley rats (16/group) exposed whole-body to PCE concentrations up to 1,000 ppm (6,783 mg/m^3) for 4 weeks (6 hours/day, 5 days/week). Specifically, there were no treatment-related changes in immune reaction in the sheep red blood cell (sRBC) antigen assay so immunosuppression was not observed.

Schlichting et al. (1992) did not identify changes in immune cell viability, T or B lymphocyte proliferation or natural killer or cytotoxic activity in splenocytes or liver immune cells after intraperitoneal administration to male mice and rats. However, more general changes in immune-related organs and cells have been identified. In male mice, WBCs were increased by 42% after 15 days of oral exposure (LOAEL of 300 mg/kg-bw/day) (Ebrahim et al., 2001). Furthermore, female mice exhibited

decreased WBCs at 7.5 and 11.5 weeks after inhalation of PCE (135 and 270 ppm, respectively) (Seidel et al., 1992).

In rats, spleen and thymus weights were significantly atrophied ($p < 0.001$ and $p < 0.01$, respectively) at 2,000 mg/kg-bw/day after 5 days of exposure but not at 1,000 mg/kg-bw/day up to 14 days (Berman et al., 1995; Hanioka et al., 1995). Boverhof et al. (2013) found no changes in spleen or thymus weight or histology, WBC differential cell distribution in bronchoalveolar lavage fluid or numbers of spleen cells in female rats exposed to 1,000 ppm PCE via inhalation for up to four weeks.

Hematological Effects

Human evidence

Emara et al. (2010) identified decreased erythrocyte counts and hemoglobin in PCE-exposed dry-cleaning workers. The study did not identify any differences in mean corpuscular volume, mean corpuscular hemoglobin of mean corpuscular hemoglobin concentration. No other human studies were found that evaluated these types of hematological parameters or anemia.

Animal evidence

Studies in mice have shown diminished erythropoiesis and anemia (U.S. EPA, 2012c). Marth (1987)and Marth et al. (Marth et al., 1989; Marth et al., 1985a; Marth et al., 1985b), as cited in U.S. EPA (2012c) exposed 135 female NMRI mice to 0.05 or 0.1 mg/kg PCE per day in drinking water for 7 weeks and examined them at 8 or 16 weeks after exposure ended. Mice exhibited reversible hemolytic anemia and microscopic changes in the spleen (Marth et al., 1985a; Marth et al., 1985b). The erythropoietic system was more sensitive than the brain, liver or kidney to PCE exposure in these studies (U.S. EPA, 2012c).

Seidel et al. (1992) exposed female mice to PCE at 270 ppm (11.5 weeks) and 135 ppm (7.5 weeks), 6 hours/day, 5 days/week. Mice exhibited decreases in erythroid colony-forming units, erythroid burst-forming units and increased number of reticulocytes, with partial regeneration three weeks after exposure ceased. These data indicate that PCE is associated with reversible bone marrow depression. Another study, (Ebrahim et al., 2001), evaluated hematological parameters after oral administration of PCE (3,000 mg/kg-day) for 15 days in male mice and found significantly decreased hemoglobin and RBC counts ($p < 0.01$) as well as significantly decreased hematocrit (packed cell volume) and platelet counts ($p < 0.001$). When 2-deoxy-D-glucose (2DG; 500 mg/kg-day i.p.), vitamin E (400 mg/kg-day oral gavage) or taurine (100 mg/kg-day by oral intubation) were administered concurrently with PCE, these hematological parameters reverted almost to near normal (Ebrahim et al., 2001).

In contrast to the mouse studies, hematologic effects were not reported in rat studies reviewed by EPA IRIS (U.S. EPA, 2012c). Furthermore, in the 4-week rat study by Boverhof et al. (2013), no exposure-related changes to hematological parameters were observed at exposure concentrations up to 1,000 ppm (6,800 mg/m^3).

3.2.3.1.6 Reproductive Toxicity

Human Evidence

Studies of PCE exposure in humans have evaluated several reproductive outcomes including effects on menstrual disorders, semen quality, fertility, time to pregnancy, and risk of adverse pregnancy outcomes including spontaneous abortion, low birth weight or gestational age, birth anomalies, and stillbirth ((Sallmen et al., 1995; Eskenazi et al., 1991b; Zielhuis et al., 1989; Rachootin and Olsen, 1983) as cited in (U.S. EPA, 2012c)).

Sperm concentration, morphology and motility were examined in California men who worked as dry cleaners (n = 34) compared with aged matched laundry workers (n = 48) (Eskenazi et al., 1991a). The three measures of exposure in this study were dry cleaners vs. laundry workers, exhaled breath concentrations of PCE and an exposure score assigned by an industrial hygienist. Clinically relevant changes in sperm concentration, morphology and motility were not associated with any measure of PCE exposure. Fertility rates were examined among wives of dry cleaners and laundry workers in this study; however, the small sample size in this study precluded a determination of findings.

The potential association between PCE exposure and time to pregnancy was evaluated in several studies including a Danish case-control study of couples treated for infertility, a retrospective time-to-pregnancy study in Finnish women, and a Finnish case-control study ((Sallmen et al., 1995; Rachootin and Olsen, 1983) as cited in (U.S. EPA, 2012c)). Some evidence of an association was identified in these studies, however the presence of confounders, absence of PCE-specific data in all values, and possibility of bias diminish the impact of the results.

Animal Evidence

A two-generation reproductive toxicity study (Tinston, 1994) exposed F0 rats to 0, 100, 300, or 1,000 ppm (0, 678, 2,035, 6,783 mg/m3) PCE, 6 hours/day, 5 days/week, for 11 weeks prior to mating and then for 6 hours/day, 7days/week during mating and through GD 20. First generation (F1) dams and litters were exposed from PND 6 through PND 29 but were not exposed from GD 21 through PND 5. Weanlings selected to as F1 parents were then exposed in the same manner as F0 rats, with a total pre-mating phase of 14 weeks for the F1 parents. F2 offspring were exposed in a similar regimen to F1 offspring, except for the 1,000 ppm group for which exposure terminated at GD 20. This study did not evaluate estrous cyclicity, sperm parameters, age to sexual maturation or enhanced reproductive organ histopathology. The only significant reproductive effect reported in this study was reduced testes weight in F1A and F1 males at 1,000 ppm (6,783 mg/m^3). Sperm abnormalities were not observed in rats exposed to 100 or 500 ppm (678 or 3,391 mg/m^3), 7 hours/day for 5 days (measured at 1, 4 and 10 weeks after the last exposure). Sperm head abnormalities were increased in mice exposed to 500 ppm (3,391 mg/m^3) PCE at 4 weeks only (Beliles et al., 1980). The temporal pattern of this effect suggests that spermatocytes and/or spermatogonia may be sensitive to PCE exposure. Female reproductive toxicity was also observed based on reduced fertilization of oocytes from exposed female rats ((Berger and Horner, 2003) as cited in (U.S. EPA, 2012c)).

3.2.3.1.7 Developmental Toxicity

Human Evidence

The epidemiological evidence for developmental effects associated with PCE exposure is suggestive based on several studies of maternal occupational exposure to PCE that suggest an increased risk of spontaneous abortion at high concentrations ((Doyle et al., 1997; Windham et al., 1991; Lindbohm et al., 1990; Olsen et al., 1990; Kyyronen et al., 1989) as cited in (U.S. EPA, 2012c)). In addition, drinking water studies have suggested associations between PCE exposure and pre-term birth, low birth weight, eye and ear anomalies, and oral cleft defects ((Ruckart et al., 2014; Aschengrau et al., 2009; Bove et al., 1995) as cited in (U.S. EPA, 2012c)).

Animal Evidence

Animal studies generally support the findings from the epidemiological literature for developmental effects associated with PCE. Inhalation exposure to PCE during gestation resulted in increases in pre- and post-implantation losses, increased incidence of total malformations, decreased fetal weight, increased incidence of skeletal retardations or delayed ossification, indications of developmental neurotoxicity, and/or decreased postnatal survival in rats ((Szakmáry et al., 1997; Schwetz et al., 1975;

Carney et al., 2006; Tinston, 1994; Nelson et al., 1979) as cited in (U.S. EPA, 2012c)); increased incidence of visceral malformations or decreased fetal weight and delayed ossification in mice ((Schwetz et al., 1975) as cited in (U.S. EPA, 2012c)); and increases in abortions, total litter resorptions, post-implantation losses, and the incidence of malformations in rabbits ((Szakmáry et al., 1997) as cited in (U.S. EPA, 2012c)).

3.2.3.2 Genotoxicity and Cancer Hazards

EPA has identified several genotoxicity and cancer studies published subsequent to the 2012 IRIS assessment of PCE (U.S. EPA, 2012c). EPA evaluated these studies as well as key and supporting studies from the IRIS assessment according to the data quality criteria published in (U.S. EPA, 2018b).

3.2.3.2.1 Genotoxicity

U.S. EPA (2012c), IARC (2014), and ATSDR (2019) provide comprehensive reviews on the genotoxicity of PCE. The discussion of PCE genotoxicity here is based on these previous assessments, supplemented by information from a few individual genotoxicity studies (Everatt et al., 2013; Irving and Elfarra, 2013; Tucker et al., 2011). Extracted results with final data quality scores for all genotoxicity studies on PCE and important metabolites are provided in Appendix J.

In Vivo Human Data

A handful of cross-sectional studies evaluating genotoxicity endpoints in exposed workers suggested that PCE may induce increases in micronuclei and DNA damage. Significant increases in the frequency of micronuclei and in DNA damage (mean tail length by comet assay) were observed in human lymphocytes from dry cleaning workers (Everatt et al., 2013). The frequency of chromosomal aberrations was not significantly different between workers and controls, but regression analysis of these results in the exposed group showed significant positive associations with PCE exposure duration and frequency (Everatt et al., 2013). A recent study published after the conclusion of the TSCA literature search ((Azimi et al., 2017) as cited in (ATSDR, 2019)) provided some support for the finding of DNA damage reported by (Everatt et al., 2013). Azimi et al. observed significant increases in comet assay tail length, percent DNA in tail, and tail moment in 33 dry cleaners employed for at least 3 months (median duration 8 years), when compared with 26 controls; exposure levels were not reported. (Tucker et al., 2011) observed statistically significant increases in the frequencies of acentric fragments and in a group of dry cleaning workers exposed for at least 1 year compared to controls, but no statistically significant difference was observed for chromosomal translocations. A previous study of these subjects reported reductions in oxidative DNA damage in leukocytes from exposed workers compared with controls, and there was no statistically significant increase in sister chromatid exchanges observed in studies on workers compared to ONUs or controls ((Toraason et al., 2003) as cited in (U.S. EPA, 2012c)).

In vivo Animal Data

Few in vivo animal studies of PCE genotoxicity have been performed, and the results of the available studies are inconclusive. A marginal but dose-related increase in DNA damage, as measured by comet assay tail intensity, was reported to occur in hepatocytes, but not kidney cells of mice given PCE orally and the significance of this results has been questioned ((Cederberg et al., 2010) as cited in (U.S. EPA, 2012c)). In an earlier study, single strand DNA breaks were reported in mouse liver and kidney (but not lung) after intraperitoneal injection of PCE, but the observed effect was no longer apparent after 24 hours ((Walles, 1986) as cited in (U.S. EPA, 2012c)). No DNA strand breaks were observed in the kidneys of male rats given PCE orally for a week ((Potter et al., 1996) as cited in (U.S. EPA, 2012c)). No increase in oxidative DNA damage was reported in urine, lymphocytes, or liver of rats exposed by intraperitoneal injection, but there was significant morbidity and mortality among the animals at the higher doses ((Toraason et al., 2003) as cited in (U.S. EPA, 2012c)).

In one study investigating micronucleus induction, no increase in the frequency of micronuclei was observed in reticulocytes or hepatocytes after intraperitoneal injection of PCE before partial hepatectomy, while an increase in micronuclei was seen in hepatocytes when treatment occurred after partial hepatectomy ((Murakami and Horikawa, 1995) as cited in (ATSDR, 2019)). Examinations for DNA binding in rats and mice after intraperitoneal exposure to radiolabeled PCE showed DNA labelling in mouse liver and stomach and, at lower levels, in mouse kidney and rat stomach ((Mazzullo et al., 1987) as cited in (U.S. EPA, 2012c)). An earlier study using a less sensitive method showed no DNA binding in mouse liver after oral or inhalation exposure ((Schumann et al., 1980) as cited in (U.S. EPA, 2012c)).

In Vitro Mutagenicity Data

A test for gene mutations in mouse lymphoma L5178Y cells was negative both with and without metabolic activation ((NTP, 1986a) as cited in (U.S. EPA, 2012c)). In vitro non-mammalian testing for mutagenicity suggests that PCE itself is not mutagenic, in contrast to some oxidative and conjugated metabolites of PCE. PCE has been extensively tested for forward and reverse mutations in Salmonella typhimurium, Escherichia coli, and Saccharomyces cerevisiae, both with and without metabolic activation. In the preponderance of tests, the results were unequivocally negative, except for one strong exception (ATSDR, 2019; IARC, 2014; U.S. EPA, 2012e).

In that exception study ((Vamvakas et al., 1989c) as cited in (U.S. EPA, 2012c)), a clear positive response was observed in *S typhimurium* TA100 with metabolic activation and supplied glutathione (GSH), with an even stronger response when purified GSH S-transferase was also added. These results suggest that metabolites of PCE in the glutathione conjugation pathway are mutagenic. Support for this finding is seen in testing of PCE metabolites for mutagenicity. Ames testing of TCVG yielded positive results with metabolic activation, and equivocal or negative results without activation ((Dreessen et al., 2003; Vamvakas et al., 1989b) as cited in (U.S. EPA, 2012c)). However, positive results were observed in Ames testing of TCVC ((Irving and Elfarra, 2013; Dreessen et al., 2003) as cited in (U.S. EPA, 2012c)), NAcTCVC (N-acetylated TCVC) ((Vamvakas et al., 1987) as cited in (U.S. EPA, 2012c)), and TCVC sulfoxide (Irving and Elfarra, 2013) without metabolic activation. The mutagenicity of NAcTCVC in Salmonella is believed to result from bacterial deacetylation to TCVC ((Vamvakas et al., 1987) as cited in (U.S. EPA, 2012c)). Irving et al. (2013) showed that TCVC was a more potent mutagen than TCVC sulfoxide, but concluded that the latter was a definite, albeit weak, mutagen.

Oxidative metabolites of PCE have also shown some evidence for mutagenic activity. Trichloroacetyl chloride exposure increased revertants in *S. typhimurium* TA100 with or without activation in one study but not in another ((Demarini et al., 1994; Reichert et al., 1983) as cited in (U.S. EPA, 2012c)). In addition, PCE oxide was positive for reverse mutations in *S. typhimurium* TA1535 without activation, but not in *E. coli* WP2uvrA ((Kline et al., 1982) as cited in (U.S. EPA, 2012c)). Testing of the oxidative metabolite trichloroacetic acid (TCA), is ambiguous because interpretation of TCA in vitro test results is complicated by pH changes induced by the compound (U.S. EPA, 2012c).

PCE has been tested for gene conversion, mitotic combination, and reverse mutation in *S. cerevisiae*. Positive results were observed only when log-phase cultures, in which xenobiotic metabolism is stimulated, were used. When stationary cultures were used, exposure did not induce gene conversion, mitotic combination, or reverse mutation ((Koch et al., 1988; Bronzetti et al., 1983) as cited in (IARC, 2014)). In growing cells of the D61.M strain, PCE exposure, both with or without metabolic activation, induced aneuploidy ((Koch et al., 1988) as cited in (IARC, 2014)). No evidence for sex-linked recessive lethal mutations was observed in tests of Drosophila melanogaster exposed to PCE by feeding,

inhalation, or injection ((NTP, 1986a; Valencia et al., 1985; Beliles et al., 1980) as cited in (U.S. EPA, 2012c)).

In vitro Micronuclei, Chromosomal Aberrations and SCEs

In mammalian cell systems tested in vitro, no evidence for chromosomal aberrations or SCEs was observed in Chinese hamster ovary cells ((Galloway et al., 1987; NTP, 1986a) as cited in (U.S. EPA, 2012c)), Chinese hamster lung cells ((Sofuni et al., 1985) as cited in (U.S. EPA, 2012c)), or human lymphocytes ((Hartmann and Speit, 1995) as cited in (U.S. EPA, 2012c)). Assays for induction of micronuclei in vitro yielded mixed results. Induction of micronuclei were reported in Chinese hamster ovary cells exposed to PCE without metabolic activation ((Wang et al., 2001)} as cited in (U.S. EPA, 2012c)), but not in Chinese hamster lung cells ((Matsushima et al., 1999) as cited in (U.S. EPA, 2012c)). Experiments in metabolically enhanced cells yielded positive results for micronucleus induction. Increases in micronuclei were seen in human AHH-1 lymphoblastoid cells (which have high GST activity) and in daughter cell lines that express human CYP2E1 (h2E1 cells) or CYPs 1A2, 2A6, 3A4, 2E1, and microsomal epoxide hydrolase (MCL-5 cells) ((White et al., 2001; Doherty et al., 1996) as cited in (U.S. EPA, 2012c)).

In Vitro DNA Damage and Morphological Cell Transformation

Few experiments examining DNA damage in cell systems in vitro after exposure to PCE have been performed. Equivocal results were reported in tests of human WI38 fibroblasts for unscheduled DNA synthesis: low doses yielded results comparable to the positive control, while high doses were negative, although the positive control response was weak and cytotoxicity was observed at high doses ((Beliles et al., 1980) as cited in (U.S. EPA, 2012c)). In other studies of unscheduled DNA synthesis in rat and mouse hepatocytes and human lymphocytes and fibroblasts, PCE did not yield positive results ((Milman et al., 1988; Shimada et al., 1985; Costa and Ivanetich, 1984; Perocco et al., 1983) as cited in (U.S. EPA, 2012c)). A more recent study reported no increase in 8-OHdG (a measure of oxidative DNA damage) or γ-H2AX levels (indicative of double strand DNA breaks) in HepG2 cells exposed to PCE (Deferme et al., 2015); however, the capacity of HepG2 cells to metabolize PCE is unknown.

PCE exposure resulted in morphological cell transformation when RLV/Fischer rat embryo cells were exposed for 2 days, but not when BALB/c-3T3 cells were exposed for 3 days followed by a 30-day incubation period ((Tu et al., 1985; Price et al., 1978) as cited in (U.S. EPA, 2012c)).

3.2.3.2.2 Carcinogenicity Epidemiological Studies

(U.S. EPA, 2012c) performed a thorough review of the epidemiological data pertaining to carcinogenicity of PCE available from studies conducted through 2011. This review concluded that there was a pattern of evidence associating PCE exposure with several types of cancer, specifically bladder cancer, non-Hodgkin's lymphoma (NHL), and multiple myeloma (MM). More limited data were available supporting carcinogenicity at other sites, including esophageal, kidney, lung, liver, cervical, and breast cancer.

Descriptions of the data supporting these conclusions can be found in the IRIS Toxicological Review for PCE (U.S. EPA, 2012c). Newer epidemiological studies not available at the time of the IRIS review are summarized in Table 3-3 along with the outcome of EPA's data quality evaluation (U.S. EPA, 2020k). A detailed description of all epidemiological data can be found in Appendix G.1.

Table 3-3. Summaries of Selected Epidemiologic Cancer Studies

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Cause-specific mortality: kidney cancer, Hodgkin's lymphoma, Leukemias, ALS	Camp Lejeune, North Carolina cohort; n=154,932 median age, start of follow-up: 20 median age, end of follow-up: 49 Camp Pendleton, California cohort n=154,969 median age, start of follow-up: 20 median age, end of follow-up: 49 exposure period: 1975-1985; mortality follow-up period: 1979-2008	Chemical name: Tetrachloroethylene (PCE); exposure matrix: estimated monthly average PCE concentration in Tarawa Terrace water system (1975-1985) Mean: 75.7 ug/L, Median: 84.9 ug/L, Range: 0-158.1 ug/L; estimated monthly average PCE concentration in Hadnot Point water system (1975-1985) Mean: 15.7 ug/L, Median: 15.4 ug/L, Range: 0-38.7 ug/L); Duration: On average an individual in the Camp Lejeune cohort resided at the base for 18 months.	NHL: β-coefficient = 0.00005, (-0.00003 – 0.00013) ALS: β-coefficient = 0.00039, (-0.00002 – 0.00080) Kidney cancer: β-coefficient = 0.00009, (-0.00048 – 0.00065)	(Bove et al., 2014b)	High
Diffuse large B-cell lymphoma	Georgia population (2000 census)	Geocoded toxic release sites data for PCE from 1988-1998 EPA's TRI	Per-mile increase in distance from site: β-coefficient = -0.0027 ($p < 0.001$)	(Bulka et al., 2016)	Medium
Cause-specific mortality: bladder or other urinary cancer, respiratory tract cancer, liver/biliary cancer, kidney cancer, esophageal cancer, all	1704 dry cleaning workers in four US cities (San Francisco/Oakland, Chicago, Detroit, and New York)	Employment in a shop using PCE, mean (sd) years of employment for exposed workers 6.2 (5.0)	Bladder/urinary: SMR = 1.81, (0.87 – 3.33) Respiratory: SMR = 1.31, (1.04 – 1.64) Kidney: SMR = 1.14 (0.37 – 2.67) Liver/biliary: SMR = 0.13, (0.00 – 0.73) Esophageal: SMR = 2.44, (1.40 – 3.97) All: SMR = 1.22, (1.09=1.36)	(Calvert et al., 2011)	Medium

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Diagnosis of cancer in oral cavity, oropharynx, hypopharynx, oral cavity, and larynx (detailed list of codes in text)	Case-control, women only, 296 cases, 775 controls, diagnosed 2001-2007, general population, 18-85 years, subset of ICARE cohort	PCE, exposure qualitatively stated, modeled as cumulative exposure index (CEI)	Head and neck cancer: OR = 2.97, (1.05 – 8.45)	(Carton et al., 2017)	Medium
Cancers of the bladder, prostate, colon, stomach, rectum, kidney, pancreas, esophagus, and liver, as well as melanoma and non-Hodgkin's lymphoma.	3730 male, Canadian patients aged 35 to 70 years diagnosed 1979-1985 in 18 largest Montreal hospitals; 533 controls from electoral lists in Quebec. A second control group consisted of the population controls together with patients with cancers at sites distal to the primary cancer being assessed.	PCE exposure determined from self-reported job history categorized by chemists and industrial hygienists based on degree of confidence, frequency, and relative levels (not quantitative)	Prostate cancer: OR = 6.0, (1.2 – 30)	(Christensen et al., 2013)	Medium
Breast cancer incidence	920 incident breast cancer cases, 1293 controls, Cape Cod, Massachusetts, 1983-1993,	Water distribution modeled exposure to PCE-lined public water distribution pipelines	OR ranging from 1.0 - 1.8 among comparison groups, LCL ranging from 0.5 – 0.9, UCL ranging from 1.4 - 4.4.	(Gallagher et al., 2011)	Medium
Bladder cancer	113,343 cases and 566,715 matched controls from the Nordic Occupational Cancer (NOCCA) project (through 2005)	PCE exposure estimated via linkage between occupational codes and Nordic Occupational Cancer (NOCCA) project job exposure matrix (JEM)	90^{th} %tile vs unexposed: HR = 0.94, (0.73 – 1.22) 50^{th} %tile vs unexposed: HR = 1.00, (0.92 – 1.09) 50^{th}-90^{th} %tile vs unexposed: HR = 1.12, (1.02 – 1.23)	(Hadkhale et al., 2017)	Medium

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Neuroblastoma	Children (75 cases, 14,602 controls), ages <6 born in 1990-2007 in California within 5 km of exposure monitoring stations, cases from California Cancer Registry	PCE (0.186 ppb) in ambient air, pollution monitoring stations used to estimate maternal exposure during pregnancy from birth certificate address	Within 5km: OR = 1.06, (0.84-1.33) Within 2.5km: OR = 1.01, (0.62-1.64)	(Heck et al., 2013)	Medium
Astrocytic brain cancer risk	Men in southern Louisiana, United States, exposed from 1978 - 1980; in northern New Jersey and Philadelphia, Pennsylvania, United States, exposed from 1979 - 1981 (n=620,300 cases, 320 controls)	PCE, low exposure (1)	Chi trend = -0.65. Exposure not significantly associated with astrocytic brain cancer	(Heineman et al., 1994)	Medium
Cancer mortality	Lockheed Martin aircraft manufacturing factory workers in Burbank, California (employed after January 1, 1960; followed up through December 31, 2008)	Years of exposure to PCE based on job histories and industrial hygiene surveys	<1 year exposed: RR = 1.04, (0.89 – 1.21) 1-4 years exposed: RR = 1.15, (1.00 – 1.32) 5-9 years exposed: RR = 0.92, (0.76 – 1.12) ≥10 years exposed: RR = 0.83, (0.66 – 1.04)	(Lipworth et al., 2011)	High
Lung cancer	Investigation of occupational exposure and environmental causes of respiratory cancers (ICARE) study subjects, population-based case-control study in France 2001-2007 (2274 men cases and 2780 men controls)	Cumulative Exposure Index (CEI) based on self-reported job histories and probability, intensity, and frequency of exposure to PCE based on jobs	Men (ever exposed, adjusted for smoking): OR = 1.26, (0.87 – 1.82) Women (ever exposed, adjusted for smoking): OR = 2.74, (1.23 – 6.09)	(Mattei et al., 2014)	Medium

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Mycosis fungoides (MF)	100 patients with Mycosis Fungoides and 2846 controls, 35-69 years of age, from Denmark, Sweden, France, Germany, Italy, and Spain, 1995-1997	Occupational exposure to PCE assessed with job exposure matrix	Women, high dose: OR = 11.38, (1.04 – 124.85) [no cases in low dose women] Men, high dose: OR = 1.60, (0.30 – 13.60) Men, low dose: OR = 1.80, (0.22 – 14.80)	(Morales-Suárez-Varela et al., 2013)	High
Brain cancer: glioma and meningioma cases	489 glioma cases, 197 meningioma cases, and 799 controls from three USA hospitals in Arizona, Massachusetts and Pennsylvania	Occupational exposure to PCE via self-reported occupational history and industrial hygienist assigned level of exposure	Glioma, possible exposure: OR = 0.7, (0.5 – 0.9) Glioma, probable exposure: OR = 0.7, (0.3 – 1.6) Meningioma, possible exposure, adjusted for other exposure: OR = 1.0, (0.5 – 2.2) Meningioma, probable exposure, adjusted for other exposure: OR = 0.3, (0.1 – 1.7)	(Neta et al., 2012)	High
Cancer of the liver, lung cervix, kidney, and NHL	15 million people participating in a decennial census in Denmark, Finland, Iceland, Norway, and Sweden. Aged 30-64 in years 1960-1990.	Employment in dry cleaning and/or laundering during time period of predominant PCE use	Cervix: SIR = 1.20, (1.08 – 1.34) NHL, male: SIR = 0.96, (0.72 – 1.25) NHL, female: SIR = 0.98, (0.86 – 1.13) Kidney: SIR = 0.96, (0.84 – 1.10) Lung: SIR = 1.28, (1.15 – 1.42) Liver: SIR = 1.13, (0.76 – 1.63)	(Pukkala et al., 2009)	Medium

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Diagnosis of kidney cancer	General population case-control study of kidney cancer (1217 cases; 1235 controls). Detroit (2002 - 2007) and Chicago (2003).	Job exposure matrix was used to determine years exposed, average weekly exposure and cumulative hours exposed to PCE	ORs based on high probability of exposure, exposure duration, average weekly exposure, or cumulative exposure ranged from 0.9 to 1.2 with LCL ranging from 0.4 – 0.6 and UCL ranging from 2.3 – 3.1. High-intensity exposure: OR = 3.1, (1.3 – 7.4).	(Purdue et al., 2017)	High
Mortality from multiple myeloma	Aircraft maintenance workers (n = 14,457; 10,730 men and 3,725 women) at Hill Air Force Base (Utah, USA), for at least one year from 1952-1956, and followed up through 2000	Occupational exposure to PCE (yes/no) based on job-exposure matrix; no quantitative assessment available	Females: HR = 7.84, (1.43 – 43.06) Male: HR = 1.71 (0.42 – 6.91)	(Radican et al., 2008)	Medium
Childhood cancers	Children born to mothers with exposure to contaminated drinking water at Camp Lejeune: 51 cases and 526 controls	PCE in drinking water during 1st trimester of pregnancy; modelled exposure high (>=44 ppb), low (<44 ppb)	Childhood leukemia + NHL: OR = 1.6, (0.5 – 4.8)	(Ruckart et al., 2013)	High
Age of diagnosis of breast cancer (male only).	Case-control, male Marines born before 1969, diagnosed 1995-2013, with identifiable tour dates/locations	PCE, residential drinking water at Camp Lejeune, cumulative exposure >159 ppb	ORs based on cumulative exposure, monthly average exposure, and high exposure ranged from 0.91 – 1.47 with LCLs ranging from 0.13 to 0.18 and UCLs ranging from 4.21 – 7.91.	(Ruckart et al., 2015)	High

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Glioma	Non-farm workers from the Upper Midwest Health Study (798 cases and 1,141 controls from Iowa, Michigan, Minnesota, and Wisconsin 1995-1997)	PCE use (self-reported occupational history through 1992, bibliographic database of published exposure)	OR = 0.75, (0.62-0.91)	(Ruder et al., 2013)	High
Total lymphoma, HL, B-NHL, T-NHL, B-NHL subentities (DLBCL, FL, CLL, multiple myeloma, marginal zone lymphoma)	710 participating cases (matched to 710 controls) with malignant lymphoma among men and women aged 18 to 80 years in 6 regions in Germany	Cumulative occupational exposure to PCE [ppm*years] based on intensity, the frequency, and duration of PCE exposure (0 to >78.8 ppm*years)	ORs based on T- or B-NHL and varying exposure levels and durations range from 0.4 – 1.7 with LCLs ranging from 0.1 – 0.5 and UCLs ranging from 1.4 – 14.4).	(Seidler et al., 2007)	High
Kidney, bladder, liver, NHL, overall cancer incidence	Swedish national cohort of dry cleaning and laundry workers (n = 10,389) assembled in 1984 followed up for new cases of cancer by matching with the Swedish cancer register from 1985 to 2006	Occupation as dry cleaners and laundry workers exposed to PCE; exposure levels in the 1970s were on the order of 100–200 mg/m3 (15–30 ppm)	Bladder: SIR = 0.92, (0.65 - 1.26) Liver: SIR = 1.12, (0.73 – 1.64) NHL: SIR = 1.38, (1.02 – 1.82) Lung: SIR = 1.32, (1.07 – 1.60) Hodgkin's lymphoma: SIR = 1.10, (0.30 – 2.81) Kidney: SIR =1.04, 0.69 – 1.49)	(Seldén and Ahlborg, 2011)	Medium

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Kidney cancer incidence	Greater Montreal metropolitan area. Case-control study of occupationally-exposed men aged 35 to 70 year old (4,263 cases, 533 population controls; also hospital and cancer controls).	Any or substantial exposure	No quantitative data for PCE were provided.	(Siemiatycki, 1991)	Medium
Cancer of bladder, kidney, liver, brain, MM, NHL	National Institute for Occupational Safety and Health (NIOSH) Cohort, 34,494 workers at NY microelectronics and business machine facility, 2009, 52-65yrs	Cumulative PCE exposure score based on department-exposure matrix	NHL: HR = 1.25, (0.90 – 1.73) HR ≤ 1.0 for other cancers, including bladder, kidney, liver, brain, or MM	(Silver et al., 2014)	Medium
Acute myeloid lymphoma	Cases of acute myeloid leukemia (n=14,337) diagnosed between 1961 and 2005, and controls (n=71,027) matched by age, sex, and country identified from the Nordic Occupational Cancer Study cohort	Cumulative PCE exposure estimated using job exposure matrix, Median (ppm-yr) 12.1	HRs inversely trended from 1.07 to 0.72 among low, medium, and high exposure groups, with LCLs ranging from 0.39 – 1.38 and UCLs ranging from 1.38 – 1.12 (p = 0.39 for negative dose-response trend).	(Talibov et al., 2014)	High

Outcome/ Endpoint	Study Population	Exposure	Results	Reference	Data Quality Evaluation
Cancer diagnosis: liver/biliary, kidney, bladder, pancreas, lung, cervix, Hodgkin's lymphoma, and non-Hodgkin's lymphoma	Adults working in the Sweden during the 1960 and 1970 census, including 31,418 women and 15,515 men working as launderers, dry cleaners, or pressers	Occupation as a dry cleaner, launderer, or presser served as surrogate for PCE exposure	Cervix: RR = 1.09, (0.57 – 2.09) Liver/biliary: RR = 1.26, (0.73 – 2.18) Bladder: RR = 1.00, (0.61 – 1.63) NHL: RR = 0.86, (0.43 – 1.72) Hodgkin's lymphoma: RR = 2.69, (1.01 – 7.19) Lung cancer: RR = 1.20, (0.84 – 1.20)	(Travier et al., 2002)	High
Lung cancer	Lung cancer cases and randomly selected population-based controls frequency matched by sex and age in Montreal Canada	PCE exposure (any or substantial) was assessed by a team of industrial chemists and hygienists based on self-reported job histories	Pooled analysis Any exposure: OR = 2.5, (1.2 – 5.6) Substantial exposure: OR = 2.4, (0.8 – 7.7)	(Vizcaya et al., 2013)	Medium
Liver and kidney cancer, non-Hodgkin's lymphoma (NHL) and multiple myeloma (MM)	All subjects aged 30–64 years who participated in 1960 through 1990 censuses in Finland, Iceland, Norway and Sweden; five matched controls per case	Job-exposure matrix, intensity × prevalence of PCE exposure (90th percentile: 0.05 units)	Liver: HR = 1.26, (0.88 – 1.80) MM: HR = 1.18, (0.87 – 1.59) NHL (men, cumulative exposure): HR = 1.54, (0.99 – 2.42) NHL (women, cumulative exposure): HR = 0.94, (0.74 – 1.20)	(Vlaanderen et al., 2013)	High
Renal pelvis cancer, bladder cancer	Employed Swedish residents (1,014 and 360 renal pelvis cancers and 18,244 and 3,347 bladder cancers among men and women, respectively)	Occupation type (workers in laundry, ironing, dyeing) or industry	Renal pelvic (F): SIR = 1.23, (0.39 – 2.86) Renal pelvic (M): SIR = 1.07, (0.21 – 3.12) Bladder (F): SIR = 1.07, (0.75 – 1.47) Bladder (M): SIR = 1.23, (0.83 – 1.74)	(Wilson et al., 2008)	Medium

3.2.3.2.3 Carcinogenicity Animal Studies

The EPA IRIS Assessment (U.S. EPA, 2012c) performed a review of the animal toxicity data pertaining to the carcinogenicity of PCE for studies conducted through 2011. No additional animal carcinogenicity studies were located in EPA's current systematic review. A summary of the identified tumors is provided below. Full study details are provided in Appendix G.2.

Liver

Hepatocellular adenomas and carcinomas exhibited a dose-related increase in male and female B6C3F1 mice exposed by inhalation to PCE at 100 or 200 ppm for 103 weeks, with significant increases in incidence of hepatocellular carcinoma and combined hepatocellular adenomas or carcinomas observed at both exposure concentrations (NTP, 1986a). A dose-related increase in hepatocellular adenomas or carcinomas was also observed in male and female Crj:BDF1 mice in a 2-year inhalation study, with increases achieving statistical significance in both sexes at 250 ppm (Jisa, 1993). A significant increase in the combined incidence of hemangiosarcomas or hemangiomas, occurring in the liver, spleen, fat, subcutaneous skin, and heart, was observed in male mice at 250 ppm (Jisa, 1993). In an oral study, the incidence of hepatocellular carcinoma was significantly increased in male and female B6C3F1 mice administered time-weighted average doses of 536 or 1,072 mg/kg-day in males and 386 or 772 mg/kg-day in females for 78 weeks, with a decreased time to first tumor in treated male and female mice, compared to controls (NCI, 1977).

Kidney

Renal tubular adenomas and adenocarcinomas were observed in male, but not female, F344/N rats exposed to PCE by inhalation at 200 or 400 ppm for 103 weeks (NTP, 1986a); although incidence was low, the rarity of renal tubular carcinomas in this strain of rat, in combination with the proliferative lesions (renal tubular cell hyperplasia) observed in male rats and one female rat, suggest that these findings are biologically significant.

Blood

A dose-related increase in the incidence and severity of Mononuclear Cell Leukemia (MCL) was observed in male and female F344/N rats exposed to PCE by inhalation at concentrations up to 400 ppm for 103 weeks, with decreased time to onset in exposed females (NTP, 1986a). The incidence of advanced stage MCL was significantly increased in both sexes at 400 ppm (NTP, 1986a). (Jisa, 1993) also observed a positive dose-related trend in the incidence of MCL in male and female F344/DuCrj rats exposed by inhalation for 2 years, reaching statistical significance in males only at 600 ppm. The time to first occurrence of MCL was reduced in exposed female rats, relative to controls (Jisa, 1993). Very high background incidences (36-56%) were observed in both sexes in (NTP, 1986a), however, background incidences were reduced to 20-22% in (Jisa, 1993).

Brain

A slight, but biologically significant, increase in brain gliomas was observed in male and female F344/N rats exposed to PCE by inhalation at 400 ppm for 103 weeks (NTP, 1986a). The fact that this is a rare tumor type, along with a decreased time to first tumor in exposed rats, support the biological significance of this finding.

Testes

F344/N rats exposed to PCE vapors at 200 or 400 ppm for 103 weeks exhibited a significant positive dose-related trend in the incidence of testicular interstitial cell tumors (NTP, 1986a).

3.2.3.3 Mode of Action for Carcinogenicity

This section summarizes available information on MOA for PCE carcinogenicity based on the mode of action (MOA) analysis performed in the 2012 EPA IRIS assessment (U.S. EPA, 2012c) and additional information made available since 2012. The Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005a) identifies steps for determining whether a hypothesized MOA is operative. The steps include an outline of the sequence of events leading to cancer, identification of the key events, and determination of whether there is a causal relationship between events and cancer.

An MOA is a biologically plausible hypothesis for describing the sequence of events leading to an observed adverse outcome (in this case, tumors). It identifies "key" cellular and biochemical events—*i.e.*, those that are both measurable (quantifiable) and critical to the observed adverse response. MOA contrasts with "mechanism" which generally implies a more detailed description of the molecular and biochemical basis for an effect. The analyses presented below follow an MOA framework developed by the International Programme on Chemical Safety (IPCS) (WHO/IPCS, 2007) and the U.S. EPA (U.S. EPA, 2005b) which is used by other regulatory agencies and international organizations (*e.g.*, the World Health Organization, Expert Panel of the Joint Meeting on Pesticide Residues). This MOA framework is based on the Bradford Hill criteria for causality, originally developed for application in epidemiological investigations (Hill, 1965). Both EPA and IPCS have emphasized that this framework "is not a checklist of criteria, but rather presents an analytical approach to considering the weight of the scientific evidence of an MOA" and whether a precursor event is shown to be causally linked to the tumor response.

When relying on laboratory animal data, two critical assumptions govern cancer risk assessment (U.S. EPA, 2005a). In the absence of information to the contrary, it is generally assumed that (1) experimental data on animal tumors are predictive of human cancer and (2) that the animal tumor effects found at high experimental doses can be used to predict human risk at lower exposures.

3.2.3.3.1 Mode of Action for Hepatocellular Tumors

EPA has conducted a weight of the scientific evidence evaluation for several proposed MOAs for liver carcinogenicity. The MOAs considered by (U.S. EPA, 2012c) for the induction of liver tumors in mice included: (1) genotoxicity; (2) epigenetic changes (altered DNA methylation); (3) cytotoxicity and oxidative stress; and (4) peroxisome proliferator-activated receptor (PPAR) activation/peroxisome proliferation. Based on their review of the available data, both (U.S. EPA, 2012c) and (IARC, 2014) determined that multiple modes of action were likely responsible for liver tumors induced by PCE. A number of more recent publications (Luo et al., 2018c; Luo et al., 2018b; Cichocki et al., 2017; Luo et al., 2017; Zhou et al., 2017; Lacey et al., 1999) examining toxicokinetic and toxicodynamic responses in the livers of mice exposed to PCE and the related compound, trichloroethylene, provide additional insight into the modes of action for PCE induced liver cancer in mice.

Much of the research on liver carcinogenicity associated with PCE exposure has focused on the role of the metabolite TCA. Further information on modes of action for TCA hepatocarcinogenicity can be found in the (U.S. EPA, 2011b) IRIS Toxicological Review for TCA.

Role of Metabolism

Available information suggests that cytochrome P450-dependent oxidation is likely the dominant metabolic pathway for PCE in rodents and humans, with the glutathione conjugation pathway contributing to PCE metabolism at a much lower extent (U.S. EPA, 2012c). Metabolic flux through the oxidative pathway was ~30-fold higher than through the conjugation pathway in male mice of three different strains following single oral doses of 1,000 mg/kg PCE (Luo et al., 2018c). The primary

oxidative metabolite of PCE is TCA, which is thought to be formed from spontaneous decomposition of trichloroacetyl chloride (TCAC). Dechlorination of TCA could yield dichloroacetic acid (DCA); however, most of the DCA excreted after exposure to PCE is believed to be produced in the kidney as an end product of β-lyase metabolism (reviewed by (Guyton et al., 2014). Initially, oxidative metabolism of PCE was believed to be mediated primarily by CYP2E1. However, (Luo et al., 2018b) observed formation of TCA in the livers of CYP2E1 knock-out mice (albeit at lower levels than in wild-type mice), demonstrating that other CYPs can also metabolize PCE to TCA.

Metabolites of the glutathione conjugation pathway are also generated in the liver. In C57BL/65J mice given a single dose of 100, 300, or 1,000 mg/kg PCE, dose-dependent increases in the concentrations of S-(1,2,2-trichlorovinyl) glutathione TCVG and N-acetyl-S-(1,2,2-trichlorovinyl)-L-cysteine (NAcTCVC) were seen in the liver, and the concentrations of these metabolites in the liver were than were measured in the kidney or serum in these animals (Luo et al., 2017). At 1,000 mg/kg, but not at lower doses, S-(1,2,2-trichlorovinyl)-L-cysteine (TCVC) was also detected in the liver (Luo et al., 2017), likely because oxidative metabolism was saturated at this dose.

Genotoxicity in the Liver

Individual studies of PCE genotoxicity are discussed above under Genotoxicity. As discussed in that section, PCE shows little to no genotoxic activity in the absence of metabolic activation. Several metabolites resulting from both the oxidative and conjugation pathways have shown some indication of mutagenic activity in vitro, including TCAC, TCVG, TCVC, TCVC sulfoxide (TCVCS), NAcTCVC, and PCE oxide. Among these, TCVG and NAcTCVC have been detected in the livers of C57BL/65J mice. The primary metabolite in the liver, TCA, has shown little to no genotoxic activity in vitro, but testing of this compound is confounded by the pH changes it induces. In vivo studies examining genotoxicity have shown negative or equivocal effects (*i.e.,* only modest increases in DNA damage and DNA binding in mouse) (Deferme et al., 2015; Cederberg et al., 2010; Mazzullo et al., 1987; Beliles et al., 1980). There is also general positive epidemiological evidence (not liver-specific) of genotoxicity from chronic PCE exposure in humans (Section 3.2.3.2.1).

Epigenetic Changes

Changes in the methylation of DNA have been shown to occur early in the development of most tumors (U.S. EPA, 2012c). There are no studies examining mouse liver DNA methylation or other epigenetic changes after exposure to PCE. A role for DNA hypomethylation in the hepatocarcinogenicity of PCE has been postulated based on observations of hypomethylation, especially in the proto-oncogenes c-myc and c-jun, in mouse liver after exposure to the metabolites TCA and DCA ((Tao et al., 2004; Tao et al., 2000; Tao et al., 1998) as cited in (IARC, 2014; U.S. EPA, 2012c)). Notably, c-myc DNA hypomethylation occurred earlier than increases in liver cell proliferation ((Ge et al., 2001) as cited in (U.S. EPA, 2012c)).

Cytotoxicity and Oxidative Stress

Studies in mice and rats exposed for at least 4 weeks provide clear evidence for the hepatotoxic effects of PCE (see Section 3.2.3.1.4), and demonstrate that mice are more sensitive to these effects than are rats. In mice, oral exposure to PCE has resulted in increased serum alanine aminotransferase (ALT) levels, increased liver weight, hepatocellular hypertrophy, fatty degeneration and necrosis, and regenerative cell proliferation/increased DNA synthesis ((Philip et al., 2007; Buben and O'Flaherty, 1985) as cited in (U.S. EPA, 2012c)), while inhalation exposure induced peroxisome proliferation, mitochondrial proliferation, increased relative liver weight, centrilobular lipid accumulation/fatty degeneration, necrosis, and degeneration ((Jisa, 1993; Odum et al., 1988; NTP, 1986a) as cited in (U.S.

EPA, 2012c)). A more recent study of male mice from 45 mouse strains given a single oral dose of PCE (1,000 mg/kg) showed a range of hepatic effects at sacrifice within 24 hours postdosing; most strains showed significant increases in liver triglycerides, and about one-third of the strains exhibited hepatosteatosis of varying severities (Cichocki et al., 2017). PCE-induced accumulation of triglycerides in the liver appears to require the presence of CYP2E1, as knock-out mice did not show this effect after 5 days of oral exposure while wild-type mice and those expressing humanized CYP2E1 did.

In the one study that examined the relationship between hepatocyte toxicity and regenerative cell proliferation in mice ((Philip et al., 2007) as cited in (U.S. EPA, 2012c)), toxicity (manifested as increased plasma ALT) was evident within 24 hours of exposure at all three dose levels (150, 500, and 1,000 mg/kg-day for 30 days). DNA synthesis was increased at all doses after 7 days of exposure (the earliest time point measured), and histopathologic evidence of regenerative repair was seen after 30 days of exposure to the two higher doses ((Philip et al., 2007) as cited in (U.S. EPA, 2012c)), demonstrating that hepatocyte injury occurred early and may have preceded cell proliferation.

In addition to regenerative cell proliferation, other sequelae of hepatotoxicity including inflammation and oxidative stress may play a role in liver tumors induced by PCE. In humans, fatty liver resulting from a high-fat diet is thought to increase oxidative stress, leading to genetic instability and release of inflammatory mediators that contribute to the induction of hepatocellular carcinoma (reviewed by (Takakura et al., 2019)). As discussed above, hepatic triglyceride accumulation and fatty degeneration are hallmarks of PCE exposure in mice. Limited data pertaining to the role of oxidative stress in PCE-induced mouse liver toxicity or carcinogenicity are available, showing that administration of the antioxidants vitamin E and taurine mitigated hepatic effects (increases in liver to body weight, alterations in glycolytic and gluconeogenic enzyme and ATPase activities, and/or hepatocyte degeneration and necrosis) in Swiss mice exposed to 3,000 mg/kg-day PCE for 15 days ((Ebrahim et al., 2001; Ebrahim et al., 1996) as cited in (U.S. EPA, 2012c)).

Deferme et al. (2015) reported no increase in oxygen radical formation (measured by electron spin resonance spectroscopy) in HepG2 cells exposed to 2 mM PCE in vitro for up to 72 hours. Consistent with this result, (Deferme et al., 2015) did not observe a significant induction of genes related to oxidative stress after PCE exposure in this system. However, in B6C3F1 mice exposed via gavage, a dose-related upregulation of genes involved in oxidation/reduction was observed after exposure to PCE (Zhou et al., 2017).

PPARα Activation

Another proposed MOA for the PCE-induced liver tumors is activation of the peroxisome proliferator-activated receptor alpha (PPARα). PPARα is a ligand-activated transcription factor that is involved in the regulation of hepatic lipid metabolism. In response to fasting, PPARα activation in mammals leads to upregulation of genes involved in fatty acid β-oxidation, mitochondrial β-oxidation, gluconeogenesis, and autophagy, all aimed at providing the fasted body with adequate glucose (reviewed by (Preidis et al., 2017)). Some research suggests that hepatocarcinogenesis caused through a PPARα activation may not be relevant to humans (Klaunig et al., 2003). The hypothesized MOA for PPARα-induced hepatocarcinogenicity includes the following key events:

- PPARα activation;
- Alteration in cell growth pathways;
- Perturbation of cell growth and survival;
- Selective clonal expansion of preneoplastic foci; and
- Increases in hepatocellular adenomas and carcinomas.

The evidence related to these key events is summarized below:

For PCE, PPARα is thought to be activated by metabolites that are produced in the liver. In laboratory animals exposed to PCE, several effects indicative of PPARα activation have been observed, including increases in the number and size of liver peroxisomes ((Odum et al., 1988) as cited in (U.S. EPA, 2012c)), increased expression of CYP4A peroxisomal marker enzymes (Cichocki et al., 2017; Zhou et al., 2017; Philip et al., 2007), and increased hepatic levels of palmitoyl coenzyme A oxidase (PCO, also known as acyl CoA oxidase) ((Odum et al., 1988; Goldsworthy and Popp, 1987) as cited in (U.S. EPA, 2012c)). Studies comparing results in rats and mice have shown greater increases in PCO in the livers of mice exposed to PCE than in rat livers after exposure to the same doses ((Odum et al., 1988; Goldsworthy and Popp, 1987) as cited in (U.S. EPA, 2012c)). In vitro testing indicates that activation of mouse and human PPARα after exposure to PCE is likely mediated primarily by the metabolites, TCA and/or DCA, as PCE itself was essentially inactive ((Maloney and Waxman, 1999) as cited in (U.S. EPA, 2012c)).

((Philip et al., 2007) as cited in (U.S. EPA, 2012c)) also reviewed the dose-response and temporal concordance between PPARα activation and cell proliferation in SW mice exposed to PCE. The original study showed that cell proliferation occurred at lower doses (≥150 mg/kg-day after 7 days after exposure) and persisted longer (14-30 days after exposure at 500 and 1,000 mg/kg-day) than increased expression of PPARα marker CYP4A (1,000 mg/kg-day and only after 7 days of exposure). The study authors suggested that their findings argued against a significant role of PPARα activation in PCE-induced liver carcinogenicity. Citing other studies in mice and rats, (U.S. EPA, 2012c) noted that PCE induces a modest peroxisome proliferating response in both species, but only mice develop liver tumors, indicating a lack of concordance between peroxisome proliferation and occurrence of liver tumors across species.

Several notable papers probing the role of PPARα activation in mouse liver after PCE exposure were published after the literature searches were performed for the (ATSDR, 2019), (IARC, 2014), and (U.S. EPA, 2012c) reviews. In a study comparing mouse liver and kidney transcriptomic responses to equimolar oral doses of trichlorethylene and PCE, (Zhou et al., 2017) observed dose-related upregulation of genes involved in PPARα signaling, fatty acid metabolism, and oxidation/reduction in the livers of male B6C3F1 mice exposed to PCE. Genes related to the ATP binding cassette (ABC) family of transporters were also upregulated by PCE; some of these transporters are involved in transportation of cholesterol and lipids, and some are expressed exclusively in peroxisomes. Genes in mitochondria-related pathways and nucleotide metabolism pathways were downregulated. The dose-related alterations in gene expression were correlated both with external PCE dose and hepatic levels of TCA. While gene expression changes related to PPARα signaling were common to both trichloroethylene and PCE, effects on genes related to ABC transporters, mitochondrial pathways, and nucleotide metabolism were unique to PCE (Zhou et al., 2017).

Cichocki et al. (2017) published a seminal paper examining mouse strain variability in toxicokinetic and toxicodynamic responses to PCE exposure. Male mice of 45 strains (Collaborative Cross) received a single oral dose of 1,000 mg/kg PCE and were sacrificed at several time points up to 24 hours after dosing. In this study, variability in liver TCA levels after exposure spanned almost an order of magnitude. In addition, the toxicodynamic response to PCE varied: some strains exhibited significantly lower body weight (as much as 15%); only a few showed significant differences in liver to body weight ratio. Most strains showed significant increases in liver triglycerides with concomitant decreases in serum triglycerides, and about one-third exhibited hepatic steatosis. Similarly, most strains showed

increased hepatic expression of PPARα markers CYP4A10 and Acox1 (the gene that encodes acyl CoA oxidase or PCO); however, the degree of upregulation varied almost 600-fold across the strains. (Cichocki et al., 2017) noted that none of the significant effects of PCE on hepatic endpoints (including CYP2E1 protein and triglyceride levels, expression of PPARα responsive genes, and histopathology changes) was correlated with hepatic TCA levels across the tested strains. The reason why dose-related gene expression changes were correlated with hepatic TCA levels in male B6C3F1 mice (Zhou et al., 2017) but not correlated across the strains tested by (Cichocki et al., 2017) is unclear, but could include strain differences in CYP isozyme activities and saturation as well as toxicodynamic differences across the strains.

Two studies of PPAR knock-out mice and mice expressing humanized PPARα exposed to the closely related compound trichloroethylene provide insight into the role of PPARα activation in PCE-induced liver effects in mice. PCE and trichloroethylene share the common metabolite TCA, which is believed to play a role in the hepatic toxicity and carcinogenicity of both compounds. (Ramdhan et al., 2010) compared the effects of trichloroethylene exposure via inhalation at 1,000 or 2,000 ppm (8 hours/day) for 7 days in male Sv/129 wild type mice, PPARα(-/-) knock-out mice, and mice modified to express human PPARα cDNA (hPPARα). Hepatic effects of trichloroethylene exposure that did not differ significantly among the three strains included increased liver weight, increased plasma aspartate aminotransferase (AST) and ALT, and histopathology evidence of liver necrosis. Hepatic inflammation was observed at the highest exposure in all strains (and not in controls) but was of lesser severity in both PPARα-null and hPPARα mice. Only wild type mice exhibited a significant increase in hepatocyte proliferation, and only at the highest exposure. In contrast, only PPARα-null and hPPARα mice exhibited significant increases in liver triglycerides (at both exposure levels in hPPARα mice, and at the highest exposure only in PPARα-null) and hepatic steatosis (at both exposure levels in both strains). No change in hepatic triglycerides or steatosis was seen in wild-type mice. Both wild-type and hPPARα mice exhibited upregulation of PPARα target genes, while PPARα-null mice did not. Interestingly, urinary excretion of TCA was significantly lower (by about half) in PPARα-null mice compared with wild type and hPPARα mice, indicating that toxicokinetics may explain some of the differences in effects.

To investigate the role of toxicokinetics, (Yoo et al., 2015) administered trichloroethylene by gavage (400 mg/kg) to male and female mice (129S1/SvImJ, PPARα-null, and hPPARα) once or 5 days/week for 4 weeks and measured metabolite levels in liver, kidney, and serum, and their relationship to PPARα activation. Marked sex-related differences in tissue levels of trichloroethylene, trichloroethanol (TCOH), and TCA were observed after single or repeat dosing, with males exhibiting significantly higher metabolite levels in liver, kidney, and serum. No differences between the strains were seen in levels of TCOH in the liver, kidney, or serum, or in levels of TCA in serum after single or repeat dosing. After both single and repeat dosing, TCA levels in the liver were significantly lower in PPARα-null and hPPARα mice of both sexes compared with wild-type mice; in addition, with repeat dosing, the level of hepatic TCA in hPPARα males was significantly lower than in PPARα-null males. Despite much lower levels of TCA, trichloroethylene-treated hPPARα mice of both sexes showed induction of CYP4A10 (a marker of PPARα activation) expression in the liver, and the mRNA levels were comparable to those seen in wild-type mice.

Summary

In summary, PCE likely induces liver tumors in mice through multiple modes of action mediated largely by metabolites. TCA appears to be an important hepatic metabolite but is probably not the only metabolite involved in hepatic effects of PCE. Available data show that the metabolism of PCE in the

liver varies by sex, strain, and CYP2E1 and PPARα genotypes, and that several PCE metabolites are genotoxic. Based on limited data on PCE and studies of the related compound, trichloroethylene, PPARα activation is not the primary MOA for PCE-induced liver tumors but may influence both the metabolism and the nature of the hepatic effects induced. In addition to PPARα activation, PCE exposure also upregulates genes involved in ABC transporters, and downregulates nucleotide metabolism and mitochondrial-related genes. In summary, the MOA by which PCE induces liver tumors is not known.

3.2.3.3.2 Mode of Action for Hemangiomas or Hemangiosarcomas

The incidence of combined hemangiomas or hemangiosarcomas in the liver or spleen was significantly increased in male Crj:BDF1 mice exposed to PCE by inhalation (Jisa, 1993). There was a corresponding dose-related increase in angiectasis, which may represent a preneoplastic lesion in the progression to vascular tumorigenesis (Kleymenova et al., 2004). There are no data available concerning the mechanisms that may contribute to the induction of hemangiosarcomas or hemangiomas in the liver or spleen in male mice. Therefore, an MOA by which PCE induces this type of tumor is not known.

3.2.3.3.3 Mode of Action for Kidney Tumors

(U.S. EPA, 2012c) considered four potential modes of action for PCE-induced kidney cancers in rats: (1) α2u-Globulin-associated nephropathy; (2) PPARα agonism/peroxisome proliferation; (3) genotoxicity; and (4) cytotoxicity not related to α2u-globulin accumulation. (U.S. EPA, 2012c) considered it likely that several mechanisms contribute to renal carcinogenesis, but found evidence insufficient to draw further conclusions, whereas (IARC, 2014) concluded that genotoxicity resulting from PCE metabolites in the kidney was the most likely mechanism for kidney cancers based on data available at the time of their review.

Role of Metabolism

(Irving and Elfarra, 2013) reviewed the available literature and concluded that the nephrotoxicity and nephrocarcinogenicity of PCE are mediated primarily through β-lyase-dependent bioactivation of the cysteine S-conjugate metabolite TCVC. The steps involved are as follows: PCE is conjugated to GSH in the liver to form TCVG; TCVG is processed into the cysteine conjugate (TCVC) in the kidney, bile duct epithelium, intestinal lumen, or bile canalicular membrane of hepatocytes; TCVC enters the circulatory system and is translocated to the kidney; and β-lyase acts on TCVC to form dichlorothioketene, a reactive electrophilic sulfur species. While TCVC has been found to be mutagenic in the Ames Salmonella mutagenicity assay, the addition of an inhibitor of β-lyase to the test system has been found to reduce the mutagenicity of TCVC, suggesting that the β-lyase-derived metabolites are primarily responsible for the mutagenicity of TCVC.

TCVC may be N-acetylated in the kidney to form the mercapturic acid, NAcTCVC (Luo et al., 2019). Both TCVC and NAcTCVC may be further metabolized to form reactive sulfoxides (Luo et al., 2019). TCVCS has been observed to have greater nephrotoxicity than TCVC (Elfarra and Krause, 2007); however, the mutagenic activity of TCVCS in Salmonella is 30-fold lower than that of TCVC (Irving and Elfarra, 2013).

In a study comparing glutathione-pathway metabolites of PCE in male mice of 45 different strains administered PCE as a single gavage dose of 1,000 mg/kg, area under the kidney tissue concentration-time curves (AUC) estimates for TCVG, TCVC, and NAcTCVC varied by at least 29-fold across the strains (Luo et al., 2019), demonstrating marked variability in the metabolism of PCE. Tissue concentrations of metabolites of the GSH pathway (liver TCVG, serum TCVG, liver NAcTCVC, and kidney NAcTCVC) were found to be significantly correlated with increased kidney levels of Kim-1

(kidney injury molecule-1), a protein marker of proximal tubular injury (Luo et al., 2019), supporting a link between this metabolic pathway and kidney toxicity.

PCE is also subject to oxidation, yielding TCA. Zhou et al. (2017) found quantifiable concentrations of TCA in the kidneys of mice at single gavage doses of 300 mg/kg and higher. TCA levels in the kidney were highly correlated with dose-related gene expression changes, including those related to peroxisomal fatty acid β oxidation, in the kidney.

α2u-Globulin-Associated Nephropathy

Evidence of hyaline droplet nephropathy has been observed in male rats exposed to PCE (Bergamaschi et al., 1992; Green et al., 1990; Goldsworthy et al., 1988). Therefore, α2u-globulin-associated nephropathy was considered as a potential mode of action for PCE-induced kidney cancer. This mode of action is unique to the male rats because the α2u-globulin isoform appears to be largely specific to male rats (U.S. EPA, 1991a). The proposed mode of action includes a progressive sequence events in the male rat kidney, starting with the excessive accumulation of hyaline droplets, which leads to sustained regenerative tubular proliferation, and ultimately results in the development of renal tumors. The hypothesized MOA described by (U.S. EPA, 2012c) for renal tumors caused by α2u-globulin-associated nephropathy includes the following key events:

- Excessive accumulation of hyaline droplets containing α2u-globulin in renal proximal tubules;
- Subsequent cytotoxicity and single-cell necrosis of the tubule epithelium
- Sustained regenerative tubule cell proliferation;
- Development of intralumenal granular casts from sloughed cellular debris associated with tubule dilatation and papillary mineralization;
- Foci of tubule hyperplasia in the convoluted proximal tubules; and
- Renal tubule tumors.

The EPA Risk Assessment Forum Report, *Alpha 2u-Globulin: Association with Chemically Induced Renal Toxicity and Neoplasia in the Male Rat* (U.S. EPA, 1991a), identified three criteria that can be used to establish that α2u-globulin may be involved in the development male rat renal tubule tumors. These criteria are: increased number and size of hyaline droplets in the renal proximal tubule cells of treated male rats, accumulating α2u-globulin in the hyaline droplets, and additional aspects of the pathological sequence of lesions associated with α2u-globulin nephropathy are present, specifically single-cell necrosis, exfoliation of epithelial cells into the proximal tubular lumen, formation of granular casts, linear mineralization of papillary tubules, and tubule hyperplasia. The evidence related to these key events is summarized below.

Evidence of increases in hyaline droplets was reported in in male F344 rats administered PCE via gavage at 1,000 mg/kg-day for 10 days (Bergamaschi et al., 1992; Green et al., 1990; Goldsworthy et al., 1988). Increased droplets were not observed in female rats. In the same study, (Bergamaschi et al., 1992; Green et al., 1990; Goldsworthy et al., 1988) conducted immunohistochemical staining for α2u-globulin and found that there was an accumulation of α2u-globulin in the droplets. In a separate study, accumulation of α2u-globulin was not observed in the kidneys of male rats exposed by inhalation to 400 ppm for 6 hours/day for 28 days (Green et al., 1990); however, (U.S. EPA, 2012c) notes that recovery may have occurred during the 18-hour period between the final exposure and sacrifice. It is also possible that longer exposures at this concentration might be required for accumulation of α2u-globulin.

The increases in hyaline droplet formation were correlated with crystalloid accumulation and cell replication in the P_2 segments of the proximal tubules (Goldsworthy et al., 1988), which are non-

neoplastic lesions that are associated with α2u-globulin nephropathy (U.S. EPA, 2012c). Accumulation of α2u-globulin in the P_2 segments was also observed in of male rats administered PCE at 500 mg/kg-day for 4 weeks by gavage (Bergamaschi et al., 1992) and increased hyaline droplets was observed in the proximal tubules of male rats exposed to PCE by gavage at 1,500 mg/kg-day for 42 days (Green et al., 1990). Formation of granular tubular casts and evidence of tubular cell regeneration were also observed in rats dosed with PCE at 1,500 mg/kg-day for 42 days (Green et al., 1990).

While some data fit the criteria α2u-globulin nephrotoxicity, such as treatment-related increases in hyaline droplets in the proximal tubule cells of male rats, other studies indicate that a causal relationship cannot be established. For example, non-neoplastic kidney lesions were also found in female rats and mice. Further, renal tumors have been observed at doses below those shown to cause the α2u-globulin accumulation (U.S. EPA, 2012c). Overall, the data are insufficient to demonstrate that PCE-induced renal cancers are caused by α2u-globulin-associated nephropathy.

PPARα Agonism/Peroxisome Proliferation

Another possible mode of action for kidney cancer examined by (U.S. EPA, 2012c) is PPARα agonism/peroxisome proliferation. The following steps are hypothesized: activation of the PPARα receptor by one or more reactive metabolites of PCE (*e.g.,* TCA), resulting alterations in cell proliferation and apoptosis, followed by clonal expansion of initiated cells (U.S. EPA, 2012c).

In an in vitro study, dichloroacetate and trichloroacetate were able to trans-activate PPARα derived from humans and mice, although PCE was inactive (Maloney and Waxman, 1999).

In vivo, the activity of PCO, a marker for peroxisomal β-oxidation, was found to be increased (1.2- to 1.6-fold) in pooled kidneys of mice exposed to PCE by inhalation (6 hours/day) at 200 ppm for 28 days or 400 ppm for 14-28 days, significantly increased (1.3-fold) in male rat kidneys at 200 ppm at 28 days but not at 400 ppm, and significantly increased (1.2- to 1.6-fold) in female rat kidneys at 200 ppm at 28 days or 400 ppm at 14-28 days; however, there was no effect on renal catalase activity in rats or mice and no peroxisome proliferation was observed in rat or mouse kidney at microscopic examination (Odum et al., 1988). PCO activity was also increased in the kidneys of male rats (1.7-fold, not significant) and male mice (2.3-fold, significant) administered PCE by gavage at 1,000 mg/kg-day for 10 days (Goldsworthy and Popp, 1987). In addition, mice treated with a single dose of 1,000 mg/kg PCE showed increased mRNA expression of PPARα-responsive genes in kidney tissue (Luo et al., 2019). Similarly, by measuring gene expression in the kidney, (Zhou et al., 2017) observed dose-dependent induction of genes associated with peroxisomal fatty acid β-oxidation pathways in a manner in mice administered a single dose of PCE.

Overall, the evidence do not support a causal link between PPARα-activation and kidney tumorigenesis, including studies that showed that the effects on PPARα-activation were only modest and were only observed for PCE at doses exceeding those associated with kidney tumors (Odum et al., 1988; Goldsworthy and Popp, 1987).

Genotoxicity in the Kidney

As discussed in Section 3.2.3.3.1, PCE showed little to no mutagenicity in the absence of metabolic activation or with the standard S9 fraction, but it was mutagenic in the presence of metabolic activation via GSH conjugation or cytochrome P450. Additional studies confirmed that the purified glutathione conjugation metabolites (*i.e.,* TCVC, TCVG, or NacTCVC) were mutagenic in Salmonella. Further research by (Vamvakas et al., 1987) demonstrated that the deaceylation of NAcTCVC to TCVC plays an

important role in the mutagenicity of NAcTCVC, while (Vamvakas et al., 1989c) showed that the mutagenicity of TCVG depends on further metabolism via a two-step process to the cysteine conjugate (TCVC). (Dekant et al., 1986) demonstrated that TCVC is mutagenic without metabolic activation in cell systems with β-lyase activity but preincubation with a β-lyase inhibitor decreased mutagenicity, indicating that β-lyase-derived secondary metabolites are primarily responsible for the mutagenicity of TCVC. Species- and sex-related differences in the activities of β-lyase and other enzymes in the glutathione pathway may explain the sex- and species-specific renal carcinogenicity of PCE. As noted earlier, metabolic differences among strains resulted in at least 29-fold differences in AUC estimates for TCVG, TCVC, and NAcTCVC in the kidneys of male mice of 45 strains exposed to PCE (Luo et al., 2019). There is also general positive epidemiological evidence (not kidney-specific) of genotoxicity from chronic PCE exposure in humans (Section 3.2.3.2.1).

Cytotoxicity not Related to α2u-Globulin Accumulation

(U.S. EPA, 2012c) also examined renal cytotoxicity as a possible mode of action for kidney cancer. It was suggested that sustained cytotoxicity and necrosis cause activation of repair processes and cellular regeneration that may lead to renal neoplasms. Reactive metabolites of PCE, including TCVC and TCVG, produced upon glutathione conjugation are known to result in kidney toxicity (U.S. EPA, 2012c). TCVC has been observed to cause dose-related cytotoxicity, measured by release of lactate dehydrogenase, in a porcine renal cell line (Vamvakas et al., 1989a) and in renal proximal tubule cells isolated from male rats (Vamvakas et al., 1989d). 1,2,2-trichlorovinylthiol, an unstable thiol produced by cleaving TCVC, may give rise to a highly reactive thioketene, which can form covalent adducts with cellular nucleophiles (U.S. EPA, 2012c; Vamvakas et al., 1989d). In another in vitro study, (Lash et al., 2002) observed that PCE and its TCVG metabolite caused increased acute renal cytotoxicity in isolated renal cortical cells from rats with the effect being greater in cells isolated from males, as compared to females. In addition, TCVC was found to cause acute cytotoxicity in primary cultures of proximal tubular cells from rat and human kidneys ((McGoldrick et al., 2003) as cited in (IARC, 2014)).

Observed signs of non-neoplastic kidney toxicity in rodents exposed to PCE in vivo have included: karyomegaly of the proximal tubules in male and female rats and mice (Jonker et al., 1996; Jisa, 1993; NTP, 1986a), tubular cell hyperplasia in male and female rats (NTP, 1986a), nephrosis (non-inflammatory degenerative kidney disease) in female mice (NTP, 1986a), casts in male and female mice (NTP, 1986a), atypical tubular dilation of the proximal tubules in male and female rats and mice (Jisa, 1993), changes in urinary markers related to kidney function (total protein and N-acetyl-β-glucosaminidase) in female rats (Jonker et al., 1996), glomerular nephrosis and degeneration in male and female mice (Ebrahim et al., 1996), exacerbation of chronic renal disease in male rats (Jisa, 1993), and toxic nephropathy in male and female rats and mice (Nci, 1977). Male rats exposed to the conjugative metabolites TCVC or TCVCS by a single intraperitoneal injection showed visible acute renal tubular necrosis, intratubular casts and interstitial congestion and hemorrhage (TCVCS only), increased urinary glucose concentration and ɣ-glutamyl transpeptidase activity, and increased blood urea nitrogen (TCVCS only), with TCVCS exhibiting greater nephrotoxicity than TCVC (Elfarra and Krause, 2007).

Although nephrotoxicity has been observed in both sexes of rats and mice, renal tubular neoplasia have been observed only in male rats (NTP, 1986a). In addition, signs of non-neoplastic kidney damage were observed in rats and mice of both sexes in the early stages of the (NTP, 1986a) inhalation study, suggesting that animals of both species and sexes surviving to scheduled termination had sustained nephrotoxicity for the majority of the study period; however, neoplasms were only observed in male rats. This is inconsistent with nephrotoxicity being the primary mode of action for kidney neoplasms.

In humans, symptoms of renal dysfunction, including proteinuria and hematuria, have been observed in patients administered PCE via inhalation as an anesthetic ((Hake and Stewart, 1977) as cited in (IARC, 2014)). One study found an increased incidence (>2.5-fold) of end-stage renal disease in dry cleaning workers exposed to PCE by inhalation ((Calvert et al., 2011) as cited in (IARC, 2014)). Urinary markers of renal damage were found to be altered in dry cleaning workers by Mutti et al. (1992); effects included increased prevalence of abnormal values for brush-border antigens, a higher geometric mean concentration of brush-border antigens, and a higher concentration of tissue non-specific alkaline phosphatase in urine. In addition, dry cleaning workers were observed to have significantly increased urinary concentrations of β-glucuronidase and lysozyme, indicators of kidney function ((Vyskocil et al., 1990; Franchini et al., 1983) as cited in (IARC, 2014)). Effects on urinary indicators of renal tubule function, including significantly increased prevalence of abnormal values of retinol-binding protein (Mutti et al., 1992) and a higher geometric mean concentration of retinol-binding protein ((Verplanke et al., 1999) as cited in (IARC, 2014)) were observed in two of six studies of dry cleaning workers.

Summary

In summary, available data provide evidence for mutagenicity as a potential MOA for renal carcinogenicity induced by PCE, however, there was not enough evidence to establish a definitive MOA for kidney cancer.

3.2.3.3.4 Mode of Action for (Blood) Tumors

There is no specific information pertaining to potential modes of action for PCE-induced hematopoietic or immune system cancers. Limited data from studies investigating immunotoxicity suggest that PCE exposure can alter white cell counts and immune system markers in humans and in mice ((Emara et al., 2010; Ebrahim et al., 2001) as cited in (U.S. EPA, 2012c)). A more recent in vitro study showed that PCE exposure increased the mRNA expression of cytokines IL-6 and IL-10 in murine macrophages, albeit at cytotoxic concentrations (Kido et al., 2013). IL-6 is a pro-inflammatory cytokine but is involved in other reactions as well; IL-10 is an anti-inflammatory cytokine that may have been elevated as a response to the increase in IL-6. The role, if any, of these immune system perturbations in carcinogenicity induced by PCE is unknown. U.S. EPA (2012c) noted that evidence for effects of PCE on hemolysis and bone marrow function in mice provides some support for a leukemogenic effect in rodents but concluded that data were inadequate to establish an MOA for mononuclear cell leukemia in rats exposed to PCE. A variety of *in vitro*, *ex vivo*, and *in vivo* data on human immune cells provides mixed evidence on whether genotoxicity may be involved in blood cell toxicity and carcinogenesis (Appendix J). The 2012 IRIS Assessment (U.S. EPA, 2012c) noted that evidence for effects of PCE on hemolysis and bone marrow function in mice provides some support for a leukemogenic effect in rodents but concluded that data were inadequate to establish a mechanism for mononuclear cell leukemia in rats exposed to PCE.

3.2.3.3.5 Overall Conclusions for MOA

Overall, the reasonably available evidence indicates that PCE is carcinogenic in animals. For the liver tumors, the data likely supports a complex MOA, with multiple contributing mechanisms. For the kidney tumors, a genotoxic MOA is supported by the evidence of kidney-specific genotoxic metabolites as well as evidence of PCE genotoxicity in humans from epidemiological studies. There was insufficient evidence for a causal link between other non-genotoxic mechanisms, including PPARα activation and α2u-globulin-associated nephropathy, and kidney tumorigenesis. Induction of these pathways was often observed at doses higher than which have been shown to promote tumorigenesis, and the effects were not consistent across sex, dose, and time. Accordingly, the available data do not support a clear indication that these are major contributors to kidney tumors in the animal cancer bioassays. For the

hemangiosarcomas and MCL, there was no information available to support an MOA for tumor induction.

According to EPA's 2005 Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005a), "a linear extrapolation approach is used when the mode of action information is supportive of linearity or mode of action is not understood." The evidence for a potential genotoxic MOA for the kidney tumors supports the use of the low-dose linear assumption. For the other tumors, an MOA has not been established that would allow for the use of a threshold approach. Therefore, EPA used the low-dose linear default non-threshold assumption for the derivation of the cancer slope factors (Section 3.2.5.3.3).

3.2.4 Weight of the Scientific Evidence

3.2.4.1.1 Acute Toxicity

Acute exposures to PCE result in neurotoxicity effects that include central nervous system depression and visual processing, including loss of consciousness which can result in death. These acute neurological effects are supported by both human and animal studies as described above in Section 3.2.4.1.2. There is only limited available information concerning acute irritation and hepatic effects and the available evidence is insufficiently quantitative for use in dose-response analysis. Therefore, acute toxicity other than neurological effects were not carried forward to dose-response analysis.

3.2.4.1.2 Neurotoxicity

The hazard database includes reported human evidence of visual deficits (Getz et al., 2012; Schreiber et al., 2002; Gobba et al., 1998; Cavalleri et al., 1994; Altmann et al., 1990), impaired cognition (Echeverria et al., 1995; Seeber, 1989), increased risky behaviors with associated head injuries following prenatal or early childhood PCE exposure (Aschengrau et al., 2016a; Aschengrau et al., 2011), and decreased math test scores (Stingone et al., 2016). Ambiguous or conflicting evidence was found for increased risk of neurodegenerative diseases (Bove et al., 2014b; Goldman et al., 2012) and autism spectrum disorders (Talbott et al., 2015; von Ehrenstein et al., 2014; Roberts et al., 2013; Kalkbrenner et al., 2010). Clinical, biochemical, and neurophysiological signs of neurotoxicity were observed in adult rodents (Mattsson et al., 1998; Jonker et al., 1996; Tinston, 1994; Kjellstrand et al., 1984) as well as indications of impaired neurobehavior and motor function in developing rats (Nelson et al., 1979). A single 4-week inhalation study in rats did not observe any clinical signs of neurotoxicity (Boverhof et al., 2013), however that study was primarily focused on immunological endpoints. Overall, based on numerous identified functional outcomes in human studies supported by both clinical and mechanistic findings in animals, neurotoxicity following PCE exposure is supported by the weight of the scientific evidence. Based on consistent supporting evidence and sufficient quantitative information, the endpoint of impaired visual function (including delayed neurological signaling, color confusion, and visual memory) was carried forward for dose-response analysis to represent the neurotoxicity hazard domain.

3.2.4.1.3 Kidney Toxicity

Mutti et al. (1992) and other epidemiological studies ((Trevisan et al., 2000; Verplanke et al., 1999; Solet and Robins, 1991; Vyskocil et al., 1990; Franchini et al., 1983; Lauwerys et al., 1983) as cited in (U.S. EPA, 2012d)) suggest likely proximal tubular injury following long-term occupational exposure to PCE. Additionally, multiple animal studies on both rats and mice demonstrated renal effects in both sexes, including increased kidney weights, tubular histopathology, and other indications of kidney toxicity (Jonker et al., 1996; Tinston, 1994; Jisa, 1993; NTP, 1986b; Nci, 1977). Since the publication of the IRIS Assessment, a single 4-week inhalation study in rats did not observe any effects on kidney weight or histology (Boverhof et al., 2013). Overall, based on effects seen in multiple studies in both animals and humans, kidney toxicity following PCE exposure is supported by the weight of the

scientific evidence. Based on consistent supporting evidence and sufficient quantitative information, the endpoints of urinary biomarkers for nephrotoxicity and nuclear enlargement of proximal tubules were carried forward for dose-response analysis to represent the kidney hazard domain.

3.2.4.1.4 Liver Toxicity

The human literature database is limited, with some indication that PCE exposure affects human liver function as well as evidence of negative associations (Silver et al., 2014; U.S. EPA, 2012c). The animal database shows very strong support for liver toxicity following PCE exposure, with reports of necrosis, vacuolization, inflammation, increased liver weight, biochemical markers, and other indicators of liver toxicity in both rats (Jonker et al., 1996; Jisa, 1993) and mice (Buben and O'Flaherty, 1985). A four-week inhalation study in rats (Boverhof et al., 2013) that was published after the IRIS Assessment also reported hepatic effects (increased relative liver weights and hepatocellular hypertrophy) at the highest dose. Overall, based on strong and consistent evidence in animals, liver toxicity following PCE exposure is supported by the weight of the scientific evidence. Based on consistent supporting evidence in rodents and sufficient quantitative information, the endpoints of increased angiectasis, increased degeneration/ necrosis, and increased liver/body-weight ratio were carried forward for dose-response analysis to represent the liver hazard domain.

3.2.4.1.5 Immune System and Hematological Effects

Immunological Effects

The largest number of human studies regarding immunotoxicity evaluated the association between PCE exposure or dry-cleaning work and various autoimmune diseases, with a majority showing some association with autoimmune disease based on ORs or RRs greater than one for many of them. EPA's IRIS assessment (U.S. EPA, 2012c) does note the limitations of these studies regarding their ability to diagnose disease to measure exposure and at least two studies (Garabrant et al., 2003) seem to indicate that when using more robust exposure measures, the effects were attenuated. However, a human study (Chaigne et al., 2015) published after the 2012 IRIS assessment identified a statistically significant association between a semiquantitative PCE exposure measure and Sjorgen's syndrome (OR of 2.64).

Furthermore, a more recent mouse study (Wang et al., 2017) identified associations between PCE exposure and multiple autoimmune measures, including increased serum anti-nuclear, anti-dsDNA, anti-scleroderma 70 antibodies and MDA-protein adducts/ antibodies. Based on the additional human and animal data published after the IRIS assessment and the number of studies identifying associations greater than 1 (even though not all associations were statistically significant), there is at least suggestive evidence of PCE's association with autoimmunity.

Studies of PCE's association with bothersome asthma and increased asthma scores are less clear. In one study (Delfino et al., 2003b), the effect was stronger for ambient PCE exposure compared with exhaled breath. In another study, the effect on asthma symptoms was attenuated when adding other pollutants into the regression model (Delfino et al., 2003a). However, other studies in humans and animals show immune marker profiles consistent with allergic responses.

EPA did not locate human studies on immunosuppression and the animal studies showed mixed results even though Aranyi et al. (1986) found decreased resistance in female mice to bacterial infection.

Despite some lack of precision and uncertainties in the results of immunotoxicity studies, evidence suggests PCE exposure may lead to immunotoxicity. Therefore, this endpoint was carried forward for dose-response analysis.

Hematological Effects

Decreased red blood cells and hemoglobin levels were observed in a single occupational epidemiology study (Emara et al., 2010). Evidence of anemia was observed in mice as cited in U.S. EPA (2012c). However, rat studies identified no hematological effects ((Boverhof et al., 2013; U.S. EPA, 2012c). Overall, the human studies that evaluated hematological endpoints is limited and conflicting results were observed in rats and mice. Nevertheless, because effects were observed in the single human study that evaluated such endpoints, PCE may be associated with these changes. EPA has carried hematological effects for dose-response analysis.

In response to SACC and public comments, EPA added a detailed synthesis of human and animal evidence for immune and hematological effects for the final Risk Evaluation (Appendix H). Based on integration of the available evidence, EPA concludes that PCE may be associated with both immunological and hematological effects.

3.2.4.1.6 Reproductive/Developmental Toxicity

While the reasonably available human evidence is too limited to conclude anything about sperm quality or infertility, the EPA IRIS Assessment (U.S. EPA, 2012c) reported consistent epidemiological evidence of adverse pregnancy outcomes in women associated with PCE exposure including increased risk of spontaneous abortion. Data from multiple human studies indicate an increased risk of spontaneous abortion). Animal evidence supports effects on both male and female reproductive systems ((Tinston, 1994; Beliles et al., 1980) as cited in (U.S. EPA, 2012c)) as well as developmental outcomes ((Carney et al., 2006; Nelson et al., 1979) as cited in (U.S. EPA, 2012c). There were not any relevant studies published after the IRIS Assessment. Overall, based on evidence of both male and female reproductive effects in animals and associations between exposure and female reproductive effects in humans along with indications of developmental effects in both study types, both reproductive and developmental toxicity following PCE exposure are supported by the weight of the scientific evidence. Based on consistent supporting evidence and sufficient quantitative information, the reproductive endpoint of reduced sperm quality and the developmental endpoints of decreased fetal/placental weight, developmental neurotoxicity, and skeletal effects were carried forward for dose-response analysis to represent the reproductive/developmental hazard domain.

3.2.4.1.7 Cancer

In accordance with EPA Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005a), PCE is considered “likely to be carcinogenic in humans” by all routes of exposure based on conclusive evidence in animals and suggestive evidence in humans.

There is conclusive evidence of the carcinogenicity of PCE, administered by ingestion or inhalation, in rats and mice. The most notable findings were statistically significant increases in the incidence of liver tumors (hepatocellular adenomas and/or carcinomas) in male and female B6C3F1 and Crj:BDF1 mice exposed by inhalation (Jisa, 1993; NTP, 1986a) and male and female B6C3F1 mice exposed by ingestion (Nci, 1977). Significant increases were also observed in the incidences of mononuclear cell leukemia (MCL) in male and female rats (F344/N and/or F344/DuCrj) exposed to PCE by inhalation (Jisa, 1993; NTP, 1986a). Additional findings potentially related to treatment included increases in testicular interstitial cell tumors and renal tubular adenomas and adenocarcinomas in male F344/N rats exposed by inhalation (NTP, 1986a), brain gliomas in male and female F344/N rats exposed by inhalation (NTP, 1986a), hemangiosarcomas/ hemangiomas in male Crj:BDF1 mice exposed by inhalation (Jisa, 1993), and adenomas of the Harderian gland in male Crj:BDF1 mice exposed by inhalation (Jisa, 1993).

There is a pattern of epidemiological evidence associating PCE exposure with NHL. There is some evidence for bladder cancer and multiple myeloma (MM) but results are mixed. Additional epidemiological data were available showing weaker support for cancers at other sites, including esophageal, lung, and blood (lymphoma). Studies provide more limited support for associations with breast cancer, with little or no support for associations with kidney, esophagus, or liver cancer, and no useful information for cervical cancer. See Section 3.2.3.2.2 and Appendix G.1 for more details on epidemiological data examining PCE carcinogenesis in humans.

Available data indicate that multiple modes of action are likely to be involved in PCE-induced liver cancers in male and female mice and possibly renal cancers in male rats as well (Section 3.2.3.3). Metabolism is a key event in the modes of action for both liver and kidney carcinogenicity. Importantly, there appear to be marked sex- and strain-related differences, and possibly species differences, in the degrees of oxidative and glutathione conjugative metabolism of PCE, which could explain the species and sex specificity of liver and kidney tumors induced by this compound. Several PCE metabolites originating from the glutathione pathway are mutagenic, particularly the electrophilic sulfur species that result from β-lyase activation of TCVC in the kidney. There is less evidence for non-mutagenic modes of action for kidney carcinogenicity associated with PCE exposure; available data do not support significant roles for α-2u globulin accumulation, cytotoxicity unrelated to α-2u globulin accumulation or PPARα agonism in renal tumor formation. In contrast, there is evidence suggesting that several modes of action, in addition to mutagenicity, may be operant in the liver, including: epigenetic changes leading to oncogene activation; cytotoxicity, inflammation, and oxidative stress; activation of PPARα leading to perturbations in cell proliferation or apoptosis; and other changes in gene expression that may influence cellular energetics, growth, and/or cell cycle. The importance of any one of these modes of action likely depends on dose, species, sex, and strain, given the variability in and importance of PCE metabolism to the various modes of action.

3.2.5 Dose-Response Assessment

3.2.5.1 Selection of Studies for Dose-Response Assessment

Dose-response analysis started with the consideration of all acceptable toxicity studies identified in the prior sections and selection of the studies that reported both adverse effects and data amenable to dose-response assessment. Dose-response assessment was organized into 5 domains: (1) acute toxicity, (2) neurotoxicity, (3) kidney toxicity, (4) liver toxicity and (5) reproductive/developmental toxicity.

3.2.5.1.1 Non-Cancer Toxicity from Acute/Short-Term Exposure

Acute exposure in humans is defined for occupational settings as exposure over the course of a single work shift (8 hours) and for consumers as a single 24-hour day. Based on the weight of the scientific evidence evaluation and available quantitative data, neurotoxicity from human studies (controlled experiments) (Altmann et al., 1990) was selected for dose-response analysis for effects from acute/short-term exposure. Data are also available from animal studies to support this health effect domain following acute exposure. The human studies are considered adequate and are preferable to animal studies.

Although developmental studies are repeated-dosing studies, certain developmental effects may result from a single exposure during a critical window of development (Davis et al., 2009; Van Raaij et al., 2003; U.S. EPA, 1991c), and therefore may be relevant for evaluating acute exposures. This is consistent with EPA's *Guidelines for Reproductive Toxicity Risk Assessment* (U.S. EPA, 1996), which state that repeated exposure is not a necessary prerequisite for the manifestation of developmental toxicity. While EPA considers certain developmental and reproductive effects observed in (Carney et al.,

2006; Tinston, 1994; Nelson et al., 1979; Beliles et al., 1980) potentially relevant to acute exposures, EPA determined that these studies were not the best choice for derivation of acute PODs. These studies presented a mix of outcomes which may not all be expected to present via acute exposures. Additionally, the range of doses evaluated in the studies was less sensitive than those from (Altmann et al., 1990), which also used human data which is preferable to the animal data available for developmental toxicity endpoints.

In the study by Altmann et al. (1990), male volunteers were exposed to PCE at 10 or 50 ppm, 4 hours/day for 4 days, with pattern reversal visual-evoked potentials evaluated after each day of exposure compared to non-exposure (subjects served as their own internal controls based on day 0 measurements). At 50 ppm, increased latencies in pattern reversal visual-evoked potential (p<0.05) were observed. Visual evoked potentials measure electrical signals recorded on the scalp near the occipital cortex in response to light. The pattern visual evoked potential represents an objective method of evaluating visual function and are sensitive measures of functional disorders. They can represent variation in arousal level or direct cortical depression. No effects on brainstem auditory-evoked potential were noted at either concentration. Because faint odor was reported by 33% of the subjects at 10 ppm and 29% of the subjects at 50 ppm on the first day of testing, and by 15% of the subjects at 10 ppm and 36% of the subjects at 50 ppm on the last day of testing, the investigators concluded that only a few subjects could identify their exposure condition. PCE in the blood increased with exposure duration, and based on linear regression, PCE was associated with increased pattern reversal visual-evoked potential latencies (r=-0.45, p<0.03) (Altmann et al., 1990). EPA considered this sensitive measure for indicating an adverse neurological outcome and selected 10 ppm as the no-observed-adverse-effect level (NOAEL) for exposures of 4 hours/day. The study scored a medium in data quality.

Other studies assessed different endpoints in the spectrum of neurotoxicity effects. Hake and Stewart (1977) exposed 4 male subjects sequentially to 0, 20, 100, and 150 ppm (each concentration 1 week) PCE 7.5 hours/day for 5 days. Changes in flash-evoked potentials or equilibrium tests were not observed. Subjective evaluation of EEG (electroencephalogram) scores suggested cortical depression in subjects exposed at 100 ppm. Decreases in the Flanagan coordination test were observed at ≥100 ppm. Rowe et al. (1952) exposed 6 volunteers to 106 ppm PCE for 1 hr. Eye irritation and a slight fullness in the head was noted by one subject, but other neurotoxicity endpoints were not evaluated.

The National Research Council (NRC) (2010) review of the PCE IRIS assessment included a recommendation of five studies for consideration in deriving the reference concentration (RfC) (Boyes et al., 2009; Gobba et al., 1998; Echeverria et al., 1995; Cavalleri et al., 1994; Altmann et al., 1990). Of these studies recommended for consideration by NRC, two are acute studies [the human chamber study of Altmann et al. (1990) and the rodent study of Boyes et al. (2009)]. The Altmann et al. (1990) study in humans is preferable to the Boyes et al. (2009) study in rodents.

Based on these considerations, EPA chose the effects observed in the human chamber study of Altmann et al. (1990) for dose-response analysis of acute effects. These studies identified increased latencies for pattern reversal visual-evoked potentials at 50 ppm and a NOAEL of 10 ppm.

3.2.5.1.2 Non-Cancer Toxicity from Chronic Exposure

The studies presented below are the principal studies containing adequate quantitative dose-response information for various endpoints within each health domain. See Section 3.2.5.4 for selection of the studies considered within each hazard domain.

Neurotoxicity

Based on the review in the EPA IRIS Assessment for PCE (U.S. EPA, 2012c) and NRC (2010), two studies, Cavalleri et al. (1994) and Echeverria et al. (1995), are considered the principal studies for the evaluation of chronic neurotoxicity. Endpoints selected were reaction time measures (Echeverria et al., 1995), cognitive changes (Echeverria et al., 1995), and visual function changes (Cavalleri et al., 1994). EPA's data quality evaluations of these studies were both medium. The 2012 Perchloroethylene IRIS Assessment (U.S. EPA, 2012c) additionally calculated the midpoint of the range from these two studies, and this value was also brought forward to dose-response analysis.

Kidney

Two acceptable studies were identified that contained adequate dose-response information: (Mutti et al., 1992) and (Jisa, 1993). Mutti et al. (1992) was an epidemiological study that identified urinary markers of neprotoxicity. JISA (1993) observed nuclear enlargement of proximal tubules in both rats and mice. Mutti et al. (1992) scored a medium in data quality and JISA (1993) scored a high.

Liver

Three studies were considered for dose-response analysis of liver effects. The same JISA (1993) study that examined kidney effects also observed increased liver angiectasis (extreme dilation of blood or lymph vessels) in mice. An NTP study (1986b) that also scored high in data quality identified increased liver degeneration and necrosis in mice, while the medium-quality study (Buben and O'Flaherty, 1985) reported increased liver/body weight ratio in mice following PCE administration.

Immune/Hematological

One epidemiological study was considered for dose-response analysis of immunological and hematological effects. Emara et al. (2010) identified statically significant changes in both measures among PCE-exposed dry cleaning workers with increased PCE exposure. While many other studies in both humans and rodents examined various immune and hematological outcomes, Emara et al. (2010) was selected for dose-response analysis because it was a high-quality occupational study with a strong exposure characterization examining long-term PCE exposure in humans that identified sensitive measures indicative of autoimmunity and other immune endpoints.

Reproductive/Developmental

Two human studies reported significantly increased ORs for spontaneous abortion with high exposure to PCE (Olsen et al., 1990; Kyyronen et al., 1989), however the numbers of cases and controls with high PCE exposure were very small, leading to very wide confidence intervals (low statistical precision) for the ORs. Additionally, a POD cannot be determined from these data due to the lack of quantitative exposure characterization. A single reproductive study in animals reported adequate dose-response information. Beliles et al. (1980) identified reduced sperm quality following 5 days of PCE exposure in mice. The study scored a high in data quality.

For developmental effects, three relevant studies in animals were identified. Nelson et al. (1979) identified decreased weight gain and developmental neurotoxicity in the form of altered behavior and changes in brain acetylcholine. The study only scored a low in data quality, however it was still

considered for dose-response analysis because it is the only identified study with adequate dose-response information relating to functional and molecular indicators of developmental neurotoxicity, and the CNS is an important target of perchloroethylene. The other two studies both scored a high in data quality and were also utilized for dose-response analysis. Tinston (1994) identified increased neonatal pup death and CNS depression in a two-generation study, and (Carney et al., 2006) observed decreased fetal/placental weight and skeletal effects in a short-term developmental toxicity study.

3.2.5.1.3 Cancer

As discussed in the Section 3.2.4.1.7, based on EPA Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005a), PCE is characterized as "likely to be carcinogenic in humans by all routes of exposure," based on conclusive evidence in mice and rats and suggestive evidence in humans. No available human studies of cancer were found to be suitable for dose-response assessment. Therefore, the following dose-response assessment is based on data from rodent bioassays. Multiple tumor type-specific MOAs for PCE carcinogenicity were considered (Section 3.2.3.3). Overall, the tumors reported in rodent bioassays are considered relevant to humans and human cancer risks are estimated from the rodent dose-response data using the linear non-threshold model.

As discussed in Section 3.2.3.2.3, three chronic exposure studies in rats and mice include an oral gavage study in mice and female rats by the National Cancer Institute (Nci, 1977) and two inhalation studies in mice and rats (Jisa, 1993; NTP, 1986b) established that PCE administration, either by ingestion or by inhalation to sexually mature rats and mice, results in increased incidence of tumors. Mouse liver tumors (hepatocellular adenomas and carcinomas) and rat mononuclear cell leukemia (MCL) were reported in both sexes in two lifetime inhalation bioassays employing different rodent strains (Jisa, 1993; NTP, 1986b), and mouse liver tumors were also reported in both sexes in an oral bioassay (Nci, 1977). Tumors reported in a single inhalation bioassay include kidney and testicular interstitial cell tumors in male F344 rats (NTP, 1986b), brain gliomas in male and female F344 rats (only male data presented below, (NTP, 1986b), and hemangiomas or hemangiosarcomas in male Crj:BDF1 mice (Jisa, 1993). See (U.S. EPA, 2012d) for more discussion.

All three bioassays (Jisa, 1993; NTP, 1986b; Nci, 1977) showed increases in hepatocellular tumors in male and female mice. Hemangiomas also increased in male mice and MCL increased in both sexes of rats. The data is summarized in Table 3-4 below.

The (NTP, 1986b) study reported dose-dependent increases in renal tubular cell adenomas and adenocarcinomas in male rats. While the increases were not statistically significant compared with the concurrent controls, the incidence was above the historical control range for the laboratory (8% vs. 0.2%, respectively). The biological significance of these results was further bolstered by the rarity of those tumors, evidence for induction of this tumor type in humans from the related trichloroethylene, and indications of nephrotic and mutagenic metabolites in the kidney following PCE exposure (U.S. EPA, 2012d). Brain tumors showed low incidence in (NTP, 1986b), however biological significance is increased by the strong association of PCE exposure with neurotoxicity and the rarity of rat brain tumors in control animals (U.S. EPA, 2012d). Testicular tumors were observed in very high control incidences in both (NTP, 1986b) and (Jisa, 1993).

Despite the positive results, the NCI (1977) study was considered to be inconclusive because of the high incidence of respiratory disease and high early mortality in exposed mice. EPA therefore considered the JISA (1993) and NTP (1986b) studies for dose-response analysis. Both studies scored a High for data quality, however (Jisa, 1993) examined an additional lower dose level and covered a broader dose range. Therefore, the JISA (1993) study was selected for use in dose-response analysis and POD derivation for

hepatocellular tumors, hemangiomas, and MCL, which all demonstrated statistically significant dose-responsive increases in (Jisa, 1993). The study is **bolded** in Table 3-4 below.

Table 3-4. Tumor incidence in mice and rats exposed to PCE

Bioassay	Doses/Exposures		Sex	Body Weight[a] (kg)	Survival-adjusted tumor incidence[b] (%)	
	Administered	Continuous Equivalent				
Hepatocellular adenomas or carcinomas						
NCI (1977)[c] B6C3F$_1$ mice Gavage: 5 d/wk, 78 wk	Vehicle control 450 mg/kg-day 900	0[e] mg/kg-day 332 663	Male	0.030	2/20 32/48 27/45	(10) (67) (60)
	Vehicle control 300 mg/kg-day[d] 600	0[e] mg/kg-day 239 478	Female	0.025	0/20 19/48 19/45	(0) (40) (42)
NTP (1986b) B6C3F$_1$ mice Inhalation: 6 hr/d, 5 d/wk, 104 wk	0 ppm 100 200	0 ppm 18 36	Male	0.037	17/49 31/47 41/50	(35) (70) (82)
	0 ppm 100 200	0 ppm 18 36	Female	0.032	4/45 17/42 38/48	(9) (40) (79)
JISA (1993) **Crj:BDF1 mice** **Inhalation:** **6 hr/d,** **5 d/wk,** **104 wk**	0 ppm 10 50 250	0 ppm 1.8 9.0 45	Male	0.048	13/46 21/49 19/48 40/49	(28) (43) (40) (82)
	0 ppm 10 50 250	0 ppm 1.8 9.0 45	Female	0.035	3/50 3/47 7/48 33/49	(6) (6) (15) (67)
Hemangioma/hemangiomasarcomas[e]: liver, spleen						
NTP (1986b) Same conditions as above	0 ppm 100 200	0 ppm 18 36	Male	0.037	3/49 2/49 2/50	(6) (4) (4)
JISA (1993) **Same conditions as above**	0 ppm 10 50 250	0 ppm 1.8 9.0 45	Male	0.048	4/46 2/49 7/48 11/49	(4) (2) (13) (18)
Mononuclear cell leukemia (MCL)						
NTP (1986b) F344/N rats Inhalation: 6 hr/d, 5 d/wk, 104 wk	0 ppm 200 400	0 ppm 36 71	Male	0.44	28/50 37/48 37/50	(56) (77) (74)
	0 ppm 200 400	0 ppm 36 71	Female	0.32	18/50 30/50 29/50	(36) (60) (58)
JISA (1993) **F344/CuCrj rats** **Inhalation:** **6 hr/d,** **5 d/wk,** **104 wk**	0 ppm 50 200 600	0 ppm 9 36 110	Male	0.45	11/50 14/50 22/50 27/50	(22) (28) (44) (54)
	0 ppm 50 200	0 ppm 9 36	Female	0.3	10/50 17/50 16/50	(20) (34) (32)

Bioassay	Doses/Exposures		Sex	Body Weight[a] (kg)	Survival-adjusted tumor incidence[b] (%)	
	Administered	**Continuous Equivalent**				
	600	110			19/50	(38)
Kidney: tubular cell adenoma or adenocarcinoma						
NTP (1986b) Same conditions as above	0 ppm 200 400	0 ppm 36 71	Male	0.44	1/49 3/47 4/50	(2) (6) (8)
Brain gliomas						
NTP (1986b) Same conditions as above	0 ppm 200 400	0 ppm 36 71	Male	0.44	1/50 0/48 4/50	(2) (0) (8)
Testicular interstitial cell tumors						
NTP (1986b) Same conditions as above	0 ppm 200 400	0 ppm 36 71	Male	0.44	35/50 39/47 41/50	(70) (83) (82)
JISA (1993) Same conditions as above	0 ppm 50 200 600	0 ppm 9 36 110	Male	0.45	47/50 46/50 45/50 48/50	(94) (92) (90) (96)

Note: Data sets carried through dose-response modeling shown in bold. Data is from Table 5-13 and 5-15 in (U.S. EPA, 2012d).

[a]Average body weight reached during adulthood.

[b]Animals dying before the first appearance of the tumor of interest but no later than Week 52 were omitted from the totals because these animals were presumed not to have adequate time on study to develop tumors.

[c]No adenomas were reported in this study.

[d]Gavage doses listed were increased after 11 weeks by 100 mg/kg-day in each low-dose group or by 200 mg/kg-day in each high-dose group. Animals surviving the 78-week exposure period were observed until Week 90 study termination. Lifetime average daily (administered) doses (LADDs) were calculated as follows:

$$\text{LADD (mg/kg-day)} = \text{Cumulative administered dose (mg/kg)/(total days on study)}$$
$$= \{[(\text{initial dose rate} \times 11 \text{ weeks}) + (\text{later dose rate} \times 67 \text{ weeks})]/90 \text{ weeks}\} \times 5/7 \text{ (days)}$$

[e]These tumors were reported as hemangioendotheliomas in the JISA (1993) report. The term has been updated to hemangiosarcoma. Note that these incidences do not match those tabulated in Tables 11 and 12 of the JISA report summary. The incidences reported here represent a tabulation of hemangioendotheliomas in liver or spleen from the individual animal data provided in the JISA report.

3.2.5.2 Potentially Exposed and Susceptible Subpopulations

TSCA Section 6(b)(4)(A) requires EPA to conduct risk evaluations to "determine whether a chemical substance presents an unreasonable risk of injury to health or the environment, without consideration of costs or other non-risk factors, including an unreasonable risk to a potentially exposed or susceptible subpopulation identified as relevant to the risk evaluation by the Administrator, under the conditions of use." TSCA § 3(12) states that "the term 'potentially exposed or susceptible subpopulation' means a group of individuals within the general population identified by the Administrator who, due to either greater susceptibility or greater exposure, may be at greater risk than the general population of adverse health effects from exposure to a chemical substance or mixture, such as infants, children, pregnant women, workers, or the elderly."

During Problem Formulation (U.S. EPA, 2018d), EPA identified potentially exposed or susceptible subpopulations during the development and refinement of the life cycle, conceptual models, exposure scenarios, and analysis plan. In this section, EPA addresses the potentially exposed or susceptible subpopulations identified as relevant based on *greater susceptibility*. EPA addresses the subpopulations identified as relevant based on *greater exposure* in Section 2.4.4.

Factors affecting susceptibility examined in the available studies on PCE include lifestage, biological sex, genetic polymorphisms, race/ethnicity, preexisting health status, lifestyle factors, and nutrition status. Individuals exhibiting any of these factors can be considered part of a susceptible subpopulation. PCE is lipophilic and accumulates in fatty fluids and tissues in the human body (Section 3.2.2.1.2). Additionally, the PCE half-life is substantially higher in adipose tissue compared to others (55-65 hours in adipose, <12-40 hours in others, see Section 3.2.2.1.4). Subpopulations that may have higher body fat composition, and therefore may be more highly exposed to sustained internal PCE concentrations/doses, include pubescent and adult women (including women of child-bearing age) as well as any individual with an elevated body-mass-index. Based on evidence of developmental toxicity from PCE exposure in both animals and humans (Section 3.2.4.1.6), pregnant women, the developing fetus and newborn infants are all considered highly susceptible subpopulations, and therefore women of childbearing age are susceptible by proxy. Effects on male fertility are more likely to present in older men, while kidney and liver effects are of most concern to subpopulations with pre-existing liver or kidney dysfunction. The partitioning of PCE to fatty tissue is of particular concern for those with fatty liver disease. Neurological endpoints are primarily related to visual function, pattern recognition, and memory. Therefore, subpopulations with poor vision or neurocognitive deficiencies may be especially susceptible to these hazards.

Variability in CYP metabolic capacity is generally believed to vary by approximately 10-fold among all humans, however individual variations in *in vitro* CYP2E1 activity as high as 20-50-fold have also been reported. Diagnoses of polymorphisms in carcinogen-activating and -inactivating enzymes and cancer susceptibility have been noted, and GST polymorphisms have been associated with increased risk of kidney cancer in the related chemical trichloroethylene. Co-exposure to other pollutants and drugs may also have either an activating or inhibitory effect on PCE-metabolizing enzymes (U.S. EPA, 2012c).

3.2.5.3 Derivation of Points of Departure (PODs)

3.2.5.3.1 Non-Cancer PODs for Acute/Short-term Inhalation Exposure

Workers and consumers can be exposed to a single acute exposure to PCE under various conditions of use via inhalation and dermal routes. EPA identified PODs for several acute inhalation exposure durations based on both hazard and exposure considerations. The duration of 4 hrs/day is based on the study conditions of Altmann et al. (1990). Longer durations of 8 hrs/day and 12 hrs/day are representative of typical work shifts and are used for occupational settings. For consumers, EPA also evaluated a 24-hr exposure to account for exposure scenarios when a user remains in the house after using a PCE-containing product, *i.e.*, a consumer product used for a specific length of time, with subsequent exposure to dissipating concentrations of PCE in the indoor environment over the course of a day. Conversion of the acute PODs for different exposure durations are shown in Table 3-5. The data from (1990) was from a human study and therefore was not subject to PBPK modeling, with Human Equivalent Concentration (HEC) values adjusted only based on exposure duration. Consequently, applied/ambient concentration of PCE was used as the dose metric.

Altmann et al. (1990) is a relatively well-conducted study of 10 volunteers each that identified increased latencies for pattern reversal visual-evoked potentials after 4 hrs/day for 4 days exposure to 50 ppm and

no effects at 10 ppm. EPA's data quality evaluation rated this study medium quality. EPA used the NOAEC of 10 ppm for the 4-hour HEC. The ATSDR Toxicity Profile included this NOAEC among endpoints for derivation of the acute MRL (minimum risk level) (ATSDR, 2019). The acute MRL was derived for exposures up to 14 days and additional information was considered for exposures longer than the 4 days of the Altmann et al. (1990). This is consistent with how EPA is considering Altmann et al. (1990) for acute exposures to workers and consumers.

Table 3-5. Conversion of Acute PODs for Different Exposure Durations

Exposure Duration	POD/HEC	Effect	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality
4 hrs/day duration of the study	10 ppm (68 mg/m^3)	Neurotoxicity increased latencies for pattern reversal visual-evoked potentials	UF_A=1; UF_H=10; UF_L=1 Total UF=10	Altmann et al. (1990)	Medium
8 hrs/day	5 ppm (34 mg/m^3)				
12 hrs/day	3.3 ppm (22 mg/m^3)				
24 hrs/day	1.7 ppm (11 mg/m^3)				

EPA applied a composite UF of 10 for the acute inhalation benchmark MOE, based on the following considerations:

1) **Interspecies uncertainty/variability factor (UF_A) of 1 -** Accounting for differences between animals and humans is not needed because the POD is based on data from humans

2) **A default intraspecies uncertainty/variability factor (UF_H) of 10 -** To account for variation in sensitivity within human populations due to limited information regarding the degree to which human variability may impact the disposition of or response to PCE. Some of the specific variabilities/uncertainties for PCE are accounted for with this UF_H include toxicokinetic differences.

3) **A LOAEC-to-NOAEC uncertainty factor (UF_L) of 1 -** The POD is based on a NOAEC so this factor is not needed.

3.2.5.3.2 Non-Cancer PODs for Chronic Inhalation Exposure

All chronic PODs were derived as 24hr Human Equivalent Concentration (HEC) values, with results from animal studies adjusted for continuous exposure based on the output from the PBPK model as presented in (U.S. EPA, 2012d). All PODs are presented in Table 3-8.

Neurotoxicity

EPA identified LOAELs for color confusion from (Cavalleri et al., 1994) and impaired pattern recognition and reaction time in pattern memory from (Echeverria et al., 1995) as relevant endpoints for POD derivation. For the studies and endpoints selected, it was determined that PODs could not be derived using dose-response modeling (described in more detail in (U.S. EPA, 2012d)). Therefore, the midpoint of the range of the two LOAELs from each study was also derived as a POD for chronic neurotoxicity overall. This is consistent with the use of the midpoint for the reference concentration/dose in (U.S. EPA, 2012d). For occupational human studies such as these, the HEC derivation also involved

adjusting the breathing rate from 10 m^3/workday over 8 hrs to 20m^3/day over 24 hrs, and multiplying the PODs by 5/7 to adjust from weekday working hours to continuous exposure (U.S. EPA, 2012d). As for the acute POD, the data underlying the chronic neurotoxicity POD was from human studies and therefore was not subject to PBPK modeling, with HEC values adjusted only based on exposure duration. Consequently, applied/ambient concentration of PCE was used as the dose metric.

EPA attempted to benchmark dose (BMD) model the results from (Cavalleri et al., 1994) and (Echeverria et al., 1995) for improved precision in the POD. However, BMD modeling was not feasible for either study. For (Cavalleri et al., 1994), a normative baseline value for color confusion could not be determined because normal ranges are influenced by age and the study did not provide ages associated with each individual score and exposure measurement. Therefore, an adequate comparison for determining a benchmark response was unavailable. For (Echeverria et al., 1995), there was no control group or historical control data available. While a control level could be inferred by extrapolating from individual exposure and response data, projecting a control response and biologically relevant level of change from that point was judged to be too uncertain (U.S. EPA, 2012d).

EPA applied a composite UF of 100 for the inhalation benchmark MOE for neurotoxicity, based on the following considerations:

1) Interspecies uncertainty/variability factor (UF_A) of 1
Accounting for differences between animals and humans is not needed because the POD is based on data from humans

2) An intraspecies uncertainty/variability factor (UF_H) of 10
To account for variation in sensitivity within human populations due to limited information regarding the degree to which human variability may impact the disposition of or response to PCE.

3) A LOAEC-to-NOAEC uncertainty factor (UF_L) of 10
To account for the lack of a NOAEC.

4) Subchronic to chronic factor (UF_S) of 1
Accounting for additional adjustment for shorter duration studies is not required because the data for these endpoints come from chronic studies covering greater than 10% of human lifetime.

Alternative HEC for Occupational Scenarios
In addition to the HEC derived from the 2012 IRIS Assessment (U.S. EPA, 2012d), EPA derived 8 hr HEC values for the above endpoints based on occupational exposure.

The 24 hr HEC as originally derived was applicable to the general population, who would be continuously exposed to PCE at a resting breathing rate. The data for these endpoints are from epidemiological studies of dry cleaning and laundry workers exposed to PCE. In order to account for increased breathing rate of workers (*i.e.*, 10 m^3 over 8 hr as opposed to 20 m^3 over 24 hr, according to (U.S. EPA, 2012d), EPA additionally derived 8 hr occupational HECs using the 8 hr LOAEC values from the original studies. 12 hr HECs were also derived based on Haber's Law adjustment from the 8 hr values for use with 12 hr Occupational Exposure Scenarios (OES). These additional derivations did not result in any change to the uncertainty factors.

Kidney
EPA identified a LOAEL from (Mutti et al., 1992) for urinary biomarkers along with NOAELs from (Jisa, 1993) for proximal tubule nuclear enlargement in both mice and rats. While it is generally believed that GSH conjugation metabolites are involved, the large uncertainty in estimates of human GSH conjugation preclude use of that dose metric. Instead, the AUC of PCE in blood was used as a surrogate for purposes of PBPK modeling. Cumulative UFs for the two NOAELs is 30, with a UF_H =10 for human uncertainty/variability and UF_A = 3 for interspecies toxicodynamic uncertainty/variability, because only toxicokinetic differences are captured by the PBPK model. The LOAEL from (Mutti et al., 1992) is a human study and therefore has a UF_A of 1, however it has an additional UF_L of 10 for being based on a LOAEL and therefore the cumulative UF is 100. All studies are of chronic duration, so UF_S = 1.

Liver
EPA identified three distinct liver endpoints in mice as suitable for dose-response analysis. TCA as the sole contributory metabolite cannot explain tetrachloroethylene-induced hepatotoxicity (Clewell et al., 2005; Buben and O'Flaherty, 1985). It is not known whether reactive intermediates such as tetrachloroethylene oxide and trichloroacetyl chloride are involved in induced liver toxicity. While the MOA and toxic moiety for PCE-induced liver toxicity are not clear, the total rate of oxidative metabolism in the liver was chosen as the dose metric because oxidative metabolism is believed to be likely involved in liver toxicity. The NOAEL from (Jisa, 1993) for increased angiectasis (abnormal dilation of blood vessels) has a cumulative UF of 30 based on UF_A and UF_H as described above. A LOAEL was obtained for increased liver degeneration/necrosis from (NTP, 1986b), resulting in a cumulative UF of 300 due to the added UF_L of 10. These two studies are of chronic duration, so UF_S = 1. A LOAEL for increased liver/body-weight ratio from subchronic data in (Buben and O'Flaherty, 1985) has a cumulative UF of 3000 due to the added UF_L of 10 and UF_S = 10.

Immune/Hematological
EPA derived a LOAEL from the mean PCE blood level of subjects in (Emara et al., 2010) based on changes in various immune and hematological parameters. The PBPK model was then used to estimate a corresponding air concentration for this blood level, assuming constant concentration during exposure**.** The AUC of PCE in blood was used as the preferred dose metric due to lack of reliable data on MOA for these effects. This POD can be considered as a chronic LOAEL, because it is based on exposure concentrations from mean 7-years of exposure resulting in an adverse outcome. The study has a cumulative UF of 100 based on UF_H and UF_L of 10 each.

Reproductive/Developmental
A reproductive NOAEL for reduced sperm quality in mice was obtained from (Beliles et al., 1980). The AUC of PCE in blood was used as the preferred dose metric due to lack of reliable data on MOA for these effects. Despite being of only 5 days exposure, this exposure duration covers the window of sperm production while the observation period up to 10 weeks covered the full period of spermatogenesis. Therefore, longer exposure would not be expected to result in additional sensitivity and UF_S = 1. The cumulative UF is 30 based on UF_A and UF_H as described above.

PODs were derived from three developmental toxicity studies in rats (Carney et al., 2006; Tinston, 1994; Nelson et al., 1979). The durations were sufficient to cover the entire developmental window, and therefore, UF_S = 1. The cumulative UF = 30 based on NOAELs from animals as previously described.

3.2.5.3.3 Cancer Slope Factor Derivation
This section provides details of the dose-response modeling carried out for developing cancer risk values and is summarized from the EPA IRIS Assessment for PCE (U.S. EPA, 2012c). This summary focuses

on hepatocellular tumors, the tumor type that was observed in all three animal bioassays and was the basis of the cancer slope factors in the EPA IRIS Assessment for PCE (U.S. EPA, 2012c). The steps include estimation of dose metrics using relevant PBPK modeling, suitable adjustment to continuous daily exposures from intermittent bioassay exposures, dose-response modeling in the range of observation, interspecies extrapolation, extrapolation to low exposures, and route-to-route extrapolation. An overview of these steps is provided in Figure 3-4.

As stated previously, the available evidence likely supports a complex MOA for PCE tumorigenesis, with multiple contributing mechanisms of varying significance. Based on EPA's 2005 Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005a), a low-dose linear default approach is supported because the "mode of action information is supportive of linearity or mode of action is not understood." Therefore, EPA derived cancer PODs as an inhalation unit risk (IUR) and oral slope factor (OSF) based on this linear modeling approach.

EPA decided not to use the IUR or OSF to calculate the theoretical cancer risk associated with single (acute) or short-term, intermittent exposures to PCE. NRC (2001) published methodology for extrapolating cancer risks from chronic to short-term exposures to mutagenic carcinogens, however these methods were published with the caveat that extrapolation of lifetime theoretical excess cancer risks to single exposures is highly uncertain. Thus, this Risk Evaluation for PCE does not estimate excess cancer risks for acute exposures because the relationship between a single short-term exposure to TCE and the induction of cancer in humans has not been established in the current scientific literature. Risk estimates for cancer will be based on lifetime exposure durations, represented as Lifetime Average Daily Concentration/Dose (LADC/LADD).

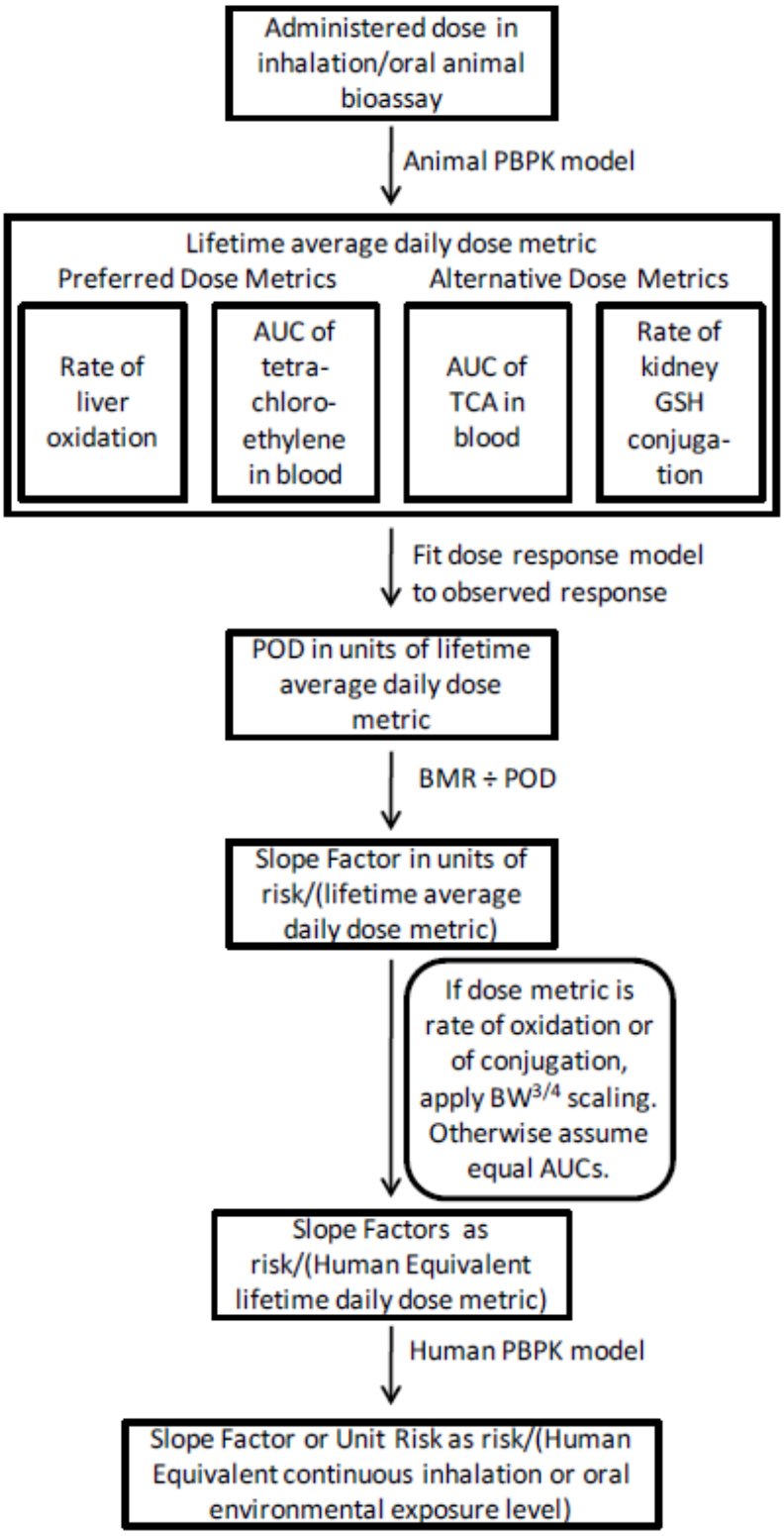


Figure 3-4. Sequence of steps for extrapolating from PCE bioassays in animals to human-equivalent exposures expected to be associated with comparable cancer risk (combined interspecies and route-to-route extrapolation).

Several metabolites of PCE are genotoxic both *in vivo and in vitro* (Section 3.2.3.2.1), and it is thought that the hepatocarcinogenicity of the parent compound is mediated through the action of one or more of its metabolites (Section 3.2.3.3). Oxidative metabolism is thought to predominate in the liver, and TCA is the major resultant urinary excretion product. As discussed in Section 3.2.3.2.1, TCA appears to be formed from spontaneous decomposition of trichloroacetyl chloride, which is known to bind to macromolecules. Dichloroacetic acid (DCA) may be formed from dechlorination of TCA, but DCA produced from this pathway is likely to be rapidly metabolized in the liver and not detected in blood or urine. DCA that has been detected in urine is thought to be the result of kidney- specific β-lyase metabolism of the results of GSH conjugation of PCE and DCA produced from this pathway is presumed to not play a role in liver toxicity or cancer. The potential role of GST conjugates of PCE in liver carcinogenicity, although unknown, is presumed to be less important than the role of oxidative metabolites.

As described in (U.S. EPA, 2012c), total (liver) oxidative metabolism and TCA AUC in the liver were considered as potential dose metrics for the liver tumors observed in male and female mice in the JISA bioassay (Jisa, 1993). While TCA is the major resultant urinary excretion product of oxidative metabolism, TCA is not formed directly, but instead, from hydrolysis of trichloroacetyl chloride (Section 3.2.3.3). In addition, tumor phenotype data suggest that TCA may not be the sole tumorigenic metabolite of PCE. However, the limited available data precludes any definitive conclusions. Therefore, total oxidative metabolism is considered to be the most relevant dose-metric for liver cancer and TCA AUC in liver was considered as an alternative dose metric. Because there is uncertainty about the MOA and toxic moiety (*e.g.*, parent or metabolite) for the hemangiomas/ hemangiosarcomas in female mice and MCL in both male and female rats, PCE AUC in blood was considered the best dose metric. The kidney tumors are thought to be associated with the production of genotoxic and nephrotoxic metabolites via the GSH conjugation pathways. While GSH metabolism is considered to be highly relevant for kidney carcinogenicity, the PBPK modeling results for that metric were highly uncertain (2011a), and as a result, less reliable (Section 3.2.2.2). Therefore, PCE AUC in blood was selected as the primary metric for kidney cancer, with total GSH metabolism selected as the alternate metric.

Modeling for all dose metrics generated fits for one-, two-, and three-stage models (details for hepatocellular cancer in Appendix F; see Appendix D in (U.S. EPA, 2012c) for results of other tumor types). All model fits had adequate goodness-of-fit p-values ($p > 0.05$), and overall adequate fit. A summary of the results for hepatocellular adenomas or carcinomas, hemangiosarcomas, and MCL from JISA (1993) are shown in Table 3-6 based on their preferred dose metric.

The majority of the National Research Council (NRC) peer review panel for the IRIS assessment (NRC, 2010) recommended that the male mouse hepatocellular tumors be used for cancer risk estimation. EPA agrees with this recommendation and notes that this decision is justified by the fact that increased incidence of hepatocellular tumors were observed in mice in three independent studies and in both sexes (Table 3-4). This tumor type also has a lower historical background incidence in mice, compared to MCL (NRC, 2010). While the slope factor for combined hemangiomas and hemangiosarcomas was more sensitive, EPA decided not to use it for the cancer risk assessment because the increased incidence was only observed in males in one study (Jisa, 1993). Further, the JISA report did not provide the individual animal data for the spleen and liver hemangiosarcomas, and therefore, it was not possible to confirm that all of the tumors arose in separate animals. Therefore, male mouse hepatocellular tumor data from the JISA (1993) bioassay was selected to represent the cancer POD for PCE. The IUR derivation is **bolded** in Table 3-6 below.

Table 3-6. Human equivalent candidate unit risks, derived using PBPK-derived dose metrics and multistage model; tumor incidence data from JISA (1993) for hepatocellular adenomas or carcinomas

Study Group	Tumor type (multistage model with all dose groups unless otherwise specified)	Human Equivalents				
		POD[a] in internal dose units and dose metric used			Candidate SF /internal dose unit[b]	Candidate IUR /ppm (PBPK range)[c]
Primary dose metrics						
Male mice JISA (1993)	**Hepatocellular adenomas or carcinomas**	**BMD_{10}** **$BMDL_{10}$**	**2.9** **2.1**	**Total liver oxidative metabolism, mg/kg0.75-d**	**4.9E-2**	**1.8E-3** (1.6–1.8)
	Hemangiomas, hemangiosarcomas	BMD_{10} $BMDL_{10}$	63 34	PCE AUC in blood, mg-hr/L-d	2.9E-3	**5.9E-3** (5.9–6.9)
Female mice JISA (1993)	Hepatocellular adenomas or carcinomas	BMD_{10} $BMDL_{10}$	8.4 4.0	Total liver oxidative metabolism, mg/kg0.75-d	2.5E-2	**0.90E-3** (0.84–0.93)
Male rats JISA (1993)	MCL	BMD_{10} $BMDL_{10}$	46 30	PCE AUC in blood, mg-hr/L-d	3.4E-3	**8.8E-3** (6.8-8.0)
	MCL (Michaelis-Menten)	BMD_{10} $BMDL_{10}$	20 5.0	PCE AUC in blood, mg-hr/L-d	2.0E-2	**4.0E-2** (40-47)
Female rats JISA (1993)	MCL	BMD_{10} $BMDL_{10}$	136 61	PCE AUC in blood, mg-hr/L-d	1.6E-3	**3.3E-3** (3.3-3.9)
	MCL (control and low dose groups only)	BMD_{10} $BMDL_{10}$	11 5.2	PCE AUC in blood, mg-hr/L-d	1.9E-02	**3.9E-2** (3.9-4.5)
Female and male rats combined JISA (1993)	MCL (Michaelis-Menten)	BMD_{10} $BMDL_{10}$	17 3.0	PCE AUC in blood, mg-hr/L-d	3.3E-2	**6.8E-2 (6.7-7.1)**

Note: From Table 5-18 in the U.S. EPA (2012d) IRIS assessment of PCE; SF = Slope Factor; IUR = Inhalation Unit Risk; MCL= Mononuclear cell leukemias.

[a] PODs were estimated at the indicated BMRs in terms of extra risk; *i.e.*, BMDL10 = lower bound for the level of the internal dose metric associated with 10% extra risk. Dose metric units are in the first column and include cross-species scaling to a human equivalent internal dose metric. Refer to Appendix D for dose-response modeling details.

[b] Slope Factor = BMR/BMDLBMR in units of risk per dose metric unit (as given in the first column).

[c] Inhalation unit risk (IUR) is given by the product of the slope factor in units of risk per dose metric unit and an inhalation dose metric conversion factor (DMCFppm): IUR = BMR/BMDLBMR × DMCFppm, where the DMCFppm is derived from the PBPK model.

Extrapolation to humans using total oxidative metabolism led to a BMD_{10} of 2.9, and its lower bound benchmark dose ($BMDL_{10}$) was 1.4-fold lower at 2.1 $mg/kg^{3/4}$-day liver oxidative metabolism. Linear extrapolation from the POD to low internal dose, followed by conversion to human exposures, led to a human equivalent unit risk of 1.8×10^{-3} per ppm (2×10^{-3} per ppm or 3×10^{-7} per $\mu g/m^3$, rounding to one significant digit)[24]. Extrapolation to humans using TCA AUC in liver led to a human equivalent internal dose POD ($BMCL_{10}$) of 69 mg-hr/L-day TCA in blood. Linear extrapolation from the POD to low internal dose, followed by conversion to human exposures, led to a human equivalent unit risk of 1.5×10^{-3} per ppm, slightly lower than the estimate using total liver oxidative metabolism. Dose-

[24] The IUR should not be used with exposures exceeding 60ppm (the equivalent ambient exposures corresponding to the POD for male mouse hepatocellular tumors), because above this exposure level, the dose-response relationship is not linear, and the unit risk would tend to overestimate risk. Lifetime Average Daily Concentration (LADC) values used for cancer risk estimates do not exceed this threshold for any occupational exposure scenario.

response modeling of the male mouse liver tumor data using administered exposure fit the data points similarly to when using total oxidative metabolism or TCA AUC in liver, and sensitivity analysis did not find that alternative models to the standard multistage model produced better results (details in (U.S. EPA, 2012c)).

3.2.5.4 Points of Departure for Human Health Hazard Endpoints and Confidence Levels

Confidence Levels

For non-cancer endpoints following acute exposures, the value used in this risk evaluation is from Altmann et al. (1990), a medium quality short-term study demonstrating neurotoxicity based on impaired visual function associated with delayed neurological signaling. This endpoint is robustly supported by multiple human and animal studies. The data from Altmann et al. (1990) is based on 4 days of 4 hr/day exposure, so applying the dose-response analysis to a single day of exposure involves some uncertainty, however it is unlikely that outcomes would substantially differ between a single day and 4 days of exposure. Overall, there is medium-high confidence in this endpoint.

For non-cancer endpoints following chronic exposures, multiple endpoints are available representing the health domains of neurotoxicity, kidney toxicity, liver toxicity, immune toxicity, and reproductive/developmental toxicity. These endpoints are supported by data in both humans and animals and the range of PODs is within ~10-fold for most endpoints, although the full set of endpoints range by as much as 150-fold. Overall, there is medium-high confidence in the chronic endpoints.

For cancer endpoints following chronic exposures, there is evidence of carcinogenicity in multiple tissues. The IUR (Inhalation Unit Risk) was developed from a High-quality animal study, however the limited available human data was ambiguous. Overall, there is medium confidence in the cancer endpoint.

Table 3-7. Summary of PODs for Evaluating Human Health Non-Cancer Hazards from Acute Exposure Scenarios

Target Organ System	Species - route	Human Equivalent Concentration (HEC)	Effect	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality
CNS	Humans - Inhalation	4 hrs/day = 10 ppm (68 mg/m^3)	Neurotoxicity increased latencies for pattern reversal visual-evoked potentials	UF_A=1; UF_H=10; UF_L=1 **Total UF=10**	Altmann et al. (1990)	Medium
		8 hrs/day = 5 ppm (34 mg/m^3)				
		12 hrs/day = 3.3 ppm (22 mg/m^3)				
		24 hrs/day = 1.7 ppm (11 mg/m^3)				

Best Overall Non-Cancer Endpoints Following Chronic Exposures for Each Health Effect Domain

From among all chronic exposure studies, EPA selected the most robust and sensitive endpoints or PODs from within each health effect domain/organ system for risk estimation under TSCA. These endpoints are highlighted in blue in Table 3-8 below. There is high confidence in these robust PODs. Justification for the selections for each health domain are provided below:

CNS (Neurotoxicity)

PODs were derived from two studies (Echeverria et al., 1995; Cavalleri et al., 1994) that both observed CNS effects presenting as visual deficits. Both studies scored a medium in data quality and both studies

are based on human data with equivalent cumulative UFs. Therefore, the midpoint of the range as derived in (U.S. EPA, 2012c) is the best overall POD for this endpoint and the neurotoxicity domain overall. EPA additionally derived occupational HECs for this POD, as described in Section 3.2.5.3.2. These HECs are provided in a separate row highlighted in green.

Kidney effects
While there was a medium-quality human that reported urinary markers of nephrotoxicity (Mutti et al., 1992), this POD was derived from a LOAEL, which resulted in a cumulative UF of 100. The rodent study by JISA (1993) score a high in data quality and only had a combined UF of 30, indicating reduced uncertainty surrounding the POD. Therefore, this study was used to represent the kidney domain. There was no discernible difference among the mice and rat data from that study, so the POD derived from mice was used in order to represent the most sensitive and robust endpoint.

Liver effects
Three studies provided sufficient dose-response information for liver effects in mice (Jisa, 1993; NTP, 1986b; Buben and O'Flaherty, 1985). Both (Jisa, 1993) and (NTP 1986b) were of high data quality. The studies were equally sensitive when accounting for UFs, however only the data from (Jisa, 1993) provided a NOAEL and therefore had reduced uncertainty without a LOAEL-to-NOAEL UF. Increased liver/body weight ratio in (Buben and O'Flaherty 1985) is not considered adverse on its own and may be due to induction of PPARα, which is less active in humans. Additionally, that study scored a Medium as opposed to a High in data quality. Therefore, the POD from (Jisa, 1993) for increased angiectasis was selected to represent the liver domain.

Immune/hematological effects
One study was considered for dose-response analysis of immune and hematological effects (Emara et al., 2010), which identified sensitive measures that could be indicative of autoimmunity, anemia, and other immune effects. The study received a high-quality rating and was used to represent the immune and hematological domains.

Reproductive
There is only a single adequate study that identified reproductive effects (Beliles et al., 1980), which observed reduced sperm quality in males following only 5 days exposure. This study scored High in data quality and was therefore used to represent reproductive effects. Of note, despite this study only examining 5 days of exposure, this exposure duration covers the window of sperm production while the observation period up to 10 weeks covered the full period of spermatogenesis. Since PCE is not bioaccumulative, continuous exposure is not expected to result in a more sensitive toxicological response.

Developmental
Three studies demonstrated adequate dose-response information for developmental endpoints, each reporting varying but overlapping effects. Nelson et al. (1979) observed decreased weight gain in offspring along with indications of developmental neurotoxicity. Tinston et al. (1994) reported neonatal mortality as well as CNS effects in a two-generation reproductive toxicity study. Carney et al. (2006) observed decreased placental and fetal weight along with skeletal effects. Nelson et al. (1979) scored a low in data quality while the other two studies scored a high. Among the two high-quality studies, the POD from (Tinston, 1994) was selected to represent the domain because the data comes from a 2-generation study which would be expected to capture all potential developmental outcomes, as opposed to the short-duration study used in (Carney et al., 2006).

Table 3-8. Summary of PODs for Evaluating Human Health Non-Cancer Hazards from Chronic Exposure Scenarios

Target Organ System	Species - route	Human Equivalent Concentration (HEC)	Effect	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality Score
CNS	Humans - Inhalation	2.2 ppm (15 mg/m^3)	Neurotoxicity - Color confusion	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total UF=100**	Cavalleri et al. (1994)	Medium
	Humans - Inhalation (inferred)	8.3 ppm (56 mg/m^3)	Visual reproduction, pattern memory, pattern recognition and reaction time in pattern memory	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total UF=100**	Echeverria et al. (1995)	Medium
	Humans - Inhalation	5.2 ppm (36 mg/m^3)	Midpoint of the range of the two neurotoxicity studies	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total UF=100**	Based on U.S. EPA (2012c)	Medium
	Humans - Inhalation	14.5 ppm [8 hr] (99 mg/m^3) 9.7 ppm [12 hr] (66 mg/m^3)	Midpoint of the range of the two neurotoxicity studies (adjusted for 8 and 12 hr occupational TWAs)	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total UF=100**	Based on U.S. EPA (2012c)	Medium
Kidney	Humans - Inhalation (inferred)	5.0 ppm (34 mg/m^3)	Urinary markers of nephrotoxicity	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total UF=100**	Mutti et al. (1992)	Medium
	Rats - Inhalation	9.0 ppm (61 mg/m^3)	Nuclear enlargement in proximal tubules	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total UF=30**	JISA (1993)	High
	Mice - Inhalation	2.1 ppm (14 mg/m^3)	Nuclear enlargement in proximal tubules	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total UF=30**	JISA (1993)	High
Liver	Mice - Inhalation	31 ppm (210 mg/m^3)	Increased angiectasis in liver	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total UF=30**	JISA (1993)	High
	Mice - Inhalation	310 ppm (2100 mg/m^3)	Increased liver degeneration/necrosis	UF_A=3; UF_H=10; UF_L=10 UF_S = 1 **Total UF=300**	NTP (1986b)	High

Target Organ System	Species - route	Human Equivalent Concentration (HEC)	Effect	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality Score
	Mice - Oral (gavage)	40 ppm (270 mg/m^3)	Increased liver/body-weight ratio	UF_A=3; UF_H=10; UF_L=10 UF_S = 10 **Total UF=3000**	Buben and Flaherty (1985)	Medium
Immune/ Hematological	Humans – Inhalation	6.4 ppm (43 mg/m^3)	Reduced red blood cells and hemoglobin; Increased immune cells, IgE, IL-4	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total UF=100**	Emara et al. (2010)	High
Reproductive	Mice - Inhalation	21 ppm (140 mg/m^3)	Reduced sperm quality following 5 days exposure	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total UF=30**	Beliles et al. (1980)	High
Developmental	Rats	29 ppm (200 mg/m^3)	Decreased weight gain; altered behavior, brain acetylcholine	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total UF=30**	Nelson et al. (1979)	Low
	Rats - Inhalation	18 ppm (122 mg/m^3)	Increased F_{2A} pup deaths by Day 29, CNS depression in F_1 and F_2	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total UF=30**	Tinston (1994)	High
	Rats - Inhalation	16 ppm (110 mg/m^3)	Decreased fetal and placental weight, skeletal effects	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total UF=30**	Carney et al. (2006)	High

Notes: Rows shaded in blue indicate PODs selected as most robust and sensitive for the associated health domain. Row shaded in green indicates occupational HECs for the chronic neurotoxicity domain.

As explained in Section 3.2.5.3.3, the primary IUR is derived from male mouse hepatocellular tumor data, while the alternative IUR is from combined male and female rat MCL data. Both values are shown in Table 3-9.

Table 3-9. Summary of PODs for Evaluating Cancer Hazards from Chronic Inhalation Scenarios

Exposure Duration for Risk Analysis	Hazard Value	Effect	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality Score
CHRONIC EXPOSURE	IUR 2×10^{-3} per ppm (3×10^{-4} per mg/m^3)	male mouse hepatocellular tumors	Not applicable	JISA (1993)	High

The inhalation unit risk should not be used with exposures exceeding 60 ppm, or 400 mg/m^3 (the equivalent ambient exposures corresponding to the POD for male mouse hepatocellular tumors), because above this exposure level, the dose-response relationship is not linear, and the unit risk would tend to overestimate risk.

Cancer risks following acute exposures were not estimated. The relationship between a single short-term exposure to PCE and the induction of cancer in humans is not known.

3.2.5.4.1 Points of Departure for Children of Employees Present at Dry Cleaners

As discussed in Section 2.4.1.16, children of employees may be present all day at dry cleaning facilities, especially those too young to be in school (*e.g.*, infants and toddlers). Therefore, EPA assumed children could have acute exposures to PCE. Chronic exposures were not considered because exposure is not expected to comprise 10% of lifetime (U.S. EPA, 2002) when considering that while infants and toddlers who are not yet school age could spend the full workday at the facility for multiple days a week, once the children reach school age, they would expected to be present for shorter durations. The HECs derived above are based on adult parameters (*e.g.*, body weight, inhalation rate). EPA derived lifestage-adjusted HEC values for the key CNS endpoints based on differences in these parameters as shown in Table 3-10.

Table 3-10. Ratios of body weight and inhalation rate/day among lifestages

Population	Body Weight	Inhalation Rate/day	IR/BW	Relative Fold of Adult
Rat	0.225 kg	0.24 m^3/day	1.07	5.9
Adult	**80 kg**[a]	**14.7 m^3/day**[b]	**0.18**	**1**
Young Adult (age 16 <21)	71.6 kg	16.3 m^3/day	0.23	1.3
Youth (age 11 <16)	56.8 kg	15.2 m^3/day	0.27	1.5
Child (age 6 <11)	31.8 kg	12.0 m^3/day	0.38	2.1
Child (age 3 <6)	18.6 kg	10.1 m^3/day	0.54	2.8
Infant/Toddler (age 1-2)	12.6 kg	8.5 m^3/day	0.67	3.7
Infant (age <1)	7.8 kg	5.4 m^3/day	0.69	3.8

[a] The lifestage-specific default body weights were from Table 8-1 of the 2011 Exposure Factors Handbook (U.S. EPA 2011a). Mean body weights for infants/toddlers 1 <2 years includes ages 1 to <2 and 2 to <3. The body weight for infants (<1) is a weighted average of the mean body weights for birth to <1 month, 1 to <3 months, 3 to <6 months, and 6 to <12 months.

[b] The lifestage-specific inhalation rates were from Tables 6-1 of the 2011 Exposure Factors Handbook (U.S. EPA 2011a).

Based on differences in the inhalation rate/body weight ratio, the HEC for an infant was estimated to be 3.8-fold lower than that of adults. Table 3-11 presents the lifestage-adjusted HECs for CNS effects for the most sensitive lifestage of infants less than 1 year old. These PODs were derived from the default resting-rate acute HECs of adults in Table 3-7. EPA is unable to fully account for all toxicokinetic differences between adults and children, and differences in metabolism and other lifestage-specific factors could either increase or decrease the relative sensitivity of younger lifestages.

Table 3-11. Lifestage-Adjusted Infant HECs for CNS effects

Exposure Scenario	Endpoint	Adult HEC	Infant HEC	Reference
Acute (8 hr)	Increased latencies for pattern reversal VEPs	5.0 ppm (34 mg/m^3)	1.3 ppm (8.9 mg/m^3)	Altmann et al. (1990)
Acute (12 hr)		3.3 ppm (22 mg/m^3)	0.87 ppm (5.8 mg/m^3)	

3.2.5.4.2 Route-to-Route Extrapolation for Dermal PODs

For various exposure scenarios, workers and consumers can be exposed to PCE via the dermal route. EPA did not identify any toxicity studies by the dermal route that were adequate for dose-response assessment and the PBPK model does not contain a dermal compartment.

For Altmann et al. (1990), the PBPK-model was not used. Instead, the study NOAEC was used directly to generate dermal PODs with the equations below. The NOAEC was multiplied by inhaled volume to calculate an external applied dermal dose. Then, the dose was divided by body weight to generate the dermal PODs and slope factors.

Inhalation to dermal extrapolation for non-cancer effects:
dermal POD = inhalation POD [mg/m^3] × inhaled volume (m^3) ÷ body weight (kg)

Inhalation to dermal extrapolation for cancer effects:
dermal slope factor = IUR [per mg/m^3] ÷ inhaled volume (m^3) × body weight (kg)

The inhaled volume was the ventilation rate 1.25 m^3/hr (for light activity) times the appropriate exposure duration for the acute endpoint (4 hours from Altmann et al. (1990)), or 20 m^3 per day (based on 24 hours duration) for the chronic endpoints; and a body weight of 80 kg was applied in all cases. The inhalation rates were assumed based on EPA RfC Guidance (U.S. EPA, 1994c). EPA assumes that activities involving PCE exposure involve some movement, and thus, assumed a ventilation rate for light activity. The mean body weight of 80 kg was assumed based on the 2011 Exposure Factors Handbook (U.S. EPA, 2011a).

For the studies where the PBPK model was used, EPA derived dermal candidate values through two approaches as a type of sensitivity analysis to account for uncertainties in the assumptions used to convert either an oral HED or inhalation HEC to a dermal POD. First, the PBPK model was used to perform the interspecies the extrapolation from rodent to human, estimating HECs. Dermal PODs and slope factors were then estimated from the HECs, as described above. For the second approach, the PBPK model was used to perform the interspecies and inhalation to oral route-to-route extrapolations, estimating an oral human equivalent dose (HED). The results are shown in Table 3-12.

Differences in absorption across routes are accounted for in the occupational (Section 2.4.1.28) and consumer (Section 2.4.2.2.2) dermal exposure assessments, respectively. EPA assumed 100% absorption of PCE by the oral route based on animal data (ATSDR, 2019; U.S. EPA, 2012c). For PCE exposures via the inhalation route, studies in humans and laboratory animals provide clear evidence that tetrachloroethylene is readily absorbed via the lungs into the systemic circulation (Dallas et al., 1994b; Section 3.2.2.1.1); however, the volatility of PCE significantly decreases the expected dermal absorption under non-occluded conditions. The occupational exposure estimates incorporated modeled absorption under non-occluded conditions through the *Dermal Exposure to Volatile Liquids Model* while consumer dermal exposure utilizes the permeability module from the Consumer Exposure Model (CEM) was used to estimate dermal exposure only for COUs under which impeded evaporation is expected. Because dermal absorption of PCE was accounted for in the dermal exposure estimates (see Sections 2.4.1.28 and 2.4.2.2.2), the HECs and HEDs were able to be used directly with the dermal exposures to calculate the MOEs.

For all endpoints that were able to be derived from both an HEC and HED, the difference between the resulting dermal PODs was less than 2-fold. Considering the uncertainties involved in extrapolation from either route (*e.g.*, effects of first-pass metabolism, uncertainties in physiological parameters used

for extrapolations), the most robust and sensitive POD was selected for use in the dermal risk estimations. The dermal POD value to be used for risk estimates is bold in the table below, and the selected studies are highlighted in blue, as was done in Table 3-8.

Table 3-12. Derivation of Dermal PODs by Route-to-Route Extrapolation

Target Organ System and Effect	Inhalation POD and Duration	Inhalation to Dermal Adjustments	Inhalation to Dermal HED (mg/kg-day)	Oral/ Dermal[a] HED (mg/kg-day)	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality
Acute Exposures							
CNS Increased latencies for pattern reversal visual-evoked potentials	10 ppm (68 mg/m^3) 4 hrs/day	1.25 m^3/hr 4 hrs/day 80 kg BW	**4.25**[b]	N/A[c]	UF_A=1; UF_H=10; UF_L=1 **Total =10**	Altmann et al. (1990)	Medium
Chronic Exposures							
CNS Color confusion	2.2 ppm (15 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	3.75	**2.6**	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total =100**	Cavalleri et al. (1994)	Medium
CNS Visual reproduction, pattern memory, pattern recognition and reaction time in pattern memory	8.3 ppm (56 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	14	**9.7**	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total =100**	Echeverria et al. (1995)	Medium
Midpoint of the range of the two neurotoxicity endpoints	5.2 ppm (36 mg/m^3)	20 m^3/day 80 kg BW	9.0	**6.2**	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total =100**	Based on U.S. EPA (2012c)	Medium
Kidney Urinary Markers of nephrotoxicity	5.0 ppm (34 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	8.5	**5.4**	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total =100**	Mutti et al. (1992)	Medium
Kidney Nuclear enlargement in proximal tubules	9.0 ppm (61 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	15	**9.5**	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total =30**	JISA (1993)	High
Kidney Nuclear enlargement in proximal tubules	2.1 ppm (14 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	3.5	**2.2**	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total =30**	JISA (1993)	High
Liver Increased angiectasis in liver	31 ppm (210 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	52.5	**24.5**	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total =30**	JISA (1993)	High

Target Organ System and Effect	Inhalation POD and Duration	Inhalation to Dermal Adjustments	Inhalation to Dermal HED (mg/kg-day)	Oral/ Dermal[a] HED (mg/kg-day)	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality
Liver Increased liver degeneration/ necrosis	310 ppm (2100 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	525	**252**	UF_A=3; UF_H=10; UF_L=10 UF_S = 1 **Total =300**	NTP (1986b)	High
Liver Increased liver/body-weight ratio	40 ppm (270 mg/m^3) 24 hrs/day	20 m^3/day 80 kg BW	67.5	**32**	UF_A=3; UF_H=10; UF_L=10 UF_S = 10 **Total =3000**	Buben and Flaherty (1985)	Medium
Immune/ Hematological Changes in blood cells and immune parameters	6.4 ppm (43 mg/m^3) 8hrs/day	20 m^3/day 80 kg BW	10.75	**6.8**	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total =100**	Emara et al. (2010)	High
Developmental Decreased weight gain; altered behavior, brain acetylcholine	29 ppm (200 mg/m^3)	20 m^3/day 80 kg BW	**50**	N/A	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total =30**	Nelson et al. (1979)	Low
Developmental Reduced sperm quality following 5 days exposure	21 ppm (140 mg/m^3)	20 m^3/day 80 kg BW	35	**22**	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total =30**	Beliles et al. (1980)	High
Developmental Increased F_{2A} pup deaths by Day 29, CNS depression in F_1 and F_2	18 ppm (122 mg/m^3)	20 m^3/day 80 kg BW	**31**	N/A	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total =30**	Tinston (1994)	High
Developmental Decreased fetal and placental weight, skeletal effects	16 ppm (110 mg/m^3)	20 m^3/day 80 kg BW	**28**	N/A	UF_A=3; UF_H=10; UF_L=1 UF_S = 1 **Total =30**	Carney et al. (2006)	High
Cancer (Lifetime Exposure)							
Male mouse hepatocellular tumors	3×10^{-4} per mg/m^3	20 m^3/day 80 kg BW	1×10^{-3} per mg/kg/day	**2×10^{-3} per mg/kg/day**	Not applicable	JISA (1993)	High

Notes:

[a] Oral HEDs were available for those endpoints derived in (U.S. EPA 2012c) using the PBPK model for route-to-route extrapolation. Dermal HEDs are identical to oral HEDs, with absorption differences accounted for in the exposure calculations (Sections 2.4.1.28 and 2.4.2.2.2).

[b] The PODs highlighted in bold are used in calculating risks

[c] N/A an acute oral to dermal POD was not calculated since an acute oral POD was not identified and the inhalation to dermal POD was used for assessing risk from dermal exposures

Note: Cancer risks following acute exposures were not estimated. The relationship between a single short-term exposure to PCE and the induction of cancer in humans is not known.

3.2.6 Key Assumptions and Uncertainties for Human Health Hazard

3.2.6.1 Hazard ID and Weight of the Scientific Evidence

There is medium-high confidence in the database and WOE determinations for human health hazard. All but one of the studies considered for dose-response analysis scored either Medium or High in data quality evaluation and were determined to be highly relevant to the pertinent health outcome. EPA selected the best overall chronic study for each identified endpoint to use for risk estimation, taking into account factors such as data quality evaluation score, species, cumulative uncertainty factor, and relevance. The only study considered for dose-response analysis that scored a Low in data evaluation was (Nelson et al., 1979), however the health outcomes observed in this study were covered by the other two high-quality developmental toxicity studies, (Tinston, 1994) and (Carney et al., 2006).

For most health domains, the weight of the scientific evidence was very clear, with consistent results observed across multiple species and representing multiple endpoints within the health domain. The data was a bit more ambiguous for immune and hematological effects, however. While there was some indication of specific endpoints related to immunotoxicity or blood effects, EPA determined that the database was not fully consistent and there was an absence of adequate quantitative information available to conclude that the domains supported dose-response analysis (Section 3.2.4.1.5). There is uncertainty whether the PODs for other endpoints carried forward are sufficiently protective of any potential immune or hematological effects that were not accounted for in this risk evaluation. Additionally, there is some uncertainty as to the weight of the evidence for liver effects relating to human relevance. Consistent effects were only observed in rodents and the potential influence of certain MOA that are more highly active in rodents (*i.e.*, PPARα, Section 3.2.3.3) suggests that observed liver toxicity may have reduced significance to the majority of human populations. However, susceptible subpopulations such as those with liver disease (Section 3.2.5.2) may still be of high risk of liver toxicity from sustained PCE exposure.

3.2.6.2 Derivation of PODs, UFs, and PBPK Results

Conceptually, the POD should represent the maximum exposure level at which there is no appreciable risk for an adverse effect in the study population under study conditions (*i.e.*, the threshold in the dose-response relationship). In fact, it is not possible to know that exact exposure level even for a laboratory study because of experimental limitations (*e.g.*, the ability to detect an effect, the doses used and dose spacing, measurement errors, etc.), and POD approximations like the doses used (*i.e.*, a NOAEL) an exposure level which is modeled from the reasonably available doses used (*i.e.*, BMDL) are used. The application of UFs is intended to account for this uncertainty/variability to allow for estimating risk for sensitive human subgroups exposed continuously for a lifetime. While the selection of UFs is informed by reasonably available data, the true necessary extent of adjustment most appropriate for capturing all relevant uncertainty and variability is unknown.

For this risk evaluation, non-cancer PODs were all based on NOAELs and LOAELs because the data for the selected endpoints was unable to be BMD modeled. This results in reduced precision in POD estimates because the POD is dependent on the dose selection of the study as opposed to the response rate/level for the effect of interest.

For each of these types of PODs, there are additional uncertainties pertaining to adjustments to the administered exposures (doses). Typically, administered exposures (doses) are converted to equivalent continuous exposures (daily doses) over the study exposure period under the assumption that the effects are related to concentration × time, independent of the daily (or weekly) exposure regimen (*i.e.*, a daily exposure of 6 hours to 4 ppm is considered equivalent to 24 hours of exposure to 1 ppm). However, the

validity of this assumption is generally unknown, and, if there are dose-rate effects, the assumption of $C \times t$ equivalence would tend to bias the POD downwards.

For the PBPK analyses in this assessment (Section 3.2.2.2), the actual administered exposures are taken into account in the PBPK modeling, and equivalent daily values (averaged over the study exposure period) for the dose-metrics are obtained. EPA determined that the peer-reviewed PBPK model sufficiently accounted for any variability and uncertainties in route-to-route extrapolation, and therefore inhalation and oral data were considered equivalently relevant. Nonetheless, this PBPK model, like any model, does not incorporate all possible sources of biological uncertainty or variability. Uncertainty is also elevated for developmental endpoints based on fetal effects due to the lack of a fetal compartment in the PBPK model, requiring reliance instead on default adult female parameters.

Use of the PBPK model resulted in data derived HEC and HED values replacing default assumptions and uncertainty factors that would have otherwise been used such as allometric scaling and a UF of 3 in accounting for interspecies toxicokinetic variability. Data-derived values are always preferred to default uncertainty adjustments and improve confidence in the adjusted PODs. There is additional uncertainty for dermal PODs which required route-to-route extrapolation based on assumed exposure factors without the availability of a dermal compartment in the PBPK model.

EPA was unable to BMD model the data from the best overall chronic neurotoxicity endpoint due to inadequate information for determining a BMR (Section 3.2.5.3.2) and similar considerations applied to the acute data from (1990). EPA relied on NOAEL/LOAEL values from these and all other studies considered for dose-response analysis, which increases uncertainty around the precision of the derived PODs. Nevertheless, EPA believes that the derived PODs for all endpoints are sufficiently sensitive and robust for characterizing the endpoints of interest evaluated in this Risk Evaluation.

For estimation of lifestage-adjusted HECs (Section 3.2.6.2), EPA used relative ratios of inhalation rate/body weight compared to adult and adjusted HECs for CNS effects downward accordingly. This is a simplistic adjustment method that does not fully account for all toxicokinetic differences between adults and children. Differences in metabolism and other lifestage-specific factors could either increase or decrease the relative sensitivity of younger lifestages. The PCE PBPK model was designed for adult parameters specifically and would be unlikely to predict child parameters or dose metric values at any improved confidence.

3.2.6.3 Cancer Dose-Response

There is uncertainty concerning the selected POD for cancer dose-response. Section 3.2.3.3 concludes that while there is some evidence that genotoxicity may play a role in carcinogenesis, the MOA for kidney cancer has not been established. Therefore, EPA used the linear low-dose extrapolation methodology to derive an IUR and dermal SF.

EPA selected the male mouse data for hepatocellular adenoma/carcinoma to use as the selected cancer POD based on the recommendation from the majority of the NRC peer review panel of the IRIS Assessment (U.S. EPA, 2012d) (Section 3.2.5.3.3). This is further supported based on a stronger weight of the scientific evidence for liver effects compared to immune outcomes. However, the NRC panel was not unanimous, and some members believed that the MCL data was better representative. The MCL IUR for the combined male and female dataset is 35x higher than the hepatocellular cancer IUR selected for use as the cancer POD. An adjustment was not made to account for the additional risk from MCL or hemangiomas and therefore the selected cancer POD may underestimate total cancer risk from PCE.

3.2.6.4 Confidence Ratings for Endpoints and Selected PODs

There is medium-high confidence in the acute non-cancer endpoint and POD based on neurotoxicity, medium-high confidence in the chronic non-cancer endpoints and PODs, and medium confidence in the cancer endpoint. There is high confidence in the robust chronic non-cancer PODs selected to represent each health domain for risk estimation. Confidence ratings are a half-step lower (*e.g.*, medium instead of medium-high) for all dermal PODs because derivation required extrapolation across routes without the availability of a PBPK model dermal compartment. See Section 3.2.5.4 for more details on the confidence descriptions for each category.

4 RISK CHARACTERIZATION

4.1 Environmental Risk

Fate, exposure, and environmental hazard were evaluated in this risk evaluation in order to characterize environmental risk of PCE. As stated in Section 2.1, PCE has low potential to bioconcentrate in biota and moderate potential to accumulate in wastewater biosolids, soil, or sediment. Releases of PCE to the environment are likely to volatilize to the atmosphere, where it will slowly photooxidize. It may migrate to groundwater, where it will slowly hydrolyze. Additionally, the bioconcentration potential of PCE is low. EPA modeled environmental exposure with surface water concentrations of PCE ranging from 9.7E-09 ppb to 2,034 ppb from facilities releasing the chemical to surface water. Measured surface water concentrations in ambient water range from below the detection limit to 1.7 ppb. The modeled data represents estimated concentrations near facilities that are actively releasing PCE to surface water, while the reported measured concentrations represent sampled ambient water concentrations of PCE. Differences in magnitude between modeled and measured concentrations may be due to measured concentrations not being geographically or temporally close to known releasers of PCE.

As stated in Section 3.1.5, EPA concludes that PCE poses a hazard to environmental aquatic receptors to include: aquatic invertebrates, fish, amphibians, and aquatic plants. For acute exposures, PCE is a hazard to aquatic invertebrates based on immobilization of midge larvae at 7.0 mg/L, to fish based on mortality of rainbow trout as the most sensitive species with acute toxicity values as low as 4.8 mg/L, and amphibians based on developmental effects to the wood frog as the most sensitive species with acute toxicity values as low as 7.8 mg/L. For chronic exposures, PCE is a hazard to aquatic invertebrates, with a chronic toxicity value of 0.5 mg/L; and a chronic toxicity value of 0.84 mg/L for fish. PCE is also a hazard for green algae with toxicity values of 3.6 mg/L.

EPA assigned an overall quality level of high, medium or low to 30 acceptable studies. These studies contained relevant aquatic toxicity data for fish, aquatic invertebrates, and aquatic plants. As shown in Table 3-1, EPA identified 12 aquatic toxicity studies as the most relevant for quantitative assessment. Four of the 12 studies were carried forward for characterizing the potential environmental risks from PCE. The rationale for selecting these studies is provided in Section 3.1.3, Weight of the Scientific Evidence.

Of the 12 acceptable aquatic environmental hazard studies identified for PCE, EPA assigned 11 high, and one medium for overall quality levels during data evaluation (See Table 3-1 in Section 3.1.2 and the *Risk Evaluation for Perchloroethylene: Systematic Review Supplemental File: Data Quality Evaluation of Environmental Hazard Studies* (U.S. EPA, 2020i)). The *Risk Evaluation for Perchloroethylene: Systematic Review Supplemental File: Data Quality Evaluation of Environmental Hazard Studies* (U.S. EPA, 2020i) presents details of the data evaluations for each study, including scores for each metric and the overall study score.

Given PCE's conditions of use under TSCA outlined in the Problem Formulation (U.S. EPA, 2018d), EPA determined that environmental exposures are expected for aquatic species, and risk estimation is discussed in Section 4.1.1.

4.1.1 Risk Estimation Approach

To assess environmental risk, EPA evaluates environmental hazard and exposure data. EPA used modeled exposure data from E-FAST (U.S. EPA, 2014b), as well as monitored data from the WQP (Nwqmc, 2017), to characterize the exposure of PCE to aquatic species. Environmental risks are

estimated by calculating risk quotients (RQs). As stated previously, modeled data were used to represent surface water concentrations near facilities actively releasing PCE to surface water. The modeled concentrations were used to represent ambient water concentrations of PCE. RQs were calculated using surface water concentrations and the COCs calculated in the hazard section of this document (Section 3.1.4). The RQ is defined as:

RQ = Predicted Environmental Concentration / Effect Level or COC

RQs equal to 1 indicate that environmental exposures are the same as the COC. If the RQ is above 1, the exposure is greater than the COC. If the RQ is below 1, the exposure is less than the COC. The COCs for aquatic invertebrates and algae shown in Table 3-2, and the environmental concentrations described in Section 2.3.4, were used to calculate RQs (U.S. EPA, 1998).

EPA considered the biological relevance of the species that the COCs were based on when integrating the COCs with the location of surface water concentration data to produce RQs. For example, certain biological factors affect the potential for adverse effects in aquatic organisms. Life-history and the habitat of aquatic organisms influences the likelihood of exposure above the hazard benchmark in an aquatic environment.

Frequency and duration of exposure also affect the potential for adverse effects in aquatic organisms. Therefore, the number of days that a COC was exceeded was also calculated using E-FAST (U.S. EPA, 2014b), as described in Section 2.3.1.2. The days of exceedance modeled in E-FAST are not necessarily consecutive and could occur sporadically throughout the year. Continuous aquatic exposures are more likely for the longer exposure scenarios (*i.e.,* 100-365 days/yr of exceedance of a COC), and more of an interval or pulse exposure for shorter exposure scenarios (*i.e.,* 1-99 days/yr of exceedances of a COC).

4.1.1.1 Calculation of Days of COC Exceedance

The PDM portion of E-FAST 2014 (U.S. EPA, 2014b) was also run for free-flowing water bodies, which predicts the number of days per year a chemical's concentration of concern (COC) in an ambient water body will be exceeded. The model is based on a simple mass balance approach presented by Di Toro (1984) that uses probability distributions as inputs to reflect that streams follow a highly variable seasonal flow pattern and there are numerous variables in a manufacturing process can affect the chemical concentration and flow rate of the effluent. PDM does not estimate exceedances for chemicals discharged to still waters, such as lakes, bays, or estuaries. For these water bodies, the days of exceedance is assumed be zero unless the predicted surface water concentration exceeds the COC. In these cases, the days of exceedance is set to the number of release days per year (see required inputs below).

4.1.1.2 Geospatial Analysis

A geospatial analysis at the watershed level (HUC-8 and HUC-12) was conducted to compare the measured and predicted surface water concentrations in 2016 and investigate if the facility releases may be associated with the observed concentrations in surface water. A geographic distribution of the concentrations is shown in Figure 4-3 and Figure 4-4 (Eastern and Western U.S.) for the maximum days of release scenario, and in Figure 4-5 and Figure 4-6 (Eastern and Western U.S.) for the 20-days of release scenario. Overall, there are 33 U.S. states/territories with either a measured concentration or a predicted concentration; at the watershed level, there are 109 HUC-8 areas and 149 HUC-12 areas with either measured or predicted concentrations. Appendix E Table_Apx E-2 and Table_Apx E-3 provides a list of states/territories with facility releases (as mapped) and/or monitoring sites.

EPA also used surface water monitoring data from the Water Quality Portal (Nwqmc, 2017) and from the published literature to characterize the risk of PCE to aquatic organisms. These monitored surface water concentrations reflect concentrations of PCE in ambient water. EPA's Storage and Retrieval (STORET) data and USGS's National Water Information System (NWIS) data were extracted on Oct 3rd, 2018 from the WQP. These data show an average concentration for PCE of 0.2 ± 0.6 µg/L or ppb in surface water from 1,597 measurements taken throughout the U.S. between 2013 and 2017. The highest value recorded during these years was 1.7 µg/L or ppb, which was measured in 2014. Table 4-1 shows that RQs were close to zero for all COCs.

Table 4-1. RQs Calculated using Monitored Environmental Concentrations from Water Quality Portal

Monitored Surface Water Concentrations (ppb) from 2013-2017	RQ using Acute COC of 1,400 ppb	RQ using Chronic COC of 50 ppb	RQ using algae COC of 360 ppb
Mean (SD): 0.23 (0.55) ppb	1.4E-04	4.6E-03	6.4E-04
Maximum: 1.69 ppb	1.2E-03	3.4E-02	4.7E-03

4.1.1.3 Surface Water Concentrations

The surface water concentrations associated with the monitoring stations and facility releases are denoted on the maps using COCs (Section 3.1.4) to determine the concentration thresholds:

Red ≥1,400 µg/L (exceeds all COC for algae, acute and chronic aquatic invertebrate)

Orange 50-1,399 µg/L (exceeds the COC for chronic aquatic invertebrate and algae)

Green 50 to 359 µg/L (exceeds the COC for chronic aquatic invertebrate)

Blue Detected, but less than 50 µg/L (less than all COC)

Purple Not Detected (applies only to measured concentrations; detection limits vary)

For the predicted concentrations, the concentrations represent conditions under low flow conditions (*i.e.*, 7Q10 flows). The harmonic mean concentrations were not mapped but are presented in the detailed summary tables.

4.1.1.4 Symbols and Layering

Due to the scale of the maps, some symbols may overlap each other if the monitoring stations and facilities are near each other or there are multiple releases modeled for the same facility (*i.e.*, one facility is both a direct discharger and a receiving facility). As such, the maps are layered to make sure that the most important information is always visible. The following rules were applied:

- Monitoring stations (small circles) are always on top of indirect discharge releases (medium triangles), which are always on top of direct discharge releases (large squares), and
- Within each symbol type (monitoring station, direct release, and indirect release), a higher concentration level is always on top of a lower concentration level (*i.e.*, from top to bottom: ≥1,400 µg/L (red), 360-1399 µg/L (orange), 50-359 µg/L (green), < 49µg/L (blue), and not detected (purple)).

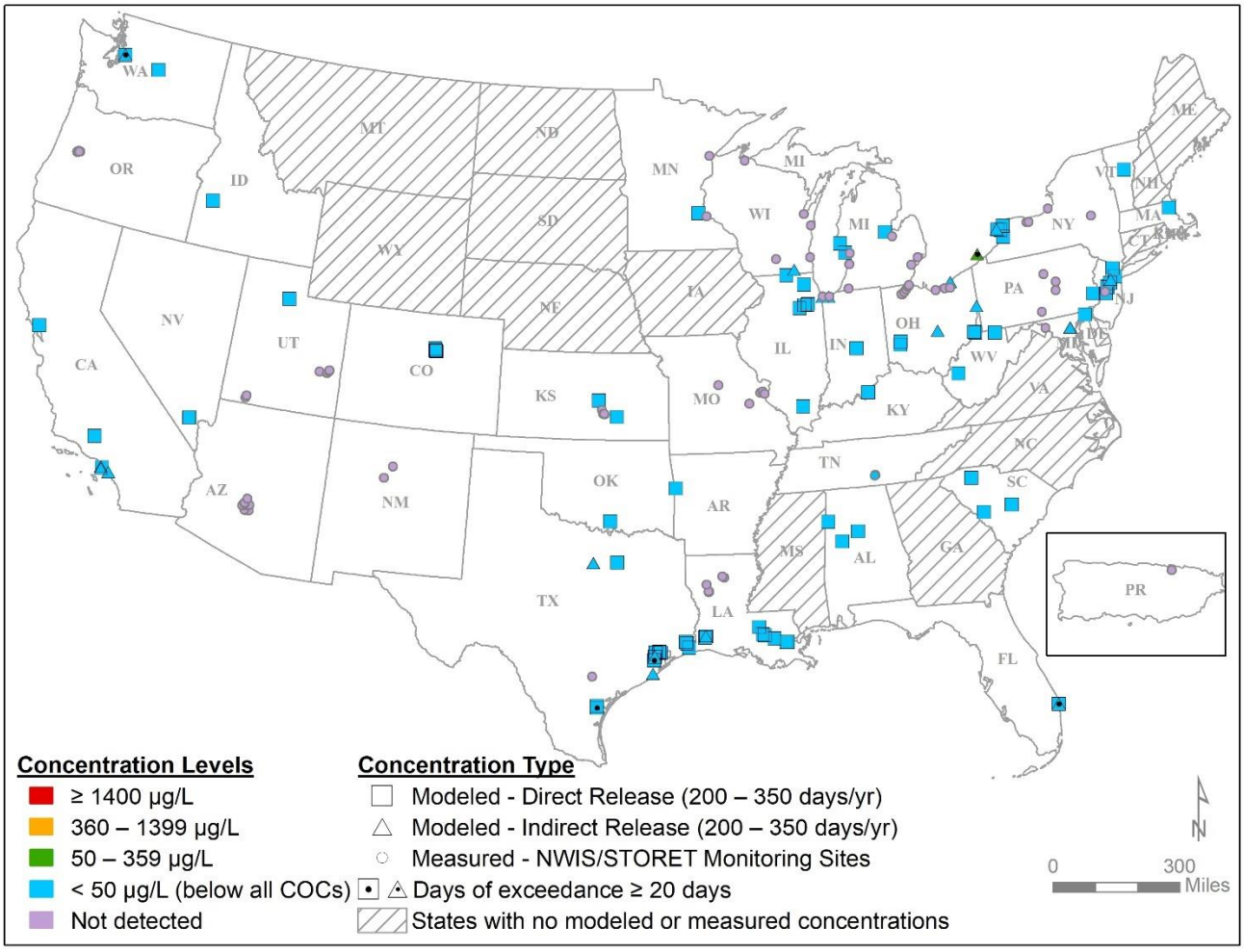


Figure 4-1. Concentrations of PCE from PCE-Releasing Facilities (Maximum Days of Release Scenario) and WQX Monitoring Stations: Year 2016, U.S. All indirect releases are mapped at the receiving facility.

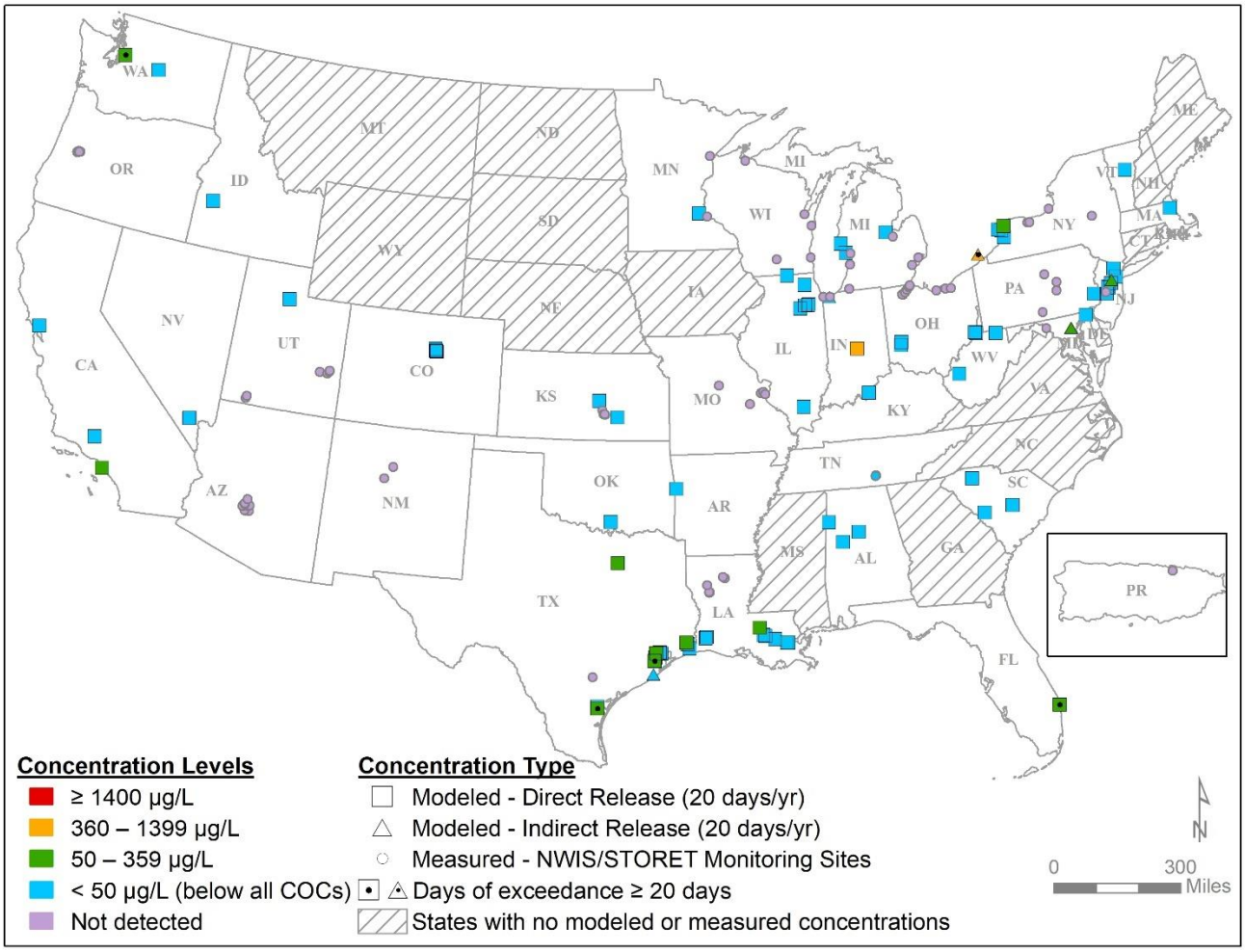


Figure 4-2. Concentrations of PCE from PCE-Releasing Facilities (20 Days of Release Scenario) and WQX Monitoring Stations: Year 2016, U.S. All indirect releases are mapped at the receiving facility.

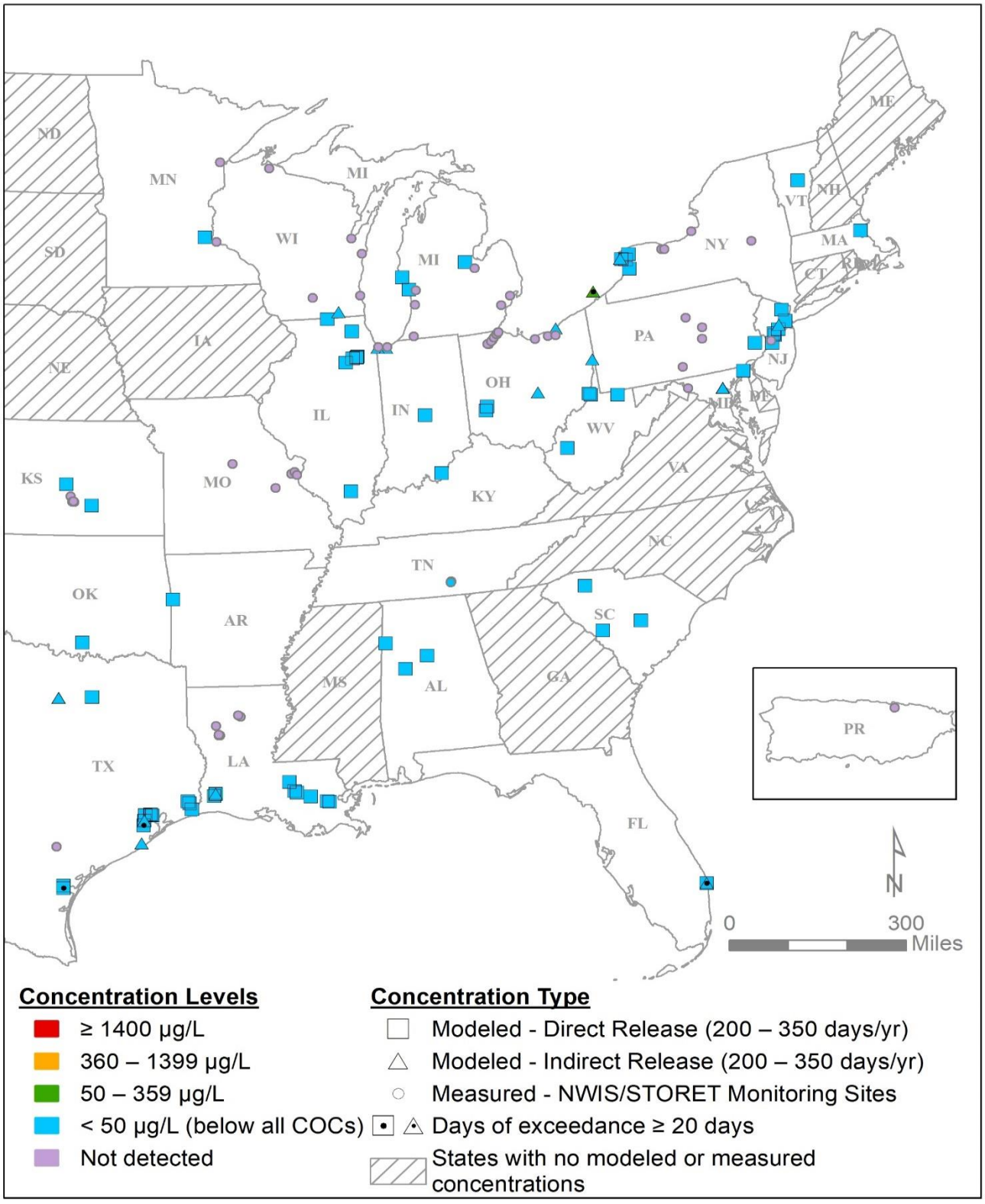


Figure 4-3. Concentrations of PCE from PCE-Releasing Facilities (Maximum Days of Release Scenario) and WQX Monitoring Stations: Year 2016, Eastern U.S. All indirect releases are mapped at the receiving facility.

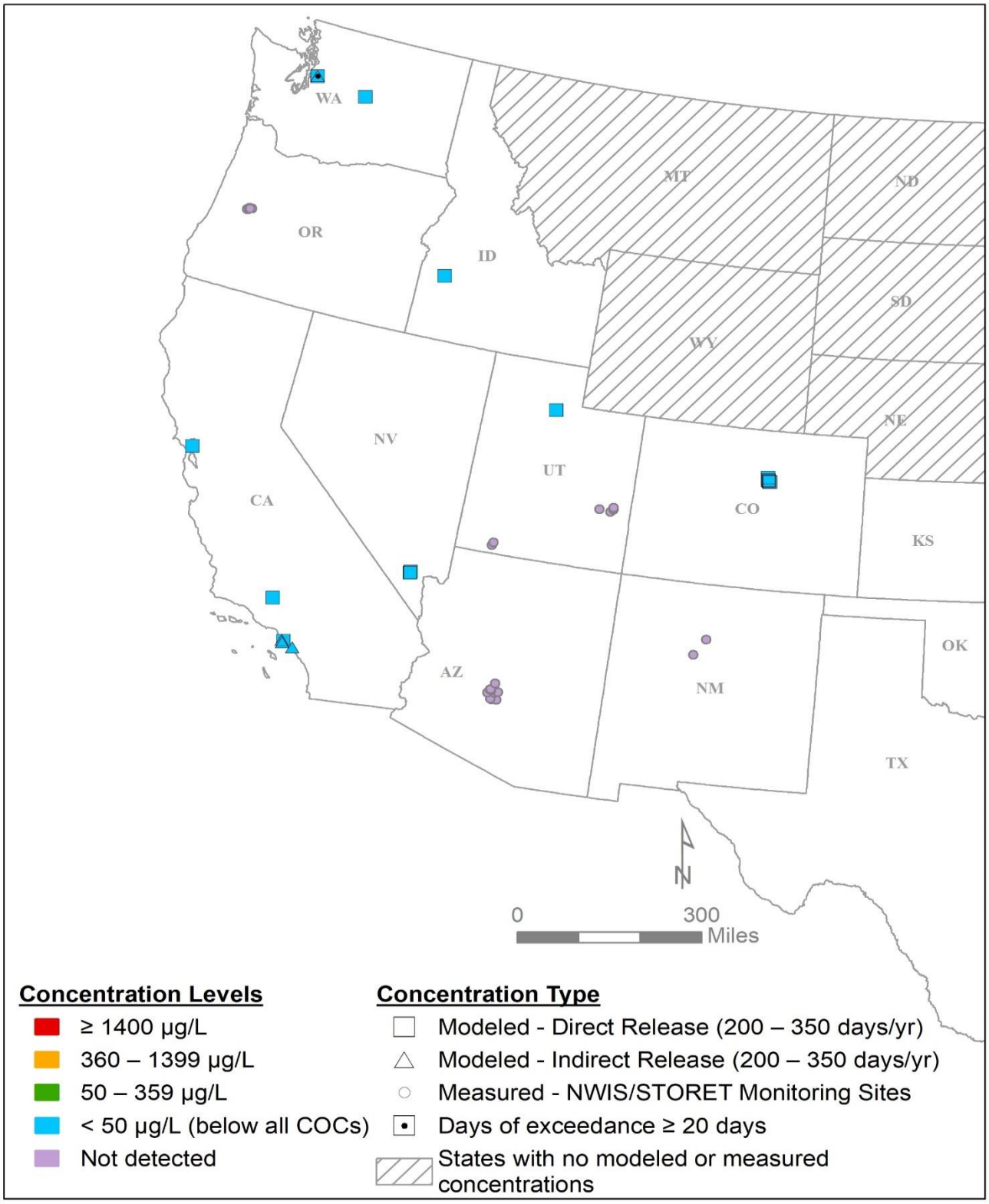


Figure 4-4. Concentrations of PCE from PCE-Releasing Facilities (Maximum Days of Release Scenario) and WQX Monitoring Stations: Year 2016, Western U.S. All indirect releases are mapped at the receiving facility.

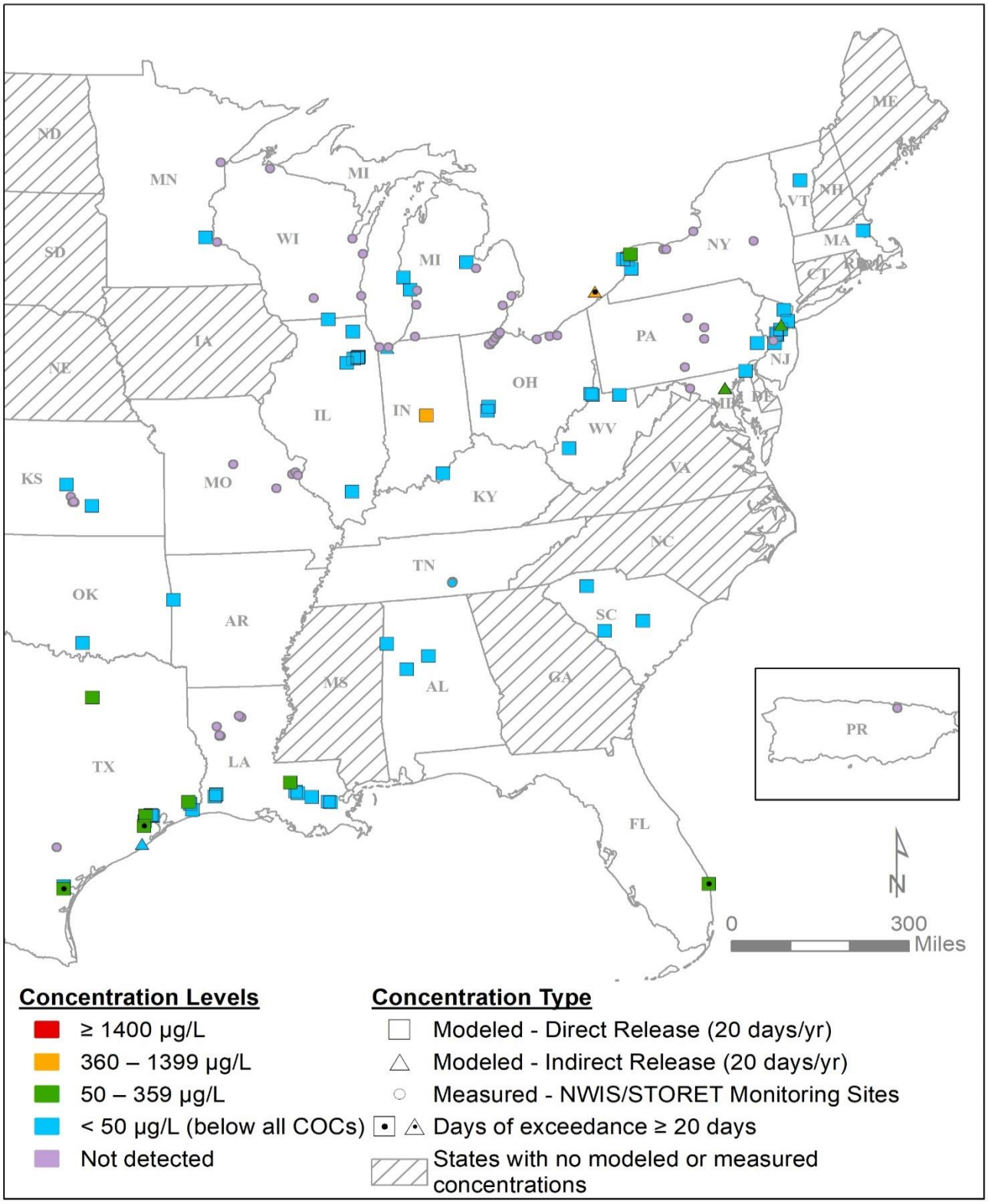


Figure 4-5. Concentrations of PCE from PCE-Releasing Facilities (20 Days of Release Scenario) and WQX Monitoring Stations: Year 2016, Eastern U.S. All indirect releases are mapped at the receiving facility.

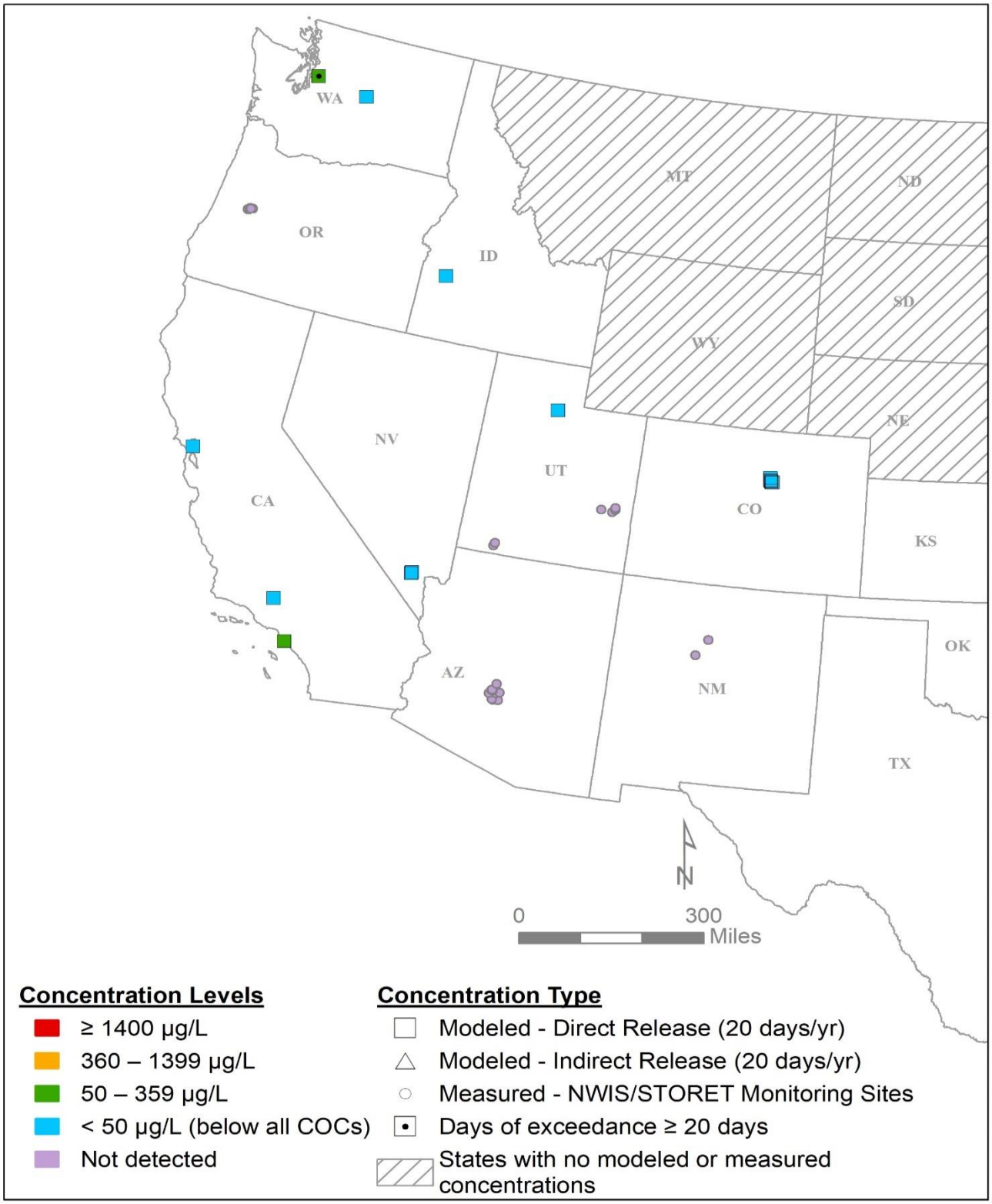


Figure 4-6. Concentrations of PCE from PCE-Releasing Facilities (20 Days of Release Scenario) and WQX Monitoring Stations: Year 2016, Western U.S. All indirect releases are mapped at the receiving facility.

4.1.2 Risk Estimation for Aquatic Environment

To characterize potential risk due to PCE exposure, RQs were calculated based on modeled data from E-FAST (U.S. EPA, 2014b) for sites that had surface water discharges of PCE according to TRI and DMR data (Table 4-1). Surface water concentrations of PCE were modeled for 199 releases: 16 manufacturing releases, eight import/repackaging releases, 35 processing as a reactant releases, six incorporation into formulation releases, 33 open top vapor degreasing releases, nine commercial dry cleaning releases, four industrial dry cleaning releases, two adhesives, paints and coatings releases, eight chemical maskant releases, 26 industrial processing aid releases, 16 other industrial use releases, 14 other commercial uses releases, and 22 waste handling, disposal, treatment, and recycling releases. Direct releases facilities (releases from an active facility directly to surface water) were modeled with two scenarios based on high-end and low-end days of release. Indirect facilities (transfer of wastewater from an active facility to a receiving POTW or non-POTW WWTP) were only modeled with a high-end days of releases scenario. As stated in Section 2.3.1.1, the maximum releases frequency (200 to 350 days) is based on release estimates specific to the facility's condition of use and the low-end releases frequency (20 days) is an estimate of releases that could lead to chronic risk for aquatic organisms.

As stated previously, the frequency and duration of exposure affects potential for adverse effects in aquatic organisms. Therefore, the number of days a COC was exceeded was also calculated using E-FAST. Facilities with RQs and days of exceedance that indicate risk for aquatic organisms (facilities with an acute RQ ≥ 1, or a chronic or algae RQ ≥ 1 and 20 days or more of exceedance for the chronic or algae COC) are presented in Section 4.4 Risk Conclusions, Table 4-124.

4.1.2.1 Confidence in Risk Estimation for Aquatic Environment

Confidence ratings for aquatic exposure scenarios are informed by uncertainties surrounding inputs and approaches used in modeling surface water concentrations. Other considerations that impact confidence in the aquatic exposure scenarios include the model used (E-FAST 2014, (U.S. EPA, 2014b)) and its associated default and user-selected values and related uncertainties. As described in Section 2.3.4.3, there are uncertainties related to the ability of E-FAST 2014 (U.S. EPA, 2014b) to incorporate downstream fate and transport; the likely number of release days from given discharging facilities; and in some cases (*i.e.*, when the NPDES for the discharging facility cannot be found within the E-FAST database), the applied stream flow distribution. Based on the data quality, uncertainties, and weight of the scientific evidence, confidence in the surface water concentration estimate is medium.

Based on the data quality, weight of the scientific evidence, and uncertainties, confidence in acute and chronic COCs for fish and invertebrates is high. The COC for algae is based on a single study that EPA assigned an overall quality level of high. Additionally, algae species tend to vary widely in their sensitivity to chemical pollutants, and data were only available for three algal species and may not represent the most sensitive species at a given site. Therefore, confidence in the algae COC is medium. The overall confidence in the risk estimate to aquatic organisms from exposure to PCE is medium based on the surface water PCE concentration and COC confidence levels.

4.1.2.1.1 Manufacturing

Six facilities for manufacturing PCE were modeled for the risk estimate. None of the facility releases show surface water concentrations that result in RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.2 Import/Repackaging

Four facilities for importing/repackaging PCE were modeled for the risk estimate. None of the facility releases show surface water concentrations that result in RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.3 Processing as a Reactant

Of the 18 facilities modeled for processing PCE as a reactant, two facilities had RQs ≥ 1 and 20 days or more of exceedance for aquatic organisms. All exceedances occurred using the direct release to surface water scenario.

- Flint Hills Resources Corpus Christi LLC – West Plant, Corpus Christi, TX: Using the scenario of 20 days of direct release to still surface water resulted in a surface water concentration of 52 ppb, aquatic invertebrates had a chronic RQ = 1.0 and 20 days of exceedance.
- Keeshan And Bost Chemical Co., Inc., Manvel, TX: Using the scenario of 20 days of direct release to still surface water resulted in a surface water concentration of 100 ppb, aquatic invertebrates had a chronic RQ = 2.0 and 20 days of exceedance.

EPA identified chronic risk to aquatic organisms from direct release of PCE to surface water from the Processing as a Reactant COU at two facilities. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.4 Incorporation into Formulation

Of the three facilities modeled for using PCE for incorporation into formulations, a single facility, Lord Corp, Saegertown, PA, had RQs ≥ 1 and 20 days or more of exceedance for chronic risks. Using the scenario of 300 days of indirect release (88% removal) to surface water resulted in a surface water concentration of 81 ppb, aquatic invertebrates had a chronic RQ = 1.6 and 81 days of exceedance.

EPA identified elevated chronic risk to aquatic organisms from indirect release (88% removal) of PCE to surface water from the Incorporation into Formulation COU at a single facility. The facility showing risk has a NPDES permit. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.5 Open Top Vapor Degreasing

None of the 17 open-top vapor degreasing facility modeled releases show surface water concentrations that result in RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

An additional 4,819 facilities not in TRI or DMR were modeled. None of the model releases from these facilities show a surface water concentrations that result in RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.6 Closed-Loop Vapor Degreasing

A total of 25,423 closed-loop vapor degreasing facilities not in TRI or DMR were modeled for the risk assessment. None of the model releases from these facilities show surface water concentrations that result in RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.7 Conveyorized Degreasing

A total of 445 conveyorized degreasing facilities not in TRI or DMR were modeled for the risk assessment. None of the model releases from these facilities show surface water concentrations that result in RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.8 Web Degreasing

A total of 445 web degreasing facilities not in TRI or DMR were modeled for the risk assessment. None of the model releases from these facilities show a surface water concentration that result in an RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.9 Dry Cleaning (Industrial and Commercial)

Two industrial and five commercial dry cleaning modeled releases (one of which was based on data from 12,822 facilities) were modeled for the risk estimate. The model used both high-end and central tendency release data for direct and indirect releases. None of the facility releases show surface water concentrations that result in RQs ≥ 1 for acute risk or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.10 Adhesives, Paints, and Coatings

Releases from two adhesive, paints, and coatings facilities were modeled for the risk estimate. The model used indirect releases (88% removal) to surface water. None of the facility releases show surface water concentrations that result in RQs ≥ 1 for acute, or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.11 Maskants for Chemical Milling

Releases from five maskants for chemical milling facilities were modeled for the risk estimate. The model used direct and indirect releases to surface water including still water bodies. None of the facility releases show surface water concentrations that resulted in RQ ≥ 1 or any days of exceedance.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.12 Industrial Processing Aid

None of the 12 industrial processing aid facility modeled releases show surface water concentrations that result in RQs ≥ 1 or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.13 Other Industrial Uses

Releases from seven with other industrial use facilities were modeled for the risk estimate. The model used direct releases to surface water. None of the facility releases show surface water concentrations that result in RQs ≥ 1 or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.14 Other Commercial Uses

Releases from seven other commercial use facilities were modeled for the risk estimate. The model used direct releases to surface water. None of the facility releases show surface water concentrations that result in RQs ≥ 1 or RQs ≥ 1 and 20 days of exceedance for chronic or algal risk.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.2.1.15 Waste Handling, Disposal, Treatment, and Recycling

Releases from 13 facilities engaged in waste handling, disposal, treatment, and recycling were modeled for the risk estimate. The model used direct and indirect releases to surface water including still water bodies. None of the facility releases show surface water concentrations that result in RQs ≥ 1 or any days of exceedance.

Risks were not identified for aquatic organisms with this COU. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.

4.1.3 Risk Estimation for Sediment Pathways

Data were not sufficient for EPA to analyze PCE exposure to sediment-dwelling organisms. PCE is expected to be moderately retained in sediment due to its water solubility (206 mg/L) and partitioning to organic matter (log K_{OC} = 2.4). Because PCE has moderate partitioning to organic matter, in sediments PCE is expected to be both sorbed to the sediment organic matter and present in the pore water. However, depending on the microbial consortia present and their previous exposure and adaptation to PCE, PCE may undergo rapid biodegradation in sediment. Thus, PCE concentrations in sediment may be lower or somewhat greater than concentrations in overlying water. While no ecotoxicity studies were available for sediment-dwelling organisms (*e.g., Lumbriculus variegatus, Hyalella azteca, Chironomus riparius*), the toxicity of PCE to sediment invertebrates is expected to be similar to the toxicity to aquatic invertebrates because of the similarities in PCE concentrations. EPA calculated an acute aquatic invertebrate COC of 1,400 ppb, and a chronic aquatic invertebrate COC of 50 ppb to assess hazards to aquatic organisms.

4.1.4 Risk Estimation for Land-Applied Biosolids Pathway

During Problem Formulation EPA conducted a screening level analysis to consider whether pathways of exposure for terrestrial organisms should be further analyzed and determined that terrestrial organism exposures to PCE was not of concern partially because PCE will not appreciably bind to sediment, soil or biosolids. In addition, the half-life of PCE in soil is short, and is unlikely to be found in food crops (U.S. EPA, 2012c). As noted in Section 1.4.2, the terrestrial pathway is not in scope of the risk evaluation. EPA did not assess exposure to terrestrial organisms through soil, land-applied biosolids, or

ambient air in this Risk Evaluation. PCE has low potential to partition to or accumulate in soil, and is primarily expected to volatilize to air or migrate through soil into groundwater based on its physical-chemical properties (log K_{OC} = 2.4, Henry's Law constant = 0.018 atm-m^3/mole, vapor pressure = 19 mmHg at 25°C).

In a 1988 National Sewage Sludge Survey, PCE was detected 3% of biosolids samples, with a 95th percentile concentration of 3,130 ug/kg dw (U.S. EPA, 1996g). Most PCE present in biosolids following wastewater treatment, processing, and land application would be expected to volatilize into air or migrate through soil into groundwater based on Level III fugacity modeling with 100% emission to soil.

4.1.5 Environmental Risk Characterization Assumptions and Key Source s of Uncertainty

PCE is toxic to aquatic organisms. The EPA has determined that data are sufficient to characterize the environmental hazards of PCE. The following uncertainties are associated with the hazard characterization. Assessment factors (AFs) were used to calculate the acute and chronic COC for PCE. As described in Section 3.1.4, AFs address the inter- and intra-species variability, as well as laboratory-to-field variability and are routinely used within TSCA for assessing chemical hazards with limited environmental data. Additionally, AFs account for potential data gaps in the literature in which data for more sensitive species were not available. Use of AFs increases the confidence that the hazard characterizations were not underestimated, resulting in false negative conclusions. Although the toxicity values for fish, amphibians, and invertebrates are relatively consistent, algae species tend to vary widely in their sensitivity to chemical pollutants. Data were only available for three algal species and may not represent the most sensitive species at a given site.

4.1.5.1 Measured Surface Water Data and Watershed Analysis

The physical properties of PCE can lead to monitoring data showing limited occurrence in surface water. PCE in surface waters can be expected to volatilize into the atmosphere. However, PCE is denser than water and only slightly soluble in water. In soil and aquifers, it will tend to remain in the aqueous phase and be transported to ground water.

WQX surface water monitoring data for the following years of 2013-2017 showed that PCE occurrence was relatively low. For the 2016 data, only 4 monitoring sites had PCE concentrations above the monitoring detection limit. The concentrations ranged from 1.4E-2 to 5.2E-2 µg/L, which are below the lowest COC of 50 µg/L that is used in the ecological assessment.

When evaluating surface water monitoring data, it must be noted that EPA only looked at surface water data that excluded other major sources of water data, *e.g.*, drinking water, superfund sites, and ground water. The quality of the data provided in the USGS-NWIS and STORET datasets varies, and some of the information provided is non-quantitative. While a large number of individual sampling results were obtained from these datasets, the monitoring studies used to collect the data were not specifically designed to evaluate PCE distribution across the U.S. As a result, there are uncertainties in the reported data that are difficult to quantify with regard to impacts on exposure estimates.

The available data represent a variety of discrete locations and time periods; therefore, it is unclear whether the data are representative of other locations in the U.S.; however, this limitation does not diminish the overall findings reported in this assessment, as the exposure data show very few instances (*i.e.*, less than 0.01 percent) where measured PCE levels in the ambient environment exceeded the identified hazard benchmarks for aquatic organisms.

The surface water monitoring results were further validated through data acquired via EPA's systematic review of surface water literature and biomonitoring data. Minimum results came from the systematic review on PCE in surface water. Data from three U.S. studies indicated that PCE occurrence and related concentrations in surface water were relatively low as well. The reported concentrations of PCE ranged from below the detection limit and reported central tendency values ranging from <0.2 to 0.7 µg/L which is below the lowest COC of 50 µg/L. The systematic review of biomonitoring data yielded three viable studies that contained PCE concentration measurements in blood. These studies did indicate that PCE was detected moderately (37-60%) in samples evaluated. However, the concentration of PCE was not higher than the detection limits of the respective studies.

4.1.5.2 Modeled Surface Water Concentrations

To further evaluate PCE exposure in surface water EPA modeled indirect and direct releases of PCE in surface water by facilities. EPA modeled releasing facilities plus one industry with sites nationwide that were obtained by three data sources (TRI, DMRs, and CDR) for the 2016 calendar year.

The modeled estimations of PCE releases and surface water monitoring data were merged and mapped to reflect where PCE occurrence and related concentrations are with respect to each other in the U.S. The maps show that there is minimum PCE exposure at the respective COC regarding environmental exposure assessment for aquatic species. The co-location of PCE releasing facilities and surface water monitoring stations in an HUC were also mapped via geospatial analysis to illustrate both measured and predicted concentrations PCE. The maps indicate that even though there are estimated releases from facilities, some of which have concentrations higher than the COC, the data from monitoring stations are not detecting PCE within the same HUC. It must be noted that the use of geospatial analysis has a limitation with the accuracy of the latitudes and longitudes therefore affecting placement of facilities and monitoring stations.

4.2 Human Health Risk

PCE exposure is associated with a variety of cancer and non-cancer adverse effects deemed relevant to humans for risk estimations for the scenarios and populations addressed in this risk evaluation under TSCA. Based on a weight of the scientific evidence analysis of the available toxicity studies from animals and humans, the most sensitive and robust non-cancer effects selected for risk estimation were neurotoxicity (*i.e.*, increased latencies for pattern reversal visual-evoked potentials) from acute exposure, developmental toxicity from repeated exposures and multiple effects including CNS, kidney, liver, immune, and developmental toxicity from chronic exposures. The evaluation of cancer includes risk estimates of risk of liver tumors.

4.2.1 Risk Estimation Approach

Equation 4-1 was used to calculate non-cancer risks using margins of exposure (MOEs) for acute or chronic exposure durations.

Equation 4-1 Equation to Calculate Non-Cancer Risks Following Acute or Chronic Exposures Using Margin of Exposures

$$\boldsymbol{MOE_{acute\ or\ chronic} = \frac{Non-cancer\ Hazard\ value\ (POD)}{Human\ Exposure}}$$

Where:

MOE = Margin of exposure (unitless)
Hazard value (POD) = HEC (ppm)
Human Exposure = Exposure estimate (in ppm) from occupational or consumer exposure assessment. ADCs were used for non-cancer chronic risks and acute concentrations were used for acute risks (see Section 3.2.5)

EPA/OPPT used margin of exposures (MOEs)[25] to estimate acute or chronic risks for non-cancer based on the following:

1. The most robust and sensitive HECs within each health effects domain/organ system reported in the literature;
2. The endpoint/study-specific UFs applied to the HECs under TSCA per EPA Guidance (U.S. EPA, 2002); and
3. The exposure estimates calculated for PCE uses examined in this risk assessment (see Section 2 Exposures).

MOEs allow for the presentation of a range of risk estimates. The occupational exposure scenarios considered both acute and chronic exposures. All consumer uses considered only acute exposure scenarios. Different adverse endpoints were used based on the expected exposure durations. For non-cancer effects, risks for neurotoxicity (*i.e.*, increased latencies for pattern reversal visual-evoked potentials) from acute exposure were evaluated.

For occupational exposure calculations, the 8 hr or 12 hr TWA was used to calculate inhalation MOEs for risk estimates for acute exposures and the chronic average daily concentration (ADC) was used for chronic exposures. For dermal estimates, acute and chronic retained doses were used. The total UF for each non-cancer POD was the benchmark MOE used to interpret the MOE risk estimates for each use scenario. The MOE estimate was interpreted as human health risk if the MOE estimate was less than

[25] Margin of Exposure (MOE) = (Non-cancer hazard value, POD) ÷ (Human Exposure), see Equation 4-1. The benchmark MOE is used to interpret the MOEs and consists of the total UF shown in Table 3-5.

the benchmark MOE (*i.e.,* the total UF). On the other hand, the MOE estimate indicated negligible concerns for adverse human health effects if the MOE estimate exceeded the benchmark MOE. Typically, the larger the MOE, the more unlikely it is that a non-cancer adverse effect would occur. Risk estimates were calculated for all of the studies per health effects domain that EPA/OPPT considered suitable for the risk evaluation of acute and chronic exposure scenarios in the work plan risk assessment for PCE.

The PBPK model (Section 3.2.2.2) was used to calculate internal dose metrics for inhaled and oral exposure to PCE for mice, rats, and humans and therefore was used for route-to-route extrapolation between oral and inhalation routes. Dermal candidate values were calculated based on route-to-route extrapolation from two different routes either inhalation or oral PODs. The PODs were extrapolated from POD values based on either human data or human equivalent values (*e.g.,* $BMDL_{HEC}$) which have already been adjusted to account for animal to human extrapolation using the best available approaches for incorporating PCE specific toxicokinetic data (*i.e.,* the PBPK model) when possible. When dermal HEDs were derived by both methods, the most sensitive resulting HED was selected for use in risk estimation in order to be health-protective.

Added cancer risks for repeated exposures to PCE were estimated using Equation 4-2. Estimates of added cancer risks should be interpreted as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (*i.e.,* incremental or added individual lifetime cancer risk).

Equation 4-2 Equation to Calculate Added Cancer Risks

$$\boldsymbol{Risk = Human\ Exposure \times IUR}$$

Where:

Risk = Added cancer risk (unitless)
Human exposure = Exposure estimate (LADC in mg/m^3) from occupational exposure assessment
IUR = Inhalation unit risk (2×10^{-3} per mg/m^3)

4.2.2 Risk Estimation for Inhalation Exposures to Workers

4.2.2.1 PODs used for Occupational Inhalation Risk Estimates

The risk assessment used the inhalation exposure estimates in Section 2.4.1 and the hazard PODs summarized in Table 3-7, Table 3-8, and Table 3-9. For acute exposure scenarios, PODs for 8 hr and 12 hr exposure durations were used because those durations are most applicable to occupational exposure scenarios. From among all chronic studies, EPA selected the most robust studies and non-cancer PODs from within each health domain to serve as the best overall endpoints for risk estimation (Section 3.2.5.4). These PODs are presented below in Table 4-2 along with the acute POD. Non-cancer risk estimates were calculated with Equation 4-1 and cancer risks were calculated with Equation 4-2. Risk is indicated for each OES or COU by bold text and a shaded cell in the respective tables.

EPA derived chronic inhalation risk estimates based on 8 hr and 12 hr/day 5 day/week occupational neurotoxicity HECs (14.5 ppm and 9.7 ppm, respectively, see Table 3-8), compared to 8 hr or 12 hr TWA exposures. These occupational HECs were used for calculating occupational risk estimates in order to account for expected increased breathing rates during occupational scenarios (as opposed to the general population HEC based on resting breathing rate as derived by (U.S. EPA, 2012d)). For other endpoints, HECs based on continuous exposure were compared to 24hr/day acute and chronic exposures. Since the occupational HECs are assumed to be based on a full-time work week

(5 days/week, ~250 days/year), chronic CNS risks may be overestimated for OES with less than 250 exposure days/year.

Table 4-2. Selected PODs for Use in Risk Estimation of Inhalation Exposures

Target Organ System	Species	Human Equivalent Concentration (HEC)	Effect	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality Score
ACUTE EXPOSURE						
CNS	Humans	8 hrs/day = 5 ppm (34 mg/m^3) 12 hrs/day = 3.3 ppm (22 mg/m^3)	Neurotoxicity increased latencies for pattern reversal visual-evoked potentials	UF_A=1; UF_H=10; UF_L=1 **Total UF=10**	Altmann et al. (1990)	Medium
CHRONIC EXPOSURE						
CNS	Humans	14.5 ppm [8 hr] (99 mg/m^3) 9.7 ppm [12 hr] (66 mg/m^3)	Midpoint of the range of the two neurotoxicity studies (occupational scenarios)	UF_A=1; UF_H=10; UF_L=10 **Total UF=100**	Based on U.S. EPA (2012c)	Medium
Kidney	Mice	2.1 ppm (14 mg/m^3)	Nuclear enlargement in proximal tubules	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	JISA (1993)	High
Liver	Mice	31 ppm (210 mg/m^3)	Increased angiectasis in liver	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	JISA (1993)	High
Immune/ Hematological	Humans	6.4 ppm (43 mg/m^3)	Reduced red blood cells and hemoglobin; Increased immune cells, IgE, IL-4	UF_A=1; UF_H=10; UF_L=10 **Total UF=100**	Emara (2010)	High
Reproductive/ Developmental	*Reproductive*					
	Mice	21 ppm (140 mg/m^3)	Reduced sperm quality following 5 days exposure	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	Beliles et al. (1980)	High
	Developmental					
	Rats	18 ppm (122 mg/m^3)	Increased F_{2A} pup deaths by Day 29, CNS depression in F_1 and F_2	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	Tinston et al. (1994)	High
CANCER						
Liver	Mouse	IUR 2×10^{-3} per ppm (3×10^{-4} per mg/m^3)	Hepatocellular tumors (males)	N/A	JISA (1993)	High

4.2.2.2 Occupational Inhalation Exposure Summary and PPE Use Determination by OES

EPA considered all reasonably available data for estimating exposures for each OES. EPA also determined whether respirator use up to APF = 50 was plausible for those OES based on expert judgment and reasonably available information. Table 4-3 presents this information below, which is considered in the risk characterization for each OES in the following sections. EPA assumes that for

some conditions of use, the use of appropriate respirators is not a standard industry practice, based on best professional judgement given the burden associated with the use of supplied-air respirators, including the expense of the equipment and the necessity of fit-testing and training for proper use. Similarly, EPA does not assume that as a standard industry practice that workers wear gloves for the industrial and commercial use of PCE for dry cleaning and spot cleaning, wipe cleaning and metal/stone polishes, other spot cleaning/spot remover, and other commercial uses.

Table 4-3. Inhalation Exposure Data Summary and Respirator Use Determination

Occupational Exposure Scenario	Inhalation Exposure Approach	Number of Data Points	Model Used	Approach for ONUs	Respirator Use	Industrial or Commercial OES
Manufacturing	Monitoring data	152 (137 worker and 15 ONU)	N/A – monitoring data only	ONU monitoring data available	May use respirators	Industrial
Repackaging	Monitoring data	11	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial
Processing as a Reactant	Surrogate monitoring data from manufacturing	152 (137 worker and 15 ONU)	N/A – monitoring data only	Surrogate monitoring data from manufacturing	May use respirators	Industrial
Incorporation into Formulation – Aerosol Packing	Monitoring data	8	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial
Incorporation into Formulation – Non-Aerosol Formulations	Modeling	N/A – model only	EPA/OAQPS AP-42 Loading Model & EPA/OPPT Mass Balance Model	Equal to workers central tendency	May use respirators	fIndustrial
Open-Top Vapor Degreasing	Monitoring data	75 (63 worker and 12 ONUs)	N/A – monitoring data only	ONU monitoring data available	May use respirators	Industrial/ Commercial
Closed-Loop Vapor Degreasing	Monitoring data	15 (13 worker and 2 ONU)	N/A – monitoring data only	ONU monitoring data available	May use respirators	Industrial/ Commercial
Conveyorized Vapor Degreasing	Model	N/A – model only	Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model	Far-field model results	May use respirators	Industrial/ Commercial
Web Degreasing	Model	N/A – model only	Web Degreasing Near-Field/Far-Field Inhalation Exposure Model	Far-field model results	May use respirators	Industrial/ Commercial
Cold Cleaning	Monitoring data supplemented by model	29	Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model	Far-field model results	May use respirators	Industrial/ Commercial
Aerosol Degreasing and Aerosol Lubricants	Monitoring data supplemented by model	144	Brake Servicing Near-Field/Far-Field Inhalation Exposure Model	Far-field model results	No respirator use – commercial use	Commercial

Occupational Exposure Scenario	Inhalation Exposure Approach	Number of Data Points	Model Used	Approach for ONUs	Respirator Use	Industrial or Commercial OES
Dry Cleaning and Spot Cleaning	Monitoring data supplemented by model	193 (188 workers and 5 ONUs)	Dry Cleaning Multi-Zone Inhalation Exposure Model	ONU monitoring data available supplemented by far-field model results	No respirator use – commercial use	Commercial
Paint and Coatings	Monitoring data	15	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial/ Commercial
Adhesives	Monitoring data	13	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial/ Commercial
Chemical Maskant	Monitoring data	60 (43 worker and 17 ONU)	N/A – monitoring data only	ONU monitoring data available	May use respirators	Industrial
Industrial Processing Aid	Monitoring data	89	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial
Other Industrial Uses	Monitoring data	57	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial
Metalworking Fluid	Emission scenario document	N/A – emission scenario document	Estimates from Use of Metalworking Fluids ESD	Equal to workers central tendency	No respirator use – ESD indicates respirators are not generally used	Industrial/ Commercial
Wipe Cleaning	Monitoring data	10 (4 workers and 6 ONUs)	N/A – monitoring data only	ONU monitoring data available	No respirator use – commercial use	Commercial
Other Spot Cleaning/Spot Removers (including Carpet Cleaning)	Monitoring data	5 (4 workers and 1 ONU)	N/A – monitoring data only	ONU monitoring data available	No respirator use – commercial use	Commercial
Other Commercial Uses	Monitoring data	116	N/A – monitoring data only	Equal to workers central tendency	No respirator use – commercial use	Commercial
Laboratory Chemicals	Monitoring data	1	N/A – monitoring data only	Equal to workers central tendency	No respirator use – lab personnel not expected to wear respirators under normal conditions	Industrial/ Commercial
Other DoD Uses	Monitoring data	2	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial/ Commercial
Disposal/Recycling	Monitoring data	12	N/A – monitoring data only	Equal to workers central tendency	May use respirators	Industrial

4.2.2.3 Manufacturing

For manufacturing, exposure estimates for TWAs of 15 mins, 30 mins, 8 hrs, and 12 hrs are available based on personal monitoring data samples, including 351 data points from one source. For workers, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. For 8-hr TWA ONU exposures, EPA calculated 50th and 95th percentiles to characterize central tendency and high-end exposures, respectively. However, for 12-hr TWA ONU exposures, all three data points available measured below the LOD. Therefore, EPA characterized the central tendency and high-end exposures as half the LOD and the LOD, respectively. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is high. Section 2.4.1.6 describes the justification for this occupational scenario confidence rating.

As stated in Section 4.2.2.1, risks for chronic CNS effects based on the occupational HEC may be overestimated for OES with less than 250 exposure days/yr. This is the case for 12hr/day Manufacturing, which has an estimated 167 exposure days/yr.

Table 4-4. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Manufacturing

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**1.9**	54	19	47	94	10
		Central Tendency	154	147	1,538	3,846	7,692	
12-hr	3.3	High-End	15	73	155	386	773	10
		Central Tendency	161	147	1,610	4,024	8,049	

[1] Data from Altmann et al. (1990)

Table 4-5. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Manufacturing

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Based on exposure data for 8 hr TWA								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**5.4**	158	**54**	136	272	100
		Central Tendency	446	427	4,462	11,154	22,308	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**3.5**	100	35	86	173	30
		Central Tendency	283	271	2,830	7,075	14,151	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	51	1,480	510	1,275	2,551	30
		Central Tendency	4,178	4,000	41,778	104,446	208,892	
	6.4	High-End	**11**	306	105	263	527	100

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Immune/ Hematological - biomarkers (Jisa, 1993)		Central Tendency	863	826	8625	21563	43126	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	35	1,003	346	864	1,728	30
		Central Tendency	2,830	2,710	28,302	70,754	141,508	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**30**	859	296	740	1,481	30
		Central Tendency	2,426	2,323	24,258	60,646	121,292	
Based on exposure data for 12 hr TWA								
CNS - Visual effects (U.S. EPA, 2012c)	9.7	High-End	**45**	215	453	1132	2,264	100
		Central Tendency	472	430	4,715	11,789	23,577	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	43	204	430	1,075	2,150	30
		Central Tendency	448	408	4,478	11,195	22,389	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	635	3,011	6,347	15,868	31,735	30
		Central Tendency	6,610	6,023	66,102	165,255	330,510	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	131	622	1310	3276	6552	100
		Central Tendency	1365	1,243	13647	34117	68234	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	430	2,040	4,300	10,749	21,498	30
		Central Tendency	4,478	4,080	44,779	111,947	223,894	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	369	1,749	3,685	9,213	18,427	30
		Central Tendency	3,838	3,497	38,382	95,954	191,909	

Table 4-6. Risk Estimation for Chronic, Cancer Inhalation Exposures for Manufacturing

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Based on exposure data for 8 hr TWA								
Cancer Risk liver tumors	2.0E-3	High-End	**6.2E-4**	2.1E-5	6.2E-5	2.5E-5	1.2E-5	10^{-4}
		Central Tendency	5.9E-6	6.2E-6	5.9E-7	2.4E-7	1.2E-7	
Based on exposure data for 12 hr TWA								
Cancer Risk Liver Tumors	2.0E-3	High-End	5.0E-5	1.1E-5	5.0E-6	2.0E-6	1.0E-6	10^{-4}
		Central Tendency	3.7E-6	4.1E-6	3.7E-7	1.5E-7	7.5E-8	

[1] Data from JISA (1993)

4.2.2.4 Repackaging

For repackaging, exposure estimates for TWAs of 15 mins, 30 mins, and 8 hrs are available based on personal monitoring data samples, including 18 data points from two sources. EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively, for the 8-hr TWAs. Due to the limited number of data points, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates, respectively, for the 15- and 30-min TWAs. EPA has not identified reasonably available data on potential ONU inhalation exposures from PCE repackaging. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.7. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium for workers and low for ONUs. Section 2.4.1.7 describes the justification for this occupational scenario confidence rating.

Table 4-7. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Import/Repackaging

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**4.1**	11	41	103	206	10
		Central Tendency	11		109	273	546	

[1] Data from Altmann et al. (1990)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-8. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Import/Repackaging

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**12**	**32**	120	299	598	100
		Central Tendency	**32**		316	791	1,582	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**7.6**	**20**	76	190	379	30
		Central Tendency	**20**		201	502	1,004	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	112	296	1,120	2,801	5,601	30
		Central Tendency	296		2,963	7,408	14,816	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	**23**	**61**	231	578	1,156	100
		Central Tendency	**61**		612	1,529	3,059	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	76	201	759	1,897	3,794	30
		Central Tendency	201		2,007	5,018	10,036	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	65	172	650	1,626	3,252	30
		Central Tendency	172		1,721	4,301	8,603	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-9. Risk Estimation for Chronic, Cancer Inhalation Exposures for Import/Repackaging

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.8E-4**	8.3E-5	2.8E-5	1.1E-5	5.7E-6	10^{-4}
		Central Tendency	8.3E-5		8.3E-6	3.3E-6	1.7E-6	

[1] Data from JISA (1993)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

4.2.2.5 Processing as Reactant

For processing as a reactant, exposure estimates for TWAs of 15 mins, 30 mins, and 8 hrs are available based on surrogate personal monitoring data samples, including 351 data points from one source. EPA uses surrogate data for PCE manufacturing to approximate exposures during processing as a reactant as monitoring data specific to this condition of use were not available and manufacturing sites and sites processing PCE as a reactant are expected to have similar operations. For workers, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. For 8-hr TWA ONU exposures, EPA calculated 50th and 95th percentiles to characterize central tendency and high-end exposures, respectively. However, for 12-hr TWA ONU exposures, all three data points

available measured below the LOW. Therefore, EPA characterized the central tendency and high-end exposures as half the LOD and the LOD, respectively. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium to high. Section 2.4.1.8 describes the justification for this occupational scenario confidence rating.

As stated in Section 4.2.2.1, risks for chronic CNS effects based on the occupational HEC may be overestimated for OES with less than 250 exposure days/yr. This is the case for 12hr/day Processing as Reactant, which has an estimated 167 exposure days/yr.

Table 4-10. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Processing as Reactant

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**1.9**	54	19	47	94	10
		Central Tendency	154	147	1,538	3,846	7,692	
12-hr	3.3	High-End	15	73	155	386	773	10
		Central Tendency	161	147	1,610	4,024	8,049	

[1] Data from Altmann et al. (1990)

Table 4-11. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Processing as Reactant

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Based on exposure data for 8 hr TWA								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**5.4**	158	**54**	136	272	100
		Central Tendency	446	427	4,462	11,154	22,308	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**3.5**	100	35	86	173	30
		Central Tendency	283	271	2,830	7,075	14,151	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	51	1,480	510	1,275	2,551	30
		Central Tendency	4,178	4,000	41,778	104,446	208,892	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	**11**	306	105	263	527	100
		Central Tendency	863	826	8,625	21,563	43,126	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	35	1,003	346	864	1,728	30
		Central Tendency	2,830	2,710	28,302	70,754	141,508	
Developmental -	18	High-End	**30**	859	296	740	1,481	30

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Mortality/ CNS effects (Tinston, 1994)		Central Tendency	2,426	2,323	24,258	60,646	121,292	
Based on exposure data for 12 hr TWA								
CNS - Visual effects (U.S. EPA, 2012c)	9.7	High-End	**45**	215	453	1,132	2,264	100
		Central Tendency	472	430	4,715	11,789	23,577	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	43	204	430	1,075	2,150	30
		Central Tendency	448	408	4,478	11,195	22,389	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	635	3,011	6,347	15,868	31,735	30
		Central Tendency	6,610	6,023	66,102	165,255	330,510	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	131	622	1,310	3,276	6,552	100
		Central Tendency	1,365	1,243	13,647	34,117	68,234	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	430	2,040	4,300	10,749	21,498	30
		Central Tendency	4,478	4,080	44,779	111,947	223,894	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	369	1,749	3,685	9,213	18,427	30
		Central Tendency	3,838	3,497	38,382	95,954	191,909	

Table 4-12. Risk Estimation for Chronic, Cancer Inhalation Exposures for Processing as Reactant

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Based on exposure data for 8 hr TWA								
Cancer Risk liver tumors	2.0E-3	High-End	**6.2E-4**	2.1E-5	6.2E-5	2.5E-5	1.2E-5	10^{-4}
		Central Tendency	5.9E-6	6.2E-6	5.9E-7	2.4E-7	1.2E-7	
Based on exposure data for 12 hr TWA								
Cancer Risk Liver Tumors	2.0E-3	High-End	5.0E-5	1.1E-5	5.0E-6	2.0E-6	1.0E-6	10^{-4}
		Central Tendency	3.7E-6	4.1E-6	3.7E-7	1.5E-7	7.5E-8	

[1] Data from JISA (1993)

4.2.2.6 Incorporation into Formulation, Mixture, or Reactant Product

For incorporation into formulation, mixture, or reaction product, exposure estimates for TWAs of 8 hrs are available based on personal monitoring data samples for aerosol packing, including 8 data points from two sources, and modeling for degreasing solvent, dry cleaning solvent, and miscellaneous product formulations. For all formulation types, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. EPA has not identified reasonably

available data to estimate potential ONU inhalation exposures from PCE incorporation into formulation, mixture, or reaction product using monitoring data or modeling. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.9. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the aerosol packing inhalation estimates in this scenario is medium to high for workers and low for ONUs and EPA's overall confidence in the modeled exposures for other formulation types is medium for workers and low for ONUs. Section 2.4.1.9 describes the justification for this occupational scenario confidence rating.

When comparing to the subcategories of use presented in Table 1-4 and Table 4-125, the aerosol packing data corresponds to formulation of "other chemical products and preparations", the degreasing and dry cleaning solvents corresponds to formulation of "cleaning and degreasing products", and the miscellaneous corresponds to the formulation of "paint and coating products" and "adhesives and sealant products."

Table 4-13. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Incorporation into Formulation, Mixture, or Reactant Product

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Aerosol Packing								
8-hr	5.0	High-End	**0.2**	**0.6**	**2.0**	**4.9**	**9.8**	10
		Central Tendency	**0.6**		**5.7**	14	29	
Degreasing Solvent								
8-hr	5.0	High-End	**1.9**	**6.8**	19	48	96	10
		Central Tendency	**6.8**		68	171	342	
Dry Cleaning Solvent								
8-hr	5.0	High-End	**0.4**	**1.3**	**3.6**	**8.9**	18	10
		Central Tendency	**1.3**		13	32	63	
Miscellaneous								
8-hr	5.0	High-End	**3.5**	13	35	89	176	10
		Central Tendency	13		126	315	629	

[1] Data from Altmann et al. (1990)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-14. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Incorporation into Formulation, Mixture, or Reactant Product

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
Aerosol Packing								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.6**	**1.7**	**5.7**	**14**	**28**	100
		Central Tendency	**1.7**		**17**	**42**	**83**	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.4**	**1.1**	**3.6**	**9.0**	**18**	30
		Central Tendency	**1.1**		**11**	**26**	53	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**5.3**	**16**	53	133	267	30
		Central Tendency	**16**		156	389	778	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	**1.1**	**3.2**	**11**	**28**	**55**	100
		Central Tendency	**3.2**		**32**	**80**	161	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**3.6**	**11**	36	90	181	30
		Central Tendency	**11**		105	263	527	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**3.1**	**9.0**	31	77	155	30
		Central Tendency	**9.0**		90	226	452	
Degreasing Solvent								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**5.6**	**20**	**56**	139	278	100
		Central Tendency	**20**		198	496	992	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**3.5**	**13**	35	88	176	30
		Central Tendency	**13**		126	315	629	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	52	186	521	1,302	2,605	30
		Central Tendency	186		1,858	4,646	9,292	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	**11**	**38**	108	269	538	100
		Central Tendency	**38**		384	959	1,918	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	35	126	353	882	1,765	30
		Central Tendency	126		1,259	3,147	6,294	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	30	108	303	756	1,513	30
		Central Tendency	108		1,079	2,698	5,395	

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
Dry Cleaning Solvent								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**1.0**	**3.7**	**10**	**26**	**52**	100
		Central Tendency	**3.7**		**37**	**91**	183	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.7**	**2.3**	**6.5**	**16**	33	30
		Central Tendency	**2.3**		**23**	58	116	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**9.7**	34	97	241	483	30
		Central Tendency	34		342	856	1,711	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	**2.0**	**7.1**	**20**	**50**	**100**	100
		Central Tendency	**7.1**		**71**	177	353	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**6.5**	**23**	65	163	327	30
		Central Tendency	**23**		232	580	1,159	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**5.6**	**20**	56	140	280	30
		Central Tendency	**20**		199	497	994	
Miscellaneous								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**10**	**37**	102	256	511	100
		Central Tendency	**37**		366	914	1,828	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**6.5**	**23**	65	162	324	30
		Central Tendency	**23**		232	580	1,160	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	96	342	958	2,394	4,788	30
		Central Tendency	342		3,424	8,561	17,121	
Immune/ Hematological - biomarkers (Jisa, 1993)	6.4	High-End	**20**	**71**	198	494	989	100
		Central Tendency	**71**		707	1,767	3,535	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	65	232	649	1,622	3,244	30
		Central Tendency	232		2,320	5,799	11,598	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	56	199	556	1,390	2,780	30
		Central Tendency	199		1,988	4,971	9,941	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-15. Risk Estimation for Chronic, Cancer Inhalation Exposures for Incorporation into Formulation, Mixture, or Reactant Product

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Aerosol Packing								
Cancer Risk Liver Tumors	2.0E-3	High-End	**6.0E-3**	**1.6E-3**	**6.0E-4**	**2.4E-4**	**1.2E-4**	10^{-4}
		Central Tendency	**1.6E-3**		**1.6E-4**	6.3E-5	3.2E-5	
Degreasing Solvent								
Cancer Risk Liver Tumors	2.0E-3	High-End	**4.7E-4**	**1.3E-4**	4.7E-5	1.9E-5	9.4E-6	10^{-4}
		Central Tendency	**1.3E-4**		1.3E-5	5.1E-6	2.5E-6	
Dry Cleaning Solvent								
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.6E-3**	**6.8E-4**	**2.6E-4**	**1.0E-4**	5.1E-5	10^{-4}
		Central Tendency	**6.8E-4**		6.8E-5	2.7E-5	1.4E-5	
Miscellaneous								
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.6E-4**	6.8E-5	2.6E-5	1.0E-5	5.1E-6	10^{-4}
		Central Tendency	6.8E-5		6.8E-6	2.7E-6	1.4E-6	

[1] Data from JISA (1993)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

4.2.2.7 Batch Open-Top Vapor Degreasing

For OTVDs, exposure estimates for TWAs of 15 mins, 4 hrs, and 8 hrs are available based on personal monitoring data samples, including 79 data points from multiple sources. For 8-hr TWAs, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. Due to the limited number of data points, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates, respectively, for the 4-hr TWA. For the 15-min TWA, exposures are based on the single data point that was available. EPA identified 12 of the 79 data points to be for ONU exposures at sites operating OTVDs as described in more detail above in Section 2.4.1.10. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium to high. Section 2.4.1.10 describes the justification for this occupational scenario confidence rating.

Table 4-16. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Batch Open-Top Vapor Degreasing

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**0.2**	**1.0**	**1.6**	**3.9**	**7.8**	10
		Central Tendency	**2.4**	**8.2**	24	60	119	

[1] Data from Altmann et al. (1990)

Table 4-17. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Batch Open-Top Vapor Degreasing

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.5**	**2.8**	**4.5**	**11**	**23**	100
		Central Tendency	**6.9**	**24**	**69**	173	345	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.3**	**1.8**	**2.9**	**7.2**	**14**	30
		Central Tendency	**4.4**	**15**	44	110	219	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**4.2**	**26**	42	106	212	30
		Central Tendency	65	224	647	1,616	3,233	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.9**	**5.4**	**8.7**	**22**	**44**	100
		Central Tendency	**13**	**46**	133	334	667	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**2.9**	**18**	**29**	72	143	30
		Central Tendency	44	152	438	1,095	2,190	
Developmental - Mortality/ CNS effects (Tinston, 1994)	21	High-End	**2.5**	**15**	**25**	61	123	30
		Central Tendency	38	130	375	939	1,877	

Table 4-18. Risk Estimation for Chronic, Cancer Inhalation Exposures for Batch Open-Top Vapor Degreasing

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	**7.5E-3**	**1.2E-3**	**7.5E-4**	**3.0E-4**	**1.5E-4**	10^{-4}
		Central Tendency	**3.8E-4**	**1.1E-4**	3.8E-5	1.5E-5	7.6E-6	

[1] Data from JISA (1993)

4.2.2.8 Batch Closed-Loop Vapor Degreasing

For batch closed-loop vapor degreasing, exposure estimates for TWAs of 4 hrs and 8 hrs are available based on personal monitoring data samples, including 18 data points from two sources. For worker 8-hr TWAs, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates. Due to the limited number of data points, for 4-hr TWAs and ONU 8-hr TWAs, EPA calculated the median and maximum to characterize the central tendency and high-end exposure estimates. EPA identified 2 of the 18 data points to be for ONU exposures at sites operating batch closed-loop vapor degreasers as described in more detail above in Section 2.4.1.11. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is high. Section 2.4.1.11 describes the justification for this occupational scenario confidence rating.

Table 4-19. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Batch Closed-Loop Vapor Degreasing

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	20	52	198	494	988	10
		Central Tendency	69	76	693	1,732	3,463	

[1] Data from Altmann et al. (1990)

Table 4-20. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Batch Closed-Loop Vapor Degreasing

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**57**	151	573	1,433	2,865	100
		Central Tendency	201	222	2,009	5,022	10,043	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	36	96	364	909	1,818	30
		Central Tendency	127	141	1,274	3,185	6,371	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	537	1,418	5,366	13,416	26,832	30
		Central Tendency	1,881	2,075	18,809	47,023	94,047	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	111	293	1,108	2,770	5,539	100
		Central Tendency	388	428	3,883	9,708	19,416	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	364	961	3,635	9,088	18,176	30
		Central Tendency	1,274	1,406	12,742	31,855	63,709	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	312	823	3,116	7,790	15,580	30
		Central Tendency	1,092	1,205	10,922	27,304	54,608	

Table 4-21. Risk Estimation for Chronic, Cancer Inhalation Exposures for Batch Closed-Loop Vapor Degreasing

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	5.9E-5	2.2E-5	5.9E-6	2.4E-6	1.2E-6	10^{-4}
		Central Tendency	1.3E-5	1.2E-5	1.3E-6	5.2E-7	2.6E-7	

[1] Data from JISA (1993)

4.2.2.9 Conveyorized Vapor Degreasing

For conveyorized vapor degreasing, exposure estimates for TWAs of 8 hrs are available based on modeling with a near-field and far-field approach. EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. EPA used the near-field air concentrations for worker exposures and the far-field air concentrations for potential ONU inhalation exposures from PCE conveyorized vapor degreasing as described in more detail above in Section 2.4.1.12. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium. Section 2.4.1.12 describes the justification for this occupational scenario confidence rating.

Table 4-22. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Conveyorized Vapor Degreasing

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**2.7E-2**	**4.0E-2**	**0.3**	**0.7**	**1.3**	10
		Central Tendency	**6.4E-2**	**0.1**	**0.6**	**1.6**	**3.2**	

[1] Data from Altmann et al. (1990)

Table 4-23. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Conveyorized Vapor Degreasing

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**7.8E-2**	**0.1**	**0.8**	**2.0**	**3.9**	100
		Central Tendency	**0.2**	**0.4**	**1.9**	**4.6**	**9.3**	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**4.9E-2**	**7.3E-2**	**0.5**	**1.2**	**2.5**	30
		Central Tendency	**0.1**	**0.2**	**1.2**	**2.9**	**5.9**	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**0.7**	**1.1**	**7.3**	**18**	37	30
		Central Tendency	**1.7**	**3.3**	**17**	43	87	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.2**	**0.2**	**1.5**	**3.8**	**7.5**	100
		Central Tendency	**0.4**	**0.7**	**3.6**	**9.0**	**18**	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	**0.5**	**0.7**	**4.9**	**12**	**25**	30
		Central Tendency	**1.2**	**2.3**	**12**	**29**	59	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**0.4**	**0.6**	**4.2**	**11**	**21**	30
		Central Tendency	**1.0**	**1.9**	**10**	**25**	50	

Table 4-24. Risk Estimation for Chronic, Cancer Inhalation Exposures for Conveyorized Vapor Degreasing

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	**3.5E-2**	**2.3E-2**	**3.5E-3**	**1.4E-3**	**7.0E-4**	10^{-4}
		Central Tendency	**1.3E-2**	**7.0E-3**	**1.3E-3**	**5.4E-4**	**2.7E-4**	

[1] Data from JISA (1993)

4.2.2.10 Web Degreasing

For web degreasing, exposure estimates for TWAs of 8 hrs are available based on modeling with a near-field and far-field approach. EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. EPA used the near-field air concentrations for worker exposures and the far-field air concentrations for potential ONU inhalation exposures from PCE web degreasing as described in more detail above in Section 2.4.1.13. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium. Section 2.4.1.13 describes the justification for this occupational scenario confidence rating.

Table 4-25. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Web Degreasing

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**2.8**	**4.3**	28	69	139	10
		Central Tendency	**8.2**	16	82	205	409	

[1] Data from Altmann et al. (1990)

Table 4-26. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Web Degreasing

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**8.0**	**12**	**80**	201	402	100
		Central Tendency	**24**	**45**	237	593	1,187	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**5.1**	**7.9**	51	128	255	30
		Central Tendency	**15**	**29**	151	376	753	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	75	116	754	1,884	3,768	30
		Central Tendency	222	425	2,223	5,557	11,113	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**16**	**24**	156	389	778	100
		Central Tendency	**46**	**88**	459	1,147	2,294	

Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	51	79	510	1,276	2,552	30
		Central Tendency	151	288	1,506	3,764	7,528	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	44	67	438	1,094	2,188	30
		Central Tendency	129	247	1,291	3,226	6,453	

Table 4-27. Risk Estimation for Chronic, Cancer Inhalation Exposures for Web Degreasing

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	**3.3E-4**	**2.1E-4**	3.3E-05	1.3E-5	6.7E-6	10^{-4}
		Central Tendency	**1.1E-4**	5.5E-5	1.1E-05	4.2E-6	2.1E-6	

[1] Data from JISA (1993)

4.2.2.11 Cold Cleaning

For cold cleaning, exposure estimates for TWAs of 4 hrs and 8 hrs are available based on personal monitoring data samples, including 34 data points from two sources. EPA supplemented the identified 8-hr TWA exposure monitoring data using modeling with a near-field and far-field approach. For 8-hr TWAs from both monitoring data and modeling, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. Due to the limited number of data points for 4-hr TWAs, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates, respectively. EPA did not identify monitoring data for ONUs; therefore, EPA used the modeled near-field air concentrations for worker exposures and the modeled far-field air concentrations for potential ONU inhalation exposures from PCE cold cleaning as described in more detail above in Section 2.4.1.14. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium to high. Section 2.4.1.14 describes the justification for this occupational scenario confidence rating.

Table 4-28. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Cold Cleaning

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Based on exposure monitoring data								
8-hr	5.0	High-End	**1.2**	EPA did not identify monitoring data for ONUs	12	30	61	10
		Central Tendency	**3.6**		36	89	179	
Based on exposure modeling								
8-hr	5.0	High-End	**3.3**	**6.4**	33	81	163	10
		Central Tendency	2,086	4,029	20,857	52,142	104,284	

[1] Data from Altmann et al. (1990)

Table 4-29. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Cold Cleaning

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Based on exposure monitoring data								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**3.5**	EPA did not identify monitoring data for ONUs	**35**	**88**	176	100
		Central Tendency	**10**		104	259	518	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**2.2**		**22**	56	111	30
		Central Tendency	**6.6**		66	164	329	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	33		329	822	1,644	30
		Central Tendency	97		970	2,425	4,849	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**6.8**		**68**	170	339	100
		Central Tendency	**20**		200	501	1,001	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**22**		223	557	1,114	30
		Central Tendency	66		657	1,643	3,285	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**19**		191	477	955	30
		Central Tendency	56		563	1,408	2,816	
Based on exposure modeling								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**9.4**	**29**	**94**	236	427	100
		Central Tendency	6,048	11,685	60,485	151,211	302,423	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**6.0**	**12**	60	150	299	30
		Central Tendency	3,837	7,412	38,368	95,920	191,840	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	88	174	884	2,210	4,420	30
		Central Tendency	56,639	109,419	566,385	1,415,963	2,831,927	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**18**	**36**	183	456	913	100
		Central Tendency	11,693	22,590	116,931	292,328	584,656	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	60	118	599	1,497	2,994	30
		Central Tendency	38,368	74,123	383,680	959,201	1,918,402	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	51	101	513	1,283	2,567	30
		Central Tendency	32,887	63,534	328,869	822,172	1,644,345	

Table 4-30. Risk Estimation for Chronic, Cancer Inhalation Exposures for Cold Cleaning

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Based on exposure monitoring data								
Cancer Risk Liver Tumors	2.0E-3	High-End	**9.7E-4**	EPA did not identify monitoring data for ONUs	9.7E-5	3.9E-5	1.9E-5	10^{-4}
		Central Tendency	**2.5E-4**		2.5E-5	1.0E-5	5.1E-6	
Based on exposure modeling								
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.6E-4**	**1.3E-4**	2.6E-5	1.0E-5	5.2E-6	10^{-4}
		Central Tendency	4.1E-7	2.1E-7	4.1E-8	1.6E-8	8.1E-9	

[1] Data from JISA (1993)

4.2.2.12 Aerosol Degreasing and Aerosol Lubricants

For aerosol degreasing and aerosol lubricants, exposure estimates for TWAs of 15 mins and 8 hrs are available based on personal monitoring data samples, including 211 data points from multiple sources. EPA supplemented the identified exposure monitoring data using modeling with a near-field and far-field approach to estimate 1- and 8-hr TWAs. For both monitoring data and modeling, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. EPA did not identify monitoring data for ONUs; therefore, EPA used the modeled near-field air concentrations for worker exposures and the modeled far-field air concentrations for potential ONU inhalation exposures from PCE aerosol degreasing and aerosol lubricants as described in more detail above in Section 2.4.1.15. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is high. Section 2.4.1.15 describes the justification for this occupational scenario confidence rating.

Table 4-31. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Aerosol Degreasing and Aerosol Lubricants

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
Based on exposure monitoring data								
8-hr	5.0	High-End	**0.7**	EPA did not identify monitoring data for ONUs	**6.7**	17	33	10
		Central Tendency	**3.5**		35	89	177	
Based on exposure modeling								
8-hr	5.0	High-End	**0.3**	**6.8**	**2.9**	**7.3**	15	10
		Central Tendency	**0.9**	50	**9.1**	23	46	

[1] Data from Altmann et al. (1990)

[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-32. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Aerosol Degreasing and Aerosol Lubricants

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[1]	Worker APF 25[1]	Worker APF 50[1]	
Based on exposure monitoring data								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**1.9**	EPA did not identify monitoring data for ONUs	**19**	**48**	**97**	100
		Central Tendency	**10**		103	257	515	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**1.2**		**12**	31	61	30
		Central Tendency	**6.5**		65	163	326	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**18**		181	453	906	30
		Central Tendency	96		964	2,409	4,818	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**3.7**		**37**	**94**	187	100
		Central Tendency	**20**		199	497	995	
Reproductive - Sperm effects (Beliles et al., 1980**)**	29	High-End	**12**		123	307	614	30
		Central Tendency	65		653	1,632	3,264	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**11**		105	263	526	30
		Central Tendency	56		560	1,399	2,798	
Based on exposure modeling								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.8**	**20**	**8.4**	**21**	**42**	100
		Central Tendency	**2.6**	145	**26**	**66**	132	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.5**	**12**	**5.4**	**13**	**27**	30
		Central Tendency	**1.7**	105	**17**	42	84	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**7.9**	182	79	198	395	30
		Central Tendency	**25**	1,550	248	620	1,240	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**1.6**	**38**	**16**	**41**	**82**	100
		Central Tendency	**5.1**	320	51	128	256	
Reproductive - Sperm effects (Beliles et al., 1980**)**	29	High-End	**5.4**	124	54	134	268	30
		Central Tendency	**17**	1,050	168	420	840	

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[1]	Worker APF 25[1]	Worker APF 50[1]	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**4.6**	106	46	115	230	30
		Central Tendency	**14**	900	144	360	720	

[1] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-33. of Risk Estimation for Chronic, Cancer Inhalation Exposures for Aerosol Degreasing and Aerosol Lubricants

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
Based on exposure monitoring data								
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.8E-3**	EPA did not identify monitoring data for ONUs	**1.8E-4**	7.0E-5	3.5E-5	10^{-4}
		Central Tendency	**2.6E-4**		2.6E-5	1.0E-5	5.1E-6	
Based on exposure modeling								
Cancer Risk Liver Tumors	2.0E-3	High-End	**3.1E-3**	**1.4E-4**	**3.1E-4**	**1.3E-4**	6.3E-5	10^{-4}
		Central Tendency	**9.4E-4**	2.0E-5	9.40E-5	3.8E-5	1.9E-5	

[1] Data from JISA (1993)
[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

4.2.2.13 Dry Cleaning and Spot Cleaning

4.2.2.13.1 Risk Estimation for Adults

For dry cleaning, exposure estimates for TWAs of 15 mins and 8 hrs are available based on personal monitoring data samples, including 84 data points from three sources for post-2006 NESHAP data and 124 data points from multiple sources for fourth and fifth generation machine data. EPA supplemented the identified 8-hr TWA exposure monitoring data using modeling with a near-field and far-field approach. For both monitoring data and modeling, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. The lone exception to this is for ONU monitoring data where, due to the limited number of data points, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates, respectively, for fourth and fifth generation machine data and a single data point for the post-2006 NESHAP data. EPA used both monitoring data and the modeled far-field air concentrations for potential ONU inhalation exposures from PCE dry cleaning as described in more detail above in Section 2.4.1.16. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is high. Section 2.4.1.16 describes the justification for this occupational scenario confidence rating.

Table 4-34. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Dry Cleaning and Spot Cleaning

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure monitoring data								
8-hr	5.0	High-End	**0.3**	14[3]	**2.9**	**7.4**	15	10
		Central Tendency	**2.3**		23	58	116	
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure modeling								
12-hr	3.3	High-End	**0.1**	**2.1**	**1.1**	**2.8**	**5.6**	10
		Central Tendency	**2.4**	30	24	59	118	
4th/5th Gen Only Dry Cleaning (including spot cleaning) - Based on exposure monitoring data								
8-hr	5.0	High-End	**0.9**	41	**8.9**	22	45	10
		Central Tendency	**5.1**	358	51	128	256	

[1] Data from Altmann et al. (1990)
[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.
[3] ONU exposure data for Post-2006 Dry Cleaning did not distinguish between central tendency and high-end.

Table 4-35. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Dry Cleaning and Spot Cleaning

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[1]	Worker APF 25[1]	Worker APF 50[1]	
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure monitoring data								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.9**	**42**	**8.5**	**21**	**43**	100
		Central Tendency	**6.7**	**42**	**67**	169	337	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.5**	**23**	**4.6**	**12**	**23**	30
		Central Tendency	**4.1**	**26**	41	104	207	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**6.8**	334	68	171	341	30
		Central Tendency	61	379	612	1,529	3,059	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**1.4**	**69**	**14**	**35**	**70**	100
		Central Tendency	**13**	**78**	126	316	631	

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[1]	Worker APF 25[1]	Worker APF 50[1]	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	**4.6**	226	46	116	231	30
		Central Tendency	41	257	414	1,036	2,072	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**4.0**	194	40	99	198	30
		Central Tendency	36	220	355	888	1,776	
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure modeling								
CNS - Visual effects (U.S. EPA, 2012c)	9.7	High-End	**0.3**	**6.2**	**3.3**	**8.2**	**16**	100
		Central Tendency	**6.9**	**89**	**69**	173	346	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.2**	**3.8**	**2.0**	**5.0**	**10**	30
		Central Tendency	**4.3**	55	43	106	213	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**3.0**	56	30	74	148	30
		Central Tendency	63	809	628	1,569	3,139	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.6**	**12**	**6.1**	**15**	**31**	100
		Central Tendency	**13**	167	130	324	648	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	**2.0**	38	**20**	50	100	30
		Central Tendency	43	548	425	1,063	2,126	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**1.7**	33	**17**	43	86	30
		Central Tendency	36	470	365	911	1,823	
4th/5th Gen Only Dry Cleaning (including spot cleaning) - Based on exposure monitoring data								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**2.6**	118	**26**	**65**	130	100
		Central Tendency	**15**	1,039	148	371	741	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**1.4**	64	**14**	35	70	30
		Central Tendency	**9.1**	639	91	228	456	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**21**	944	207	518	1,036	30
		Central Tendency	135	9,432	1,346	3,364	6,728	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**4.3**	195	**43**	107	214	100
		Central Tendency	**28**	1,947	278	695	1,389	
	21	High-End	**14**	639	140	351	702	30

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[1]	Worker APF 25[1]	Worker APF 50[1]	
Reproductive - Sperm effects (Beliles et al., 1980**)**		Central Tendency	91	6,389	912	2,279	4,558	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**12**	548	120	301	602	30
		Central Tendency	78	5,476	781	1,953	3,907	

[1] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-36. of Risk Estimation for Chronic, Cancer Inhalation Exposures for Dry Cleaning and Spot Cleaning

Endpoint, Tumor Types[1]	IUR (risk per mg/m^3)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure monitoring data								
Cancer Risk Liver Tumors	2.0E-3	High-End	**4.7E-3**	9.5E-5	**4.7E-4**	**1.9E-4**	9.3E-5	10^{-4}
		Central Tendency	**4.0E-4**	6.5E-5	4.0E-5	1.6E-5	8.1E-6	
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure modeling								
Cancer Risk Liver Tumors	2.0E-3	High-End	**8.1E-3**	**4.3E-4**	**8.1E-4**	**3.2E-4**	**1.6E-4**	10^{-4}
		Central Tendency	**3.8E-4**	2.9E-5	3.8E-5	1.5E-5	7.6E-6	
4th/5th Gen Only Dry Cleaning (including spot cleaning) - Based on exposure monitoring data								
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.5E-3**	3.4E-5	**1.5E-4**	6.1E-5	3.1E-5	10^{-4}
		Central Tendency	**1.8E-4**	2.6E-6	1.8E-5	7.3E-6	3.7E-6	

[1] Data from JISA (1993)
[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

4.2.2.13.2 Risk Estimation for Children of Employees Present at Dry Cleaners

As discussed in Section 2.4.1.16, it is possible that children may be present at the dry cleaners, during which they may be exposed at similar air concentration levels as occupational non-users. EPA derived lifestage-adjusted acute HECs for CNS effects for the most sensitive lifestage of infants less than 1 year old (Section 3.2.5.4.1). Risk estimates for this population are presented below in Table 4-37. Children are considered occupationally exposed equivalent to ONUs; risk estimates are therefore based on ONU exposure estimates and PPE usage is not assumed. As noted in the 2012 IRIS PCE assessment (U.S. EPA, 2012c), children who live or attend daycare or school above or adjacent to dry cleaners can also have relatively high PCE exposures. While these exposures would be higher than the general population, they would be lower than exposures to children present within dry cleaning facilities. Therefore, EPA

expects that risks to those populations are covered by evaluation of children within dry cleaning facilities.

Table 4-37. Risk Estimates for Infants Present at Dry Cleaners based on CNS Effects

Exposure Scenario	Infant HEC	Exposure Level	Risk Estimates	Benchmark MOE	Reference
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure monitoring data (8hr)					
Acute	1.3 ppm (8.9 mg/m^3)	High-End	**3.7**	10	Altmann et al. (1990)
		Central Tendency			
Post-2006 Dry Cleaning (including spot cleaning) - Based on exposure modeling (12hr)					
Acute	0.87 ppm (5.8 mg/m^3)	High-End	**0.6**	10	Altmann et al. (1990)
		Central Tendency	**8.0**		
4th/5th Gen Only Dry Cleaning (including spot cleaning) - Based on exposure monitoring data (8hr)					
Acute	1.3 ppm (8.9 mg/m^3)	High-End	11	10	Altmann et al. (1990)
		Central Tendency	93		

4.2.2.14 Adhesives, Sealants, Paints, and Coatings

For adhesives, sealants, paints, and coatings, exposure estimates for TWAs of 15 mins and 8 hrs are available based on personal monitoring data samples, including 13 data points from one source for adhesives/sealants and 20 data points from multiple sources for paints/coatings. For adhesives/sealants, discrete data points were not available; therefore, EPA used the mean and maximum reported in the study to characterize the central tendency and high-end, respectively. For 8-hr TWAs for paints/coatings, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. Due to the limited number of data points for 15-min TWAs, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates, respectively. EPA has not identified reasonably available data on potential ONU inhalation exposures from PCE adhesives, sealants, paints, and coatings. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.17. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium for workers and low for ONUs. Section 2.4.1.17 describes the justification for this occupational scenario confidence rating.

Table 4-38. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Adhesives, Sealants, Paints, and Coatings

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Paints/Coatings								
8-hr	5.0	High-End	**1.1**	21	11	27	55	10
		Central Tendency	21		214	536	1,071	
Adhesives								
8-hr	5.0	High-End	**6.2**	57	62	154	308	10
		Central Tendency	57		565	1,413	2,825	

[1] Data from Altmann et al. (1990)
[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-39. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Adhesives, Sealants, Paints, and Coatings

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
Paints/Coatings								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**3.2**	**62**	**32**	**79**	159	100
		Central Tendency	**62**		621	1,554	3,107	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**2.0**	39	**20**	50	101	30
		Central Tendency	39		394	986	1,971	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**30**	582	298	744	1,489	30
		Central Tendency	582		5,819	14,548	29,096	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**6.1**	120	**61**	154	307	30
		Central Tendency	120		1,201	3,003	6,007	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**20**	394	**202**	504	1,009	100
		Central Tendency	394		3,942	9,855	19,710	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**17**	338	173	432	864	30
		Central Tendency	338		3,379	8,447	16,894	
Adhesives								
CNS - Visual effects	14.5	High-End	**18**	164	179	447	894	100
		Central	164		1,639	4,096	8,193	

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
(U.S. EPA, 2012c)		Tendency						
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**11**	104	113	283	567	30
		Central Tendency	104		1,039	2,598	5,197	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	167	1,534	1,674	4,184	8,369	30
		Central Tendency	1,534		15,343	38,358	76,716	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**35**	317	346	864	1,728	100
		Central Tendency	317		3,168	7,919	15,838	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	113	1,039	1,134	2,835	5,669	30
		Central Tendency	1,039		10,394	25,984	51,969	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	97	891	972	2,430	4,859	30
		Central Tendency	891		8,909	22,272	44,545	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-40. Risk Estimation for Chronic, Cancer Inhalation Exposures for Adhesives, Sealants, Paints, and Coatings

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
	Paints/Coatings							
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.1E-3**	4.2E-5	**1.1E-4**	4.3E-5	2.1E-5	10^{-4}
		Central Tendency	4.2E-5		4.2E-6	1.7E-6	8.5E-7	
	Adhesives							
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.9E-4**	1.6E-5	1.9E-5	7.6E-6	3.8E-6	10^{-4}
		Central Tendency	1.6E-5		1.6E-6	6.4E-7	3.2E-7	

[1] Data from JISA (1993)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

4.2.2.15 Maskant for Chemical Milling

For maskant for chemical milling, exposure estimates for TWAs of 15 mins, 4 hrs, and 8 hrs are available based on personal monitoring data samples, including 86 data points from multiple sources. EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium to high. Section 2.4.1.18 describes the justification for this occupational scenario confidence rating.

Table 4-41. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Maskant for Chemical Milling

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**8.8E-2**	**2.3**	**0.9**	**2.2**	**4.4**	10
		Central Tendency	**2.2**	**4.8**	22	56	112	

[1] Data from Altmann et al. (1990)

Table 4-42. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Maskant for Chemical Milling

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.3**	**6.7**	**2.6**	**6.4**	**13**	100
		Central Tendency	**6.5**	**14**	**65**	162	324	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.2**	**4.2**	**1.6**	**4.1**	**8.1**	30
		Central Tendency	**4.1**	**8.8**	41	103	205	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**2.4**	62	**24**	60	120	30
		Central Tendency	61	130	606	1,516	3,031	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.5**	**13**	**4.9**	**12**	**25**	100
		Central Tendency	**13**	**27**	125	313	626	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	**1.6**	42	**16**	41	81	30
		Central Tendency	41	88	411	1,027	2,054	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**1.4**	36	**14**	35	69	30
		Central Tendency	35	75	352	880	1,760	

Table 4-43. Risk Estimation for Chronic, Cancer Inhalation Exposures for Maskant for Chemical Milling

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.3E-2**	**5.1E-4**	**1.3E-3**	**5.3E-4**	**2.7E-4**	10^{-4}
		Central Tendency	**4.1E-4**	**1.9E-4**	4.1E-5	1.6E-5	8.1E-6	

[1] Data from JISA (1993)

4.2.2.16 Industrial Processing Aid

For industrial processing aid, exposure estimates TWAs of 30 mins and 8 hrs are available based on personal monitoring data samples, including 91 data points from multiple sources. For 8-hr TWAs, EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. Due to the limited number of data points, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates for the 30-min TWA. EPA has not identified reasonably available data on potential ONU inhalation exposures from PCE industrial processing aids. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.19. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium for workers and low for ONUs. Section 2.4.1.19 describes the justification for this occupational scenario confidence rating.

Table 4-44. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Industrial Processing Aid

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	**4.2**	83	42	106	212	10
		Central Tendency	83		833	2,083	4,167	

[1] Data from Altmann et al. (1990)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-45. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Industrial Processing Aid

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**12**	242	123	307	614	100
		Central Tendency	242		2,417	6,042	12,083	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**7.8**	153	78	195	390	30
		Central Tendency	153		1,533	3,833	7,665	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	115	2,263	1,151	2,877	5,753	30
		Central Tendency	2,263		22,630	56,575	113,150	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**24**	467	238	594	1,188	100
		Central Tendency	467		4,672	11,680	23,360	

Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	78	1,533	779	1,949	3,897	30
		Central Tendency	1,533		15,330	38,325	76,650	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	67	1,314	668	1,670	3,341	30
		Central Tendency	1,314		13,140	32,850	65,700	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-46. Risk Estimation for Chronic, Cancer Inhalation Exposures for Industrial Processing Aid

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.8E-4**	1.1E-5	2.8E-5	1.1E-5	5.5E-6	10^{-4}
		Central Tendency	1.1E-5		1.1E-6	4.4E-7	2.2E-7	

[1] Data from JISA (1993)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

4.2.2.17 Metalworking Fluids

For metalworking fluids, exposure estimates for TWAs of 8 hrs are available based on estimates from the Emission Scenario Document (ESD) on the Use of Metalworking Fluids (OECD, 2011). EPA uses the geometric mean and 90th percentile as presented in the ESD to characterize the central tendency and high-end exposure estimates, respectively. EPA has not identified reasonably available data on potential ONU inhalation exposures from PCE metalworking fluids. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.20. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium for workers and low for ONUs. Section 2.4.1.20 describes the justification for this occupational scenario confidence rating.

Table 4-47. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Metalworking Fluids

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10[3]	Worker APF 25[3]	Worker APF 50[3]	
8-hr	5.0	High-End	239	869	2,387	5,968	11,937	10
		Central Tendency	869		8,692	21,731	43,462	

[1] Data from Altmann et al. (1990)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

[3] EPA does not assume routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-48. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Metalworking Fluids

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	692	2,521	6,923	17,308	34,616	100
		Central Tendency	2,521		25,208	63,019	126,038	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	439	1,599	4,392	10,979	21,959	30
		Central Tendency	1,599		15,990	39,976	79,952	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	6,483	23,605	64,830	162,075	324,151	30
		Central Tendency	23,605		236,048	590,121	1,180,242	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	1,338	4,873	13,384	33,461	66,921	100
		Central Tendency	4,873		48,733	121,831	243,663	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	4,392	15,990	43,917	109,793	219,586	30
		Central Tendency	15,990		159,904	399,759	799,518	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	3,764	13,706	37,643	94,108	188,217	30
		Central Tendency	13,706		137,060	342,651	685,302	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-49 Risk Estimation for Chronic, Cancer Inhalation Exposures for Metalworking Fluids

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10[3]	Worker APF 25[3]	Worker APF 50[3]	
Cancer Risk Liver Tumors	2.0E-3	High-End	4.9E-6	1.0E-6	4.9E-7	2.0E-7	9.8E-8	10^{-4}
		Central Tendency	1.0E-6		1.0E-7	4.2E-8	2.1E-8	

[1] Data from JISA (1993)
[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[3] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

4.2.2.18 Wipe Cleaning and Metal/Stone Polishes

For wipe cleaning and metal/stone polishes, exposure estimates for TWAs of 15 mins, 4 hrs, and 8 hrs are available based on personal monitoring data samples, including 20 data points from two sources. For 8-hr TWAs for ONUs and 15-min TWAs for workers, EPA uses the 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. Due to the limited number of data points, EPA used the median and maximum to characterize the central tendency and

high-end exposure estimates, respectively, for worker 8-hr TWAs. The 4-hr TWA estimates are based on a single data point. EPA identified 6 of the 20 data points to be for ONU exposures for wipe cleaning as described in more detail above in Section 2.4.1.21. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium. Section 2.4.1.21 describes the justification for this occupational scenario confidence rating.

Table 4-50. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Wipe Cleaning and Metal/Stone Polishes

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
8-hr	5.0	High-End	**2.2E-2**	**0.2**	**0.2**	**0.5**	**1.1**	10
		Central Tendency	**3.8E-2**	229	**0.4**	**0.9**	**1.9**	

[1] Data from Altmann et al. (1990)
[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-51. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Wipe Cleaning and Metal/Stone Polishes

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator	Worker APF 10[1]	Worker APF 25[1]	Worker APF 50[1]	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**6.5E-2**	**0.6**	**0.6**	**1.6**	**3.2**	100
		Central Tendency	**0.1**	664	**1.1**	**2.7**	**5.5**	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**4.0E-2**	**0.4**	**0.4**	**1.0**	**2.0**	30
		Central Tendency	**7.0E-2**	421	**0.7**	**1.7**	**3.5**	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**0.6**	**5.9**	**6.0**	**15**	**30**	30
		Central Tendency	**1.0**	6,220	**10**	**26**	51	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.1**	**1.2**	**1.2**	**3.1**	**6.1**	100
		Central Tendency	**0.2**	1,284	**2.1**	**5.3**	**11**	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**0.4**	**4.0**	**4.0**	**10**	**20**	30
		Central Tendency	**0.7**	4,213	**7.0**	**17**	35	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**0.3**	**3.4**	**3.5**	**8.6**	**17**	30
		Central Tendency	**0.6**	3,611	**6.0**	**15**	**30**	

[1] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-52. of Risk Estimation for Chronic, Cancer Inhalation Exposures for Wipe Cleaning and Metal/Stone Polishes

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
Cancer Risk Liver Tumors	2.0E-3	High-End	**5.3E-2**	**5.4E-3**	**5.3E-3**	**2.1E-3**	**1.1E-3**	10^{-4}
		Central Tendency	**2.4E-2**	4.0E-6	**2.4E-3**	**9.6E-4**	**4.8E-4**	

[1] Data from JISA (1993)
[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

4.2.2.19 Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

For other spot cleaning/spot removers (including carpet cleaning), exposure estimates for TWAs of 8 hrs are available based on personal monitoring data samples, including five data points from two sources. Due to the limited number of data points, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates, respectively, for worker 8-hr TWAs. The 8-hr TWA estimates for ONUs are based on a single data point. EPA identified one of the five data points to be for ONU exposures for other spot cleaning/spot removers (including carpet cleaning) as described in more detail above in Section 2.4.1.22. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium. Section 2.4.1.22 describes the justification for this occupational scenario confidence rating.

Table 4-53. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10[3]	Worker APF 25[3]	Worker APF 50[3]	
8-hr	5.0	High-End	**1.5**	167	15	37	75	10
		Central Tendency	**3.3**		33	82	165	

[1] Data from Altmann et al. (1990)
[2] ONU exposure data did not distinguish central tendency and high-end.
[3] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-54. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU[1] No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**4.3**	483	**43**	108	216	100
		Central Tendency	**9.6**		**96**	239	478	

Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**2.7**	307	**27**	69	137	30
		Central Tendency	**6.1**		61	152	303	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	41	4,526	405	1,013	2,025	30
		Central Tendency	90		896	2,240	4,480	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**8.4**	934	**84**	209	418	100
		Central Tendency	**18**		185	462	925	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**27**	3,066	274	686	1,372	30
		Central Tendency	61		607	1,517	3,035	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**24**	2,628	235	588	1,176	30
		Central Tendency	52		520	1,301	2,601	

[1] ONU exposure data did not distinguish central tendency and high-end

[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-55. of Risk Estimation for Chronic, Cancer Inhalation Exposures for Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
Cancer Risk Liver Tumors	2.0E-3	High-End	**7.9E-4**	7.0E-6	7.9E-5	3.1E-5	1.6E-5	10^{-4}
		Central Tendency	**2.8E-4**	5.4E-6	2.8E-5	1.1E-5	5.5E-6	

[1] Data from JISA (1993)

[2] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

4.2.2.20 Other Industrial Uses

For other industrial uses, exposure estimates for 8-hr TWAs are available based on 59 data points from two sources, including 38 data points for textile processing, 13 data points for wood furniture manufacturing, 4 data points for foundry applications, 2 data points for miscellaneous industrial uses, 1 data point for DoD use for water pipe repair, and 1 data point for DoD use for oil analysis. For textile processing and wood furniture manufacturing, EPA calculated 50th and 95th percentiles to characterize the central tendency and the high-end exposure estimates, respectively. Due to the limited number of data points, EPA calculated the median and maximum to characterize the central tendency and high-end exposure estimates, respectively, for miscellaneous industrial uses and foundry applications. For the oil analysis results exposure results are based on a single data point. For the water pipe repair, only one data point was available that measured below the LOD; therefore, EPA characterized the central tendency and high-end exposures as half the LOD and the LOD, respectively.

EPA has not identified reasonably available data on potential ONU inhalation exposures from other industrial uses. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail

above in Section 2.4.1.23. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium for workers for textile processing, wood furniture manufacturing, foundry applications, and miscellaneous uses and high for the two DoD uses. EPA's overall confidence is low for ONUs. Section 2.4.1.23 describes the justification for this occupational scenario confidence rating.

As stated in Section 4.2.2.1, risks for chronic CNS effects based on the occupational HEC may be overestimated for OES with less than 250 exposure days/yr. The estimated exposure days/yr for the Other DOD uses were too low for EPA to have confidence in applying the occupational HEC for risk estimation (20-36 days/yr for Water Pipe Repair, 125-150 days for Oil Analysis). Therefore, EPA used the default HEC values for chronic CNS effects for these exposure scenarios. This may underestimate risks for this exposure scenario but is a more accurate estimate than would result from use of the occupational HEC.

Table 4-56. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Other Industrial Uses

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Textile Processing								
8-hr	5.0	High-End	**0.3**	**4.0**	**2.8**	**6.9**	14	10
		Central Tendency	**4.0**		40	100	200	
Wood Furniture Manufacturing								
8-hr	5.0	High-End	**0.1**	**0.7**	**1.1**	**2.8**	**5.6**	10
		Central Tendency	**0.7**		**6.8**	17	34	
Foundry Applications								
8-hr	5.0	High-End	**2.1E-2**	**0.3**	**0.2**	**0.5**	**1.0**	10
		Central Tendency	**0.3**		**3.4**	**8.5**	17	
Miscellaneous Industrial Uses								
8-hr	5.0	High-End	**1.1**	**1.3**	11	28	57	10
		Central Tendency	**1.3**		13	34	67	
Other DoD Use – Water Pipe Repair								
8-hr	5.0	High-End	**2.2**	**4.3**	22	54	108	10
		Central Tendency	**4.3**		43	108	216	
Other DoD Use – Oil Analysis[3]								
8-hr	5.0	High-End	**5.7**	**5.7**	57	142	284	10
		Central Tendency						

[1] Data from Altmann et al. (1990)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[3] Oil analysis exposure data did not distinguish between central tendency and high-end.

Table 4-57. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Other Industrial Uses

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
Textile Processing								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.8**	**12**	**8.0**	**20**	**40**	100
		Central Tendency	**12**		116	291	581	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.5**	**7.4**	**5.1**	**13**	**25**	30
		Central Tendency	**7.4**		74	184	369	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**7.5**	109	75	187	374	30
		Central Tendency	109		1,089	2,722	5,445	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**1.5**	**22**	**15**	**39**	**77**	100
		Central Tendency	**22**		225	562	1,124	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**5.1**	74	51	127	253	30
		Central Tendency	74		738	1,844	3,688	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**4.3**	63	43	108	217	30
		Central Tendency	63		632	1,581	3,161	
Wood Furniture Manufacturing								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.3**	**2.0**	**3.3**	**8.2**	**16**	100
		Central Tendency	**2.0**		**20**	**49**	**98**	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.2**	**1.2**	**2.1**	**5.2**	**10**	30
		Central Tendency	**1.2**		**12**	31	62	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**3.1**	**18**	31	76	153	30
		Central Tendency	**18**		184	460	920	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.6**	**3.8**	**6.3**	**16**	**32**	100
		Central Tendency	**3.8**		**38**	**95**	190	
	21	High-End	**2.1**	**12**	**21**	52	104	30

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
Reproductive - Sperm effects (Beliles et al., 1980**)**		Central Tendency	**12**		125	312	623	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**1.8**	**11**	**18**	44	89	30
		Central Tendency	**11**		107	267	534	
Foundry Applications								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**6.0E-2**	**1.0**	**0.6**	**1.5**	**3.0**	100
		Central Tendency	**1.0**		**9.8**	**25**	**49**	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**3.8E-2**	**0.6**	**0.4**	**1.0**	**1.9**	30
		Central Tendency	**0.6**		**6.2**	**16**	31	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**0.6**	**9.2**	**5.7**	**14**	**28**	30
		Central Tendency	**9.2**		92	230	461	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.1**	**1.9**	**1.2**	**2.9**	**5.8**	100
		Central Tendency	**1.9**		**19**	**48**	**95**	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	**0.4**	**6.2**	**3.8**	**9.6**	**19**	30
		Central Tendency	**6.2**		62	156	312	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**0.3**	**5.4**	**3.3**	**8.2**	**16**	30
		Central Tendency	**5.4**		54	134	268	
Miscellaneous Industrial Uses								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**3.3**	**3.9**	**33**	**82**	165	100
		Central Tendency	**3.9**		**39**	**97**	195	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**2.1**	**2.5**	**21**	52	105	30
		Central Tendency	**2.5**		**25**	62	124	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	31	37	309	772	1,544	30
		Central Tendency	37		365	913	1,826	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**6.4**	**7.5**	**64**	159	319	100
		Central Tendency	**7.5**		**75**	188	377	
	21	High-End	**21**	**25**	209	523	1,046	30

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
Reproductive - Sperm effects (Beliles et al., 1980**)**		Central Tendency	**25**		247	618	1,237	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**18**	**21**	179	448	897	30
		Central Tendency	**21**		212	530	1,060	
DoD Use – Water Pipe Repair								
CNS - Visual effects (U.S. EPA, 2012c)	5.2	High-End	**68**	164	684	1,710	3,420	100
		Central Tendency	164		1,642	4,104	8,208	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**28**	66	276	691	1,381	30
		Central Tendency	66		663	1,657	3,315	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	408	979	4,077	10,194	20,387	30
		Central Tendency	979		9,786	24,465	48,930	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**84**	202	842	2,105	4,209	100
		Central Tendency	202		2,020	5,051	10,102	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	276	633	2,762	6,905	13,811	30
		Central Tendency	663		6,629	16,573	33,146	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	237	568	2,368	5,919	11,838	30
		Central Tendency	568		5,682	14,205	28,411	
DoD Use – Oil Analysis								
CNS - Visual effects (U.S. EPA, 2012c)	5.2	High-End	**43**	**52**	431	1,077	2,154	100
		Central Tendency	**52**		517	1,293	2,585	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**17**	**21**	174	435	870	30
		Central Tendency	**21**		209	522	1,044	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	257	308	2,569	6,422	12,843	30
		Central Tendency	308		3,082	7,706	15,412	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**53**	**64**	530	1,326	2,651	100
		Central Tendency	**64**		636	1,591	3,182	

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
Reproductive - Sperm effects (Beliles et al., 1980**)**	21	High-End	174	209	1,740	4,350	8,700	30
		Central Tendency	209		2,088	5,220	10,440	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	149	179	1,491	3,729	7,457	30
		Central Tendency	179		1,790	4,474	8,949	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-58. Risk Estimation for Chronic, Cancer Inhalation Exposures for Other Industrial Uses

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Textile Processing								
Cancer Risk Liver Tumors	2.0E-3	High-End	**4.3E-3**	**2.3E-4**	**4.3E-4**	**1.7E-4**	8.5E-5	10^{-4}
		Central Tendency	**2.3E-4**		2.3E-5	9.1E-6	4.5E-6	
Wood Furniture Manufacturing								
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.0E-2**	**1.3E-3**	**1.0E-3**	**4.2E-4**	**2.1E-4**	10^{-4}
		Central Tendency	**1.3E-3**		**1.3E-4**	5.4E-5	2.7E-5	
Foundry Applications								
Cancer Risk Liver Tumors	2.0E-3	High-End	**5.6E-2**	**2.7E-3**	**5.6E-3**	**2.2E-3**	**1.1E-3**	10^{-4}
		Central Tendency	**2.7E-3**		**2.7E-4**	**1.1E-4**	5.3E-5	
Miscellaneous Industrial Uses								
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.0E-3**	**6.7E-4**	**1.0E-4**	4.1E-5	2.1E-5	10^{-4}
		Central Tendency	**6.7E-4**		6.7E-5	2.7E-5	1.3E-5	
DoD Use – Water Pipe Repair								
Cancer Risk Liver Tumors	2.0E-3	High-End	7.8E-05	2.5E-05	7.8E-06	3.1E-6	1.6E-6	10^{-4}
		Central Tendency	2.5E-05		2.5E-06	1.0E-6	5.0E-7	
DoD Use – Oil Analysis								
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.2E-04**	8.0E-05	1.2E-05	5.0E-6	2.5E-6	10^{-4}
		Central Tendency	8.0E-05		8.0E-06	3.2E-6	1.6E-6	

[1] Data from JISA (1993)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

4.2.2.21 Other Commercial Uses

For other commercial uses, exposure estimates for TWAs of 15 mins and 8 hrs are available based on personal monitoring data samples, including 45 data points for printing applications, 3 data points for photocopying, 102 data points for photographic film applications, and 7 data points for mold release uses. EPA calculated the 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively, for 8-hr TWAs for printing applications and 15-min and 8-hr TWAs for photographic film applications. Due to the limited number of data points, EPA used the median and maximum to characterize the central tendency and high-end exposure estimates, respectively, for photocopying. The 15-min TWA exposure estimates for printing applications is based on a single data point. For mold release products, all available data points measured below the LOD; therefore, EPA characterized the central tendency and high-end exposures as half the LOD and the LOD, respectively. EPA has not identified reasonably available data on potential ONU inhalation exposures from other commercial uses. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.24. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium to high for printing, photographic film, and photocopying workers, medium for mold release workers, and low for ONUs. Section 2.4.1.24 describes the justification for this occupational scenario confidence rating.

Table 4-59. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Other Commercial Uses

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10[3]	Worker APF 25[3]	Worker APF 50[3]	
Printing								
8-hr	5.0	High-End	**0.4**	**3.0**	**3.7**	**9.3**	19	10
		Central Tendency	**3.0**		30	76	152	
Photocopying								
8-hr	5.0	High-End	10,000	26,667	100,000	250,000	500,000	10
		Central Tendency	26,667		266,667	666,667	1,333,333	
Photographic Film								
8-hr	5.0	High-End	**8.9E-2**	**0.8**	**0.9**	**2.2**	**4.4**	10
		Central Tendency	**0.8**		**7.9**	20	40	
Mold Release								
8-hr	5.0	High-End	44	88	441	1,102	2,205	10
		Central Tendency	88		882	2,205	4,410	

[1] Data from Altmann et al. (1990)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

[3] EPA does not expect routine use of PPE with this exposure scenario (including all sub-scenarios) and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-60. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Other Commercial Uses

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
Printing								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**1.1**	**8.8**	**11**	**27**	**54**	100
		Central Tendency	**8.8**		**88**	221	441	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.7**	**5.6**	**6.8**	**17**	34	30
		Central Tendency	**5.6**		56	140	280	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**10**	83	101	252	505	30
		Central Tendency	83		826	2,065	4,131	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**2.1**	**17**	**21**	**52**	104	100
		Central Tendency	**17**		171	426	853	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**6.8**	56	68	171	342	30
		Central Tendency	56		560	1,399	2,798	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**5.9**	48	59	146	293	30
		Central Tendency	48		480	1,199	2,399	
Photocopying								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	29,000	77,333	290,000	725,000	1,450,000	100
		Central Tendency	77,333		773,333	1,933,333	3,866,667	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	18,396	49,056	183,960	459,900	919,800	30
		Central Tendency	49,056		490,560	1,226,400	2,452,800	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	271,560	724,160	2,715,600	6,789,000	13,578,000	30
		Central Tendency	724,160		7,241,600	18,104,000	36,208,000	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	56,064	149,504	560,640	1,401,600	2,803,200	100
		Central Tendency	149,504		1,495,040	3,737,600	7,475,200	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	183,960	490,560	1,839,600	4,599,000	9,198,000	30
		Central Tendency	490,560		4,905,600	12,264,000	24,528,000	
Developmental - Mortality/	18	High-End	157,680	420,480	1,576,800	3,942,000	7,884,000	30

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10[2]	Worker APF 25[2]	Worker APF 50[2]	
CNS effects (Tinston, 1994)		Central Tendency	420,480		4,204,800	10,512,000	21,024,000	
Photographic Film								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**0.3**	**2.3**	**2.6**	**6.4**	**13**	100
		Central Tendency	**2.3**		**23**	**58**	115	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**0.2**	**1.5**	**1.6**	**4.1**	**8.2**	30
		Central Tendency	**1.5**		**15**	37	73	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	**2.4**	**22**	**24**	60	120	30
		Central Tendency	**22**		216	539	1,079	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**0.5**	**4.5**	**5.0**	**12**	**25**	100
		Central Tendency	**4.5**		**45**	111	223	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	**1.6**	**15**	**16**	41	82	30
		Central Tendency	**15**		146	365	731	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	**1.4**	**13**	**14**	35	70	30
		Central Tendency	**13**		125	313	626	
Mold Release								
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	128	256	1,279	3,197	6,394	100
		Central Tendency	256		2,558	6,394	12,788	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	81	162	811	2,028	4,056	30
		Central Tendency	162		1,622	4,056	8,112	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	1,198	2,395	11,975	29,938	59,876	30
		Central Tendency	2,395		23,950	59,876	119,751	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	247	494	2,472	6,181	12,361	100
		Central Tendency	494		4,945	12,361	24,723	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	811	1,622	8,112	20,280	40,561	30
		Central Tendency	1,622		16,224	40,561	81,122	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	695	1,391	6,953	17,383	34,767	30
		Central Tendency	1,391		13,907	34,767	69,533	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[2] EPA does not expect routine use of PPE with this exposure scenario (including all sub-scenarios) and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-61. Risk Estimation for Chronic, Cancer Inhalation Exposures for Other Commercial Uses

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10[3]	Worker APF 25[3]	Worker APF 50[3]	
Printing								
Cancer Risk Liver Tumors	2.0E-3	High-End	**3.2E-3**	**3.0E-4**	**3.2E-4**	**1.3E-4**	6.3E-5	10^{-4}
		Central Tendency	**3.0E-4**		3.0E-5	1.2E-5	6.0E-6	
Photocopying								
Cancer Risk Liver Tumors	02.0E-3	High-End	1.2E-7	3.4E-8	1.2E-8	4.7E-9	2.3E-9	10^{-4}
		Central Tendency	3.4E-8		3.4E-9	1.4E-9	6.8E-10	
Photographic Film								
Cancer Risk Liver Tumors	2.0E-3	High-End	**1.3E-2**	**1.1E-3**	**1.3E-3**	**5.3E-4**	**2.6E-4**	10^{-4}
		Central Tendency	**1.1E-3**		**1.1E-4**	4.6E-5	2.3E-5	
Mold Release								
Cancer Risk Liver Tumors	2.0E-3	High-End	2.7E-5	1.0E-5	2.7E-6	1.1E-6	5.3E-7	10^{-4}
		Central Tendency	1.0E-5		1.0E-6	4.1E-7	2.1E-7	

[1] Data from JISA (1993)
[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[3] EPA does not expect routine use of PPE with this exposure scenario (including all sub-scenarios) and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

4.2.2.22 Laboratory Chemicals

For laboratory chemicals at university laboratories, exposure estimates 8-hr TWAs are available based on personal monitoring data samples, including one data points from one source. Exposure results are based on a single data point. EPA has not identified reasonably available data on potential ONU inhalation exposures from laboratory uses. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.25. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs.

For commercial laboratories, EPA did not have any reasonably available data to assess occupational exposures. However, due to the expected safety practices when using chemicals in a laboratory setting, PCE is expected to be applied in small amounts under a fume hood, thus reducing the potential for inhalation exposures. Based on the low confidence in the quantitative assessment and the expected limited exposure to PCE during commercial laboratory use, the risk estimates for university laboratories

likely represent an overestimation of risk. Therefore, inhalation risks below are only presented for university labs and inhalation exposures to workers and ONUs at commercial labs are unlikely to result in risk when accounting for both PPE usage and expected use scenarios. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is low for workers and low for ONUs. Section 2.4.1.25 describes the justification for this occupational scenario confidence rating.

Table 4-62. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for University Laboratory Chemicals

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator[2]	ONU No respirator[3]	Worker APF 10[4]	Worker APF 25[4]	Worker APF 50[4]	
8-hr	5.0	High-End	**4.2**	**4.2**	42	105	210	10
		Central Tendency						

[1] Data from Altmann et al. (1990)
[2] Exposure data did not distinguish between central tendency and high-end
[3] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[4] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-63. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for University Laboratory Chemicals

Endpoint	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator[1]	ONU No respirator[2]	Worker APF 10[3]	Worker APF 25[3]	Worker APF 50[3]	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	**12**	**12**	122	305	610	100
		Central Tendency						
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	**7.7**	**7.7**	77	194	387	30
		Central Tendency						
Liver - Vessel dilation (Jisa, 1993)	31	High-End	114	114	1,143	2,857	5,713	30
		Central Tendency						
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	**24**	**24**	236	590	1,180	100
		Central Tendency						
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	77	77	774	1,935	3,870	30
		Central Tendency						
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	66	66	663	1,659	3,317	30
		Central Tendency						

[1] Exposure data did not distinguish between central tendency and high-end.

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[3] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

Table 4-64. of Risk Estimation for Chronic, Cancer Inhalation Exposures for University Laboratory Chemicals

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10[3]	Worker APF 25[3]	Worker APF 50[3]	
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.8E-4**	**2.2E-4**	2.8E-5	1.1E-5	5.6E-6	10^{-4}
		Central Tendency	**2.2E-4**		2.2E-5	8.6E-6	4.3E-6	

[1] Data from JISA (1993)
[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.
[3] EPA does not expect routine use of PPE with this exposure scenario and risk estimates are shown as a what-if scenario, even if those limits are not used for risk determination.

4.2.2.23 Waste Handling, Disposal, Treatment, and Recycling

For waste handling, disposal, treatment, and recycling, exposure estimates for 8-hr TWAs are available based on 12 data points from one source. EPA calculated 50th and 95th percentiles to characterize the central tendency and high-end exposure estimates, respectively. EPA has not identified reasonably available data on potential ONU inhalation exposures from waste handling, disposal, treatment, and recycling. ONU inhalation exposures are expected to be lower than worker inhalation exposures however the relative exposure of ONUs to workers cannot be quantified as described in more detail above in Section 2.4.1.26. In lieu of data, EPA uses worker central tendency values as a surrogate to estimate risks for ONUs. Considering the overall strengths and limitations of the data, EPA's overall confidence in the occupational inhalation estimates in this scenario is medium for workers and low for ONUs. Section 2.4.1.26 describes the justification for this occupational scenario confidence rating.

Table 4-65. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Waste Handling, Disposal, Treatment, and Recycling

HEC Time Period Endpoint = CNS Effects[1]	Acute HEC (ppm)	Exposure Level	MOEs for Acute Exposures					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
8-hr	5.0	High-End	50	1,315	502	1,254	2,508	10
		Central Tendency	1,315		13,150	32,874	65,749	

[1] Data from Altmann et al. (1990)
[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-66. Risk Estimation for Chronic, Non-Cancer Inhalation Exposures for Waste Handling, Disposal, Treatment, and Recycling

Endpoint[1]	Chronic HEC (ppm)	Exposure Level	MOEs for Chronic Exposure					Benchmark MOE (= Total UF)
			Worker No respirator	ONU No respirator[1]	Worker APF 10	Worker APF 25	Worker APF 50	
CNS - Visual effects (U.S. EPA, 2012c)	14.5	High-End	145	3,813	1,455	3,636	7,273	100
		Central Tendency	3,813		38,134	95,336	190,672	
Kidney - Histopathology (Jisa, 1993)	2.1	High-End	92	2,419	923	2,307	4,613	30
		Central Tendency	2,419		24,190	60,476	120,952	
Liver - Vessel dilation (Jisa, 1993)	31	High-End	1,362	35,709	13,620	34,050	68,101	30
		Central Tendency	35,709		357,095	892,727	1,785,475	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.4	High-End	281	7,372	2,812	7,030	14,060	100
		Central Tendency	7,372		73,723	184,307	368,614	
Reproductive - Sperm effects (Beliles et al., 1980)	21	High-End	923	24,190	9,227	23,066	46,133	30
		Central Tendency	24,190		241,903	604,758	1,209,515	
Developmental - Mortality/ CNS effects (Tinston, 1994)	18	High-End	791	20,735	7,908	19,771	39,542	30
		Central Tendency	20,735		207,345	518,364	1,036,727	

[1] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

Table 4-67. Risk Estimation for Chronic, Cancer Inhalation Exposures for Waste Handling, Disposal, Treatment, and Recycling

Endpoint, Tumor Types[1]	IUR (risk per ppm)	Exposure Level	Cancer Risk Estimates					Benchmark
			Worker No respirator	ONU No respirator[2]	Worker APF 10	Worker APF 25	Worker APF 50	
Cancer Risk Liver Tumors	2.0E-3	High-End	2.3E-5	6.9E-7	2.3E-6	9.3E-7	4.7E-7	10^{-4}
		Central Tendency	6.9E-7		6.9E-8	2.8E-8	1.4E-8	

[1] Data from JISA (1993)

[2] EPA is unable to estimate ONU exposures separately from workers. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

4.2.3 Risk Estimation for Dermal Exposures to Workers

To assess dermal exposure, EPA used the *Dermal Exposure to Volatile Liquids Model* (see Section 2.4.1.5) to calculate the dermal retained dose. EPA "binned" exposure scenarios based on likely level of exposure. Overall, EPA has a medium level of confidence in the assessed baseline exposure.

The hazard HEDs are summarized in Table 3-7, Table 3-8 and Table 3-9. From among all chronic studies, EPA selected the most robust studies and non-cancer PODs from within each health domain to serve as the best overall endpoints for risk estimation (Section 3.2.5.4). These PODs are presented below

in Table 4-68 along with the single acute POD. Dermal PODs were calculated as extrapolated from both inhalation and oral POD values, when possible (Section 3.2.5.4.2 and Table 3-12). When extrapolation was available via both routes, the more sensitive POD was selected in order to be health-protective given the relative similarity in magnitude of uncertainties via either route. Of note, in all cases the difference in the derived dermal POD between routes is no more than approximately 2-fold. The dermal POD value to be used for risk estimates is bold in the table below. Non-cancer risk estimates were calculated with Equation 4-1 and cancer risks were calculated with Equation 4-2.

Table 4-68. Selected PODs for Use in Risk Estimation of Dermal Exposures

Target Organ System and Effect	Type of Extrapolation	Dermal HED (mg/kg-day)	Total Uncertainty Factor (UF) for Benchmark MOE	Reference	Data Quality
ACUTE EXPOSURES					
CNS Neurotoxicity increased latencies for pattern reversal visual-evoked potentials	Inhalation to Dermal	**4.25**	UF_A=1; UF_H=10; UF_L=1 **Total UF=10**	Altmann et al. (1990)	Medium
Midpoint of the range of the two neurotoxicity endpoints	Oral to Dermal	**6.2**	UF_A=1; UF_H=10; UF_L=10 **Total UF=100**	Based on U.S. EPA (2012c)	Medium
CHRONIC EXPOSURES					
Kidney Nuclear enlargement in proximal tubules	Oral to Dermal	**2.2**	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	JISA (1993)	High
Liver Increased angiectasis in liver	Oral to Dermal	**24.5**	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	JISA (1993)	High
Immune/ Hematological Changes in blood cells and immune parameters	Oral to Dermal	**6.8**	UF_A=1; UF_H=10; UF_L=10 UF_S = 1 **Total =100**	Emara (2010)	High
Reproductive Reduced sperm quality following 5 days exposure	Oral to Dermal	**22**	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	Beliles et al. (1980)	High
Developmental Increased F_{2A} pup deaths by Day 29, CNS depression in F_1 and F_2	Inhalation to Dermal	**31**	UF_A=3; UF_H=10; UF_L=1 **Total UF=30**	Tinston et al. (1994)	High
CANCER (LIFETIME EXPOSURE)					
male mouse hepatocellular tumors	Oral to Dermal	**2×10^{-3} per mg/kg/day**	Not applicable	JISA (1993)	High

4.2.3.1 Industrial Uses That Generally Occur in Closed Systems

For these uses, dermal exposure is likely limited to chemical loading/unloading activities (*e.g.*, connecting hoses) and taking quality control samples. The exposure scenarios include:

- Manufacture
- Import/Repackaging
- Processing as a Reactant
- Incorporation into Formulation, Mixture, or Reaction Product
- Industrial Processing Aid
- Other Industrial Uses
- Laboratory Chemicals
- Waste Handling, Disposal, Treatment, and Recycling

Table 4-69. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Industrial Uses That Generally Occur in Closed Systems

Endpoint	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS - Visual effects (Altmann et al., 1990)	4.3	High-End	**1.2**	**6.0**	12	24	10
		Central Tendency	**3.6**	18	36	72	

Table 4-70. Risk Estimation for Chronic, Non-Cancer Dermal Exposures for Industrial Uses That Generally Occur in Closed Systems

Endpoint	Chronic HED (mg/kg/day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**2.6**	**13**	**26**	**51**	100
		Central Tendency	**7.7**	**38**	**77**	154	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**0.9**	**4.6**	**9.1**	**18**	30
		Central Tendency	**2.7**	**14**	**27**	55	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	**10**	51	101	203	30
		Central Tendency	30	152	304	608	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**2.8**	**14**	**28**	**56**	100
		Central Tendency	**8.4**	**42**	**84**	169	
Reproductive - Sperm effects (Beliles et al., 1980)	22	High-End	**9.1**	45	91	182	30
		Central Tendency	**27**	136	273	546	
Developmental - Mortality/	31	High-End	**13**	64	128	256	30

Endpoint	Chronic HED (mg/kg/ day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS effects (Tinston, 1994)		Central Tendency	**38**	192	384	769	

Table 4-71. Risk Estimation for Chronic, Cancer Dermal Exposures for Industrial Uses That Generally Occur in Closed Systems

Endpoint, Tumor Types[1]	Dermal slope factor (risk per mg/kg/day)	Exposure Level	Cancer Risk Estimates				Benchmark
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.5E-3**	**5.0E-4**	**2.5E-4**	**1.2E-4**	10^{-4}
		Central Tendency	**6.4E-4**	**1.3E-4**	6.4E-5	3.2E-5	

[1] Based on route to route extrapolation from the oral slope factor using data from JISA (1993)

4.2.3.2 Industrial Degreasing and Chemical Maskant Uses Which Are Not Closed Systems

For these uses, there is greater opportunity for dermal exposure during activities such as charging and draining degreasing/milling equipment, drumming waste solvent, handling recycled/re-captured maskants, and removing waste sludge. The exposure scenarios include:

- Batch Open-Top Vapor Degreasing
- Batch Closed-Loop Vapor Degreasing
- Conveyorized Vapor Degreasing
- Web Degreasing
- Cold Cleaning
- Maskant for Chemical Milling

Table 4-72. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Industrial Degreasing and Chemical Maskant Uses Which Are Not Closed Systems

Endpoint	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS - Visual effects (Altmann et al., 1990)	4.3	High-End	**1.2**	**6.0**	12	24	10
		Central Tendency	**3.6**	18	36	72	

Table 4-73. Risk Estimation for Chronic, Non-Cancer Dermal Exposures for Industrial Degreasing and Chemical Maskant Uses Which Are Not Closed Systems

Endpoint	Chronic HED (mg/kg/ day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**2.6**	**13**	**26**	**51**	100
		Central Tendency	**7.7**	**38**	**77**	154	

Endpoint	Chronic HED (mg/kg/day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**0.9**	**4.5**	**9.1**	**18**	30
		Central Tendency	**2.7**	**14**	**27**	55	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	**10**	51	101	203	30
		Central Tendency	30	152	304	608	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**2.8**	**14**	**28**	**56**	100
		Central Tendency	**8.4**	42	84	169	
Reproductive - Sperm effects (Beliles et al., 1980)	22	High-End	**9.1**	45	91	182	30
		Central Tendency	**27**	136	273	546	
Developmental - Mortality/ CNS effects (Tinston, 1994)	31	High-End	**13**	64	128	256	30
		Central Tendency	**38**	192	384	769	

Table 4-74. Risk Estimation for Chronic, Cancer Dermal Exposures for Industrial Degreasing and Chemical Maskant Uses Which Are Not Closed Systems

Endpoint, Tumor Types[1]	Dermal slope factor (risk per mg/kg/day)	Exposure Level	Cancer Risk Estimates				Benchmark
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.5E-3**	**5.0E-4**	**2.5E-4**	**1.2E-4**	10^{-4}
		Central Tendency	**6.4E-4**	**1.3E-4**	6.4E-5	3.2E-5	

[1] Based on route to route extrapolation from the oral slope factor using data from JISA (1993)

4.2.3.3 Aerosol Uses

For these uses, workers are likely to have direct dermal contact with film applied to substrate and incidental deposition of aerosol to skin. The exposure scenario is specific to aerosol degreasing and aerosol lubricants. EPA does not expect routine use of dermal PPE with this exposure scenario for commercial use.

Table 4-75. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Aerosol Uses

Endpoint [1]	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5[3]	Worker PF 10	Worker PF 20	
CNS - Visual effects (Altmann et al., 1990)	4.3	High-End	**0.8**	**4.0**	**8.0**	16	10
		Central Tendency	**2.4**	12	24	48	

Table 4-76. Risk Estimation for Chronic, Non-Cancer Dermal Exposures for Aerosol Uses

Endpoint	Chronic HED (mg/kg/day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**1.7**	**8.6**	**17**	**34**	100
		Central Tendency	**5.1**	**26**	**51**	103	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**0.6**	**3.0**	**6.1**	**12**	30
		Central Tendency	**1.8**	**9.1**	**18**	36	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	**6.8**	34	68	135	30
		Central Tendency	**20**	101	203	406	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**1.9**	**9.4**	**19**	**38**	100
		Central Tendency	**5.6**	**28**	**56**	113	
Reproductive - Sperm effects (Beliles et al., 1980)	22	High-End	**6.1**	30	61	121	30
		Central Tendency	**18**	91	182	364	
Developmental - Mortality/ CNS effects (Tinston, 1994)	31	High-End	**8.6**	43	86	171	30
		Central Tendency	**26**	128	257	513	

Table 4-77. Risk Estimation for Chronic, Cancer Dermal Exposures for Aerosol Uses

Endpoint, Tumor Types[1]	Dermal slope factor (risk per mg/kg/day)	Exposure Level	Cancer Risk Estimates				Benchmark
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Cancer Risk Liver Tumors	2.0E-3	High-End	**3.7E-3**	**7.4E-4**	**3.7E-4**	**1.9E-4**	10^{-4}
		Central Tendency	**9.6E-4**	**1.9E-4**	9.6E-5	4.8E-5	

[1] Based on route to route extrapolation from the oral slope factor using data from JISA (1993)

4.2.3.4 Dry Cleaning

At dry cleaning shops, workers may be exposed to bulk liquids while charging and draining solvent to/from machines, removing and disposing sludge, and maintaining equipment. Workers can also be exposed to PCE used in spot cleaning products at the same shop. EPA does not expect routine use of dermal PPE with this exposure scenario.

Table 4-78. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Dry Cleaning

Endpoint	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5[1]	Worker PF 10[1]	Worker PF 20[1]	
CNS -	4.3	High-End	**0.8**	**3.9**	**7.9**	16	10

Endpoint	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5[1]	Worker PF 10[1]	Worker PF 20[1]	
Visual effects (Altmann et al., 1990)		Central Tendency	**2.4**	12	24	47	

[1] EPA does not expect routine use of PPE with this exposure scenario.

Table 4-79. Risk Estimation for Chronic, Non-Cancer Dermal Exposures for Dry Cleaning

Endpoint	Chronic HED (mg/kg/day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5[1]	Worker PF 10[1]	Worker PF 20[1]	
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**1.4**	**7.2**	**14**	**29**	100
		Central Tendency	**4.9**	**24**	**49**	**97**	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**0.5**	**2.5**	**5.1**	**10**	30
		Central Tendency	**1.7**	**8.6**	**17**	35	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	**5.7**	**28**	57	113	30
		Central Tendency	**19**	96	193	385	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**1.6**	**7.8**	**16**	**31**	100
		Central Tendency	**5.3**	**27**	**53**	107	
Reproductive - Sperm effects (Beliles et al., 1980)	22	High-End	**5.1**	**25**	51	102	30
		Central Tendency	**17**	86	173	346	
Developmental - Mortality/ CNS effects (Tinston, 1994)	31	High-End	**7.2**	36	72	143	30
		Central Tendency	**24**	122	244	487	

[1] EPA does not expect routine use of PPE with this exposure scenario.

Table 4-80. Risk Estimation for Chronic, Cancer Dermal Exposures for Dry Cleaning

Endpoint, Tumor Types[1]	Dermal slope factor (risk per mg/kg/day)	Exposure Level	Cancer Risk Estimates				Benchmark
			Worker No gloves	Worker PF 5[2]	Worker PF 10[2]	Worker PF 20[2]	
Cancer Risk Liver Tumors	2.0E-3	High-End	**4.4E-3**	**8.9E-4**	**4.4E-4**	**2.2E-4**	10^{-4}
		Central Tendency	**1.0E-3**	**2.0E-4**	**1.0E-4**	5.1E-5	

[1] Based on route to route extrapolation from the oral slope factor using data from JISA (1993)
[2] EPA does not expect routine use of PPE with this exposure scenario.

4.2.3.5 Commercial Activities of Similar Maximum Concentration

Most of these uses are uses with concentrations up to 100% PCE and occur at dry cleaners, and/or uses expected to have direct dermal contact with bulk liquids. At dry cleaning shops, workers may be

exposed to bulk liquids while charging and draining solvent to/from machines, removing and disposing sludge, and maintaining equipment. Workers can also be exposed to PCE used in spot cleaning products at the same shop. The exposure scenarios include:

- Wipe Cleaning and Metal/Stone Polishes
- Other Spot Cleaning/Spot Remover
- Other Commercial Uses

EPA does not expect routine use of dermal PPE with these exposure scenarios for commercial use.

Table 4-81. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Commercial Activities of Similar Maximum Concentration

Endpoint [1]	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5[1]	Worker PF 10[1]	Worker PF 20[1]	
CNS - Visual effects (Altmann et al., 1990)	4.3	High-End	**0.8**	**3.9**	**7.9**	16	10
		Central Tendency	**2.4**	12	24	47	

[1] EPA does not expect routine use of PPE with this exposure scenario.

Table 4-82. Risk Estimation for Chronic, Non-Cancer Dermal Exposures for Commercial Activities of Similar Maximum Concentration

Endpoint	Chronic HED (mg/kg/day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5[1]	Worker PF 10[1]	Worker PF 20[1]	
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**1.7**	**8.4**	**17**	**34**	100
		Central Tendency	**5.0**	**25**	**50**	101	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**0.6**	**3.0**	**6.0**	**12**	30
		Central Tendency	**1.8**	**8.9**	**18**	36	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	**6.6**	33	66	133	30
		Central Tendency	**20**	99	199	398	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**1.8**	**9.2**	**18**	**37**	100
		Central Tendency	**5.5**	**28**	**55**	110	
Reproductive - Sperm effects (Beliles et al., 1980)	22	High-End	**6.0**	**30**	60	119	30
		Central Tendency	**18**	89	179	357	
Developmental - Mortality/ CNS effects (Tinston, 1994)	31	High-End	**8.4**	42	84	168	30
		Central Tendency	**25**	126	252	503	

[1] EPA does not expect routine use of PPE with this exposure scenario.

Table 4-83. Risk Estimation for Chronic, Cancer Dermal Exposures for Commercial Activities of Similar Maximum Concentration

Endpoint, Tumor Types[1]	Dermal slope factor (risk per mg/kg/day)	Exposure Level	Cancer Risk Estimates				Benchmark
			Worker No gloves	Worker PF 5[2]	Worker PF 10[2]	Worker PF 20[2]	
Cancer Risk Liver Tumors	2.0E-3	High-End	**3.8E-3**	**7.6E-4**	**3.8E-4**	**1.9E-4**	10^{-4}
		Central Tendency	**9.8E-4**	**2.0E-4**	9.8E-5	4.9E-05	

[1] Based on route to route extrapolation from the oral slope factor using data from JISA (1993)
[2] EPA does not expect routine use of PPE with this exposure scenario.

4.2.3.6 Metalworking Fluids

These product formulations are expected to be used in industrial settings and workers may be exposed when unloading the metalworking fluid from containers; transferring fluids to the trough; and performing metal shaping operations. The exposure scenario is specific to metalworking fluids.

Table 4-84. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Metalworking Fluids

Endpoint	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS - Visual effects (Altmann et al., 1990)	4.3	High-End	12	60	120	241	10
		Central Tendency	36	181	361	722	

Table 4-85. Risk Estimation for Chronic, Non-Cancer Dermal Exposures for Metalworking Fluids

Endpoint	Chronic HED (mg/kg/day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**26**	128	256	513	100
		Central Tendency	**77**	384	769	1,538	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**9.1**	45	91	182	30
		Central Tendency	**27**	136	273	546	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	101	506	1,013	2,026	30
		Central Tendency	304	1,519	3,039	6,077	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**28**	141	281	562	100
		Central Tendency	**84**	422	843	1,687	

Endpoint	Chronic HED (mg/kg/ day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Reproductive - Sperm effects (Beliles et al., 1980**)**	22	High-End	91	455	910	1819	30
		Central Tendency	273	1364	2729	5457	
Developmental - Mortality/ CNS effects (Tinston, 1994)	31	High-End	128	641	1282	2563	30
		Central Tendency	384	1922	3845	7690	

Table 4-86. Risk Estimation for Chronic, Cancer Dermal Exposures for Metalworking Fluids

Endpoint, Tumor Types[1]	Dermal slope factor (risk per mg/kg/day)	Exposure Level	Cancer Risk Estimates				Benchmark
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.5E-4**	5.0E-5	2.5E-5	1.2E-5	10^{-4}
		Central Tendency	6.4E-5	1.3E-5	6.4E-6	3.2E-6	

[1] Based on route to route extrapolation from the oral slope factor using data from JISA (1993)

4.2.3.7 Adhesives, Sealants, Paints, and Coatings

These product formulations may have both industrial and commercial uses and workers may be exposed when mixing coating/adhesive, charging products to application equipment (*e.g.*, spray guns, roll applicators, etc.), and cleaning application equipment. Other workers may also have incidental contact with applied products during subsequent fabrication steps. The exposure scenario is specific to adhesives, sealants, paints, and coatings.

Table 4-87. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Adhesives, Sealants, Paints, and Coatings

Endpoint [1]	Acute HED (mg/kg/day)	Exposure Level	MOEs for Acute Exposures				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Commercial Uses							
CNS - Visual effects (Altmann et al., 1990)	4.3	High-End	**1.0**	**4.9**	**9.8**	20	10
		Central Tendency	**3.0**	15	30	59	
Industrial Uses							
CNS - Visual effects (Altmann et al., 1990)	4.3	High-End	**1.5**	**7.5**	15	30	10
		Central Tendency	**4.5**	23	45	90	

Table 4-88. Risk Estimation for Chronic, Non-Cancer Dermal Exposures for Adhesives, Sealants, Paints, and Coatings

Endpoint	Chronic HED (mg/kg/day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Commercial Uses							
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**2.1**	**10**	**21**	**42**	100
		Central Tendency	**6.3**	**31**	**63**	126	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**0.7**	**3.7**	**7.4**	**15**	30
		Central Tendency	**2.2**	**11**	**22**	45	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	**8.3**	41	83	166	30
		Central Tendency	**25**	124	248	497	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**2.3**	**11**	**23**	**46**	100
		Central Tendency	**6.9**	**34**	**69**	138	
Reproductive - Sperm effects (Beliles et al., 1980)	22	High-End	**7.4**	37	74	149	30
		Central Tendency	**22**	112	223	446	
Developmental - Mortality/ CNS effects (Tinston, 1994)	31	High-End	**10**	52	105	210	30
		Central Tendency	**31**	157	314	629	
Industrial Uses							
CNS - Visual effects (U.S. EPA, 2012c)	6.2	High-End	**3.2**	**16**	**32**	**64**	100
		Central Tendency	**9.6**	**48**	**96**	192	
Kidney - Histopathology (Jisa, 1993)	2.2	High-End	**1.1**	**5.7**	**11**	**23**	30
		Central Tendency	**3.4**	**17**	34	68	
Liver - Vessel dilation (Jisa, 1993)	24.5	High-End	**13**	63	127	253	30
		Central Tendency	38	190	380	760	
Immune/ Hematological - biomarkers (Emara et al., 2010)	6.8	High-End	**3.5**	**18**	**35**	**70**	100
		Central Tendency	**11**	**53**	105	211	
Reproductive - Sperm effects (Beliles et al., 1980)	22	High-End	**11**	57	114	227	30
		Central Tendency	34	171	341	682	

Endpoint	Chronic HED (mg/kg/ day)	Exposure Level	MOEs for Chronic Exposure				Benchmark MOE (= Total UF)
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Developmental - Mortality/ CNS effects (Tinston, 1994)	31	High-End	**16**	80	160	320	30
		Central Tendency	48	240	481	961	

Table 4-89. Risk Estimation for Chronic, Cancer Dermal Exposures for Adhesives, Sealants, Paints, and Coatings

Endpoint, Tumor Types[1]	Dermal slope factor (risk per mg/kg/day)	Exposure Level	Cancer Risk Estimates				Benchmark
			Worker No gloves	Worker PF 5	Worker PF 10	Worker PF 20	
Commercial Uses							
Cancer Risk Liver Tumors	2.0E-3	High-End	**3.0E-3**	**6.1E-4**	**3.0E-4**	**1.5E-4**	10^{-4}
		Central Tendency	**7.8E-4**	**1.6E-4**	7.8E-5	3.9E-5	
Industrial Uses							
Cancer Risk Liver Tumors	2.0E-3	High-End	**2.0E-3**	**4.0E-4**	**2.0E-4**	9.9E-5	10^{-4}
		Central Tendency	**5.1E-4**	1.0E-4	5.1E-5	2.6E-5	

[1] Based on route to route extrapolation from the oral slope factor using data from JISA (1993)

4.2.4 Risk Estimation for Exposures to Consumers

Risk estimates for consumers were calculated for consumers for acute inhalation and dermal exposures. Risk estimates for chronic exposures were not calculated because it is unknown how the available toxicological data relates to the human exposures expected in consumer exposure scenarios. The toxicity studies are based on human worker studies or continuous subchronic-to-chronic repeated dose animal studies. In contrast, the consumer exposure scenarios are expected to be intermittent and it is unlikely that the expected use patterns would cumulatively be equivalent to these scenarios. It therefore cannot be ruled out whether there is any risk for chronic non-cancer or cancer associated with regular, intermittent exposures at the very high end of use frequency, however this scenario cannot be adequately evaluated and is unlikely to apply to the vast majority of users.

Risk estimates were presented for differing acute exposure assumptions, categorized as high, moderate, or low intensity users based on variation in weight fraction, mass of product used, and duration of use/exposure duration. Risk estimates primarily utilized central tendency values for other modeling parameters (*e.g.*, room volume, air exchange rate, building volume) and therefore do not necessarily represent an upper bound of possible exposures. For more details on the characterization of consumer exposure see Section 2.4.2.2. For MOE estimates of all modeled scenarios see supplemental files: *Risk Evaluation for Perchloroethylene Consumer Inhalation Risk Calculations* (U.S. EPA, 2020c) and *Risk Evaluation for Perchloroethylene Consumer Dermal Risk Calculations* (U.S. EPA, 2020b). The HEC (Table 3-7) and HED values (Table 3-12) for neurotoxicity derived from (Altmann et al., 1990) was used for estimating of all acute consumer risks.

4.2.4.1 Aerosol Cleaners for Motors, Coils, Electrical Parts, Cables, Stainless Steel and marine Equipment, and Wire and Ignition Demoisturants

Estimates of MOEs for acute inhalation and dermal exposures for the aerosol cleaners for motors, coils and electrical parts, etc. consumer use are presented in
Table 4-90 and Table 4-91, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.1.1.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.1.

Table 4-90. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Aerosol Cleaners for Motors Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	**7.7**	39
Moderate Intensity User	**0.2**	**0.8**
High Intensity User	**1.3E-02**	**5.2E-02**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-91. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Aerosol Cleaners for Motors Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	601
	Youth (16-20 years)	642
	Youth (11-15 years)	587
Moderate Intensity User	Adult (≥21 years)	10
	Youth (16-20 years)	11
	Youth (11-15 years)	**9.8**
High Intensity User	Adult (≥21 years)	**1.0**
	Youth (16-20 years)	**1.1**
	Youth (11-15 years)	**1.0**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate intensity users and bystanders by inhalation, and for high and moderate (youth age 11-15) user by dermal exposures. The MOEs are above the benchmark MOE for the low intensity users and bystander by inhalation, and for moderate (adult, youth age 16-20) and low intensity users by dermal exposure.

4.2.4.2 Aerosol Brake Cleaners

Estimates of MOEs for acute inhalation and dermal exposures for the aerosol brake cleaners consumer use are presented in Table 4-92 and Table 4-93, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.1.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.1.

Table 4-92. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Aerosol Brake Cleaners Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	**2.0**	**7.1**
Moderate Intensity User	**0.2**	**0.8**
High Intensity User:	**4.5E-02**	**0.2**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-93. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Aerosol Brake Cleaner Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	369
	Youth (16-20 years)	394
	Youth (11-15 years)	360
Moderate Intensity User	Adult (≥21 years)	11
	Youth (16-20 years)	12
	Youth (11-15 years)	11
High Intensity User	Adult (≥21 years)	**1.2**
	Youth (16-20 years)	**1.3**
	Youth (11-15 years)	**1.2**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for all users and bystanders by inhalation exposures, and for the high intensity user by dermal exposure. The MOEs are above the benchmark MOE for the high and Moderate Intensity Users by dermal exposure.

4.2.4.3 Parts Cleaners

Estimates of MOEs for acute inhalation and dermal exposures for the immersive parts cleaner consumer use are presented in Table 4-94 and Table 4-95, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section

2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.2.

Considering the overall strengths and limitations of the data, EPA's overall confidence is medium for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.2.

Table 4-94. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Parts Cleaners Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	31	174
Moderate Intensity User	**0.6**	**3.3**
High Intensity User	**7.1E-02**	**0.4**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-95. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Parts Cleaners Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	145
	Youth (16-20 years)	155
	Youth (11-15 years)	142
Moderate Intensity User	Adult (≥21 years)	12
	Youth (16-20 years)	13
	Youth (11-15 years)	12
High Intensity User	Adult (≥21 years)	**2.0**
	Youth (16-20 years)	**2.2**
	Youth (11-15 years)	**2.0**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate intensity users and bystanders by inhalation exposures, and for the high intensity user by dermal exposure. The MOEs are above the benchmark MOE for low intensity users and bystanders by inhalation, and for low and moderate intensity users by dermal exposure.

4.2.4.4 Mold Cleaners, and Weld Splatter Protectants

Estimates of MOEs for acute inhalation and dermal exposures for the mold cleaners, and weld splatter protectants consumer use are presented in Table 4-96 and Table 4-97, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.3

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.3.

Table 4-96. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Mold Cleaners, and Weld Splatter Protectants Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	15	77
Moderate Intensity User	**0.3**	**1.6**
High Intensity User	**1.3E-02**	**5.2E-02**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-97. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Mold Cleaners, and Weld Splatter Protectants Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	182
	Youth (16-20 years)	194
	Youth (11-15 years)	178
Moderate Intensity User	Adult (≥21 years)	**3.8**
	Youth (16-20 years)	**4.1**
	Youth (11-15 years)	**3.7**
High Intensity User	Adult (≥21 years)	**0.6**
	Youth (16-20 years)	**0.7**
	Youth (11-15 years)	**0.6**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate intensity users and bystanders by inhalation exposure, and for moderate and high intensity users by dermal exposure. The MOEs are above benchmark MOE for low intensity users and bystanders by inhalation exposure, and for low intensity users by dermal exposure.

4.2.4.5 Vandalism Stain Removers

Estimates of MOEs for acute inhalation and dermal exposures for the vandalism stain removers consumer use are presented in Table 4-98 and Table 4-99, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs as presented in Section 2.4.2.3.4.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.4.

Table 4-98. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Vandalism Stain Removers

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	**7.7**	39
Moderate Intensity User	**0.6**	**3.2**
High Intensity User	**6.5E-02**	**0.3**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-99. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Vandalism Stain Removers

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	805
	Youth (16-20 years)	860
	Youth (11-15 years)	787
Moderate Intensity User	Adult (≥21 years)	54
	Youth (16-20 years)	57
	Youth (11-15 years)	53
High Intensity User	Adult (≥21 years)	**6.7**
	Youth (16-20 years)	**7.2**
	Youth (11-15 years)	**6.6**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate intensity users and bystanders by inhalation exposures, and high intensity users by dermal exposures. The MOEs are above benchmark MOE for low intensity users and bystanders by inhalation exposures, and low and moderate intensity users by dermal exposures.

4.2.4.6 Liquid Marble and Stone Polish

Estimates of MOEs for acute inhalation and dermal exposures for the liquid-based marble polish consumer use are presented in Table 4-100 and Table 4-101, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.5.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.5.

Table 4-100. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Liquid-Based Marble Polish Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	**3.3**	17
Moderate Intensity User	**6.8E-02**	**0.4**
High Intensity User	**1.2E-02**	**5.0E-02**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-101. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Liquid-Based Marble Polish Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	300
	Youth (16-20 years)	321
	Youth (11-15 years)	294
Moderate Intensity User	Adult (≥21 years)	**4.7**
	Youth (16-20 years)	**5.0**
	Youth (11-15 years)	**4.6**
High Intensity User	Adult (≥21 years)	**0.5**
	Youth (16-20 years)	**0.5**
	Youth (11-15 years)	**0.5**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high, moderate, and low intensity users and moderate and high intensity bystanders by inhalation exposures, and high and moderate intensity users by dermal exposures. The MOEs are above the benchmark MOE low intensity bystanders by inhalation exposure, and low intensity users by dermal exposure.

4.2.4.7 Cutting Fluid

Estimates of MOEs for acute inhalation and dermal exposures for the cutting fluid consumer use are presented in Table 4-102 and Table 4-103, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.6.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.6.

Table 4-102. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Cutting Fluid Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	**8.1**	39
Moderate Intensity User	**1.3**	**6.7**
High Intensity User	**0.1**	**0.6**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-103. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Cutting Fluid Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	252
	Youth (16-20 years)	269
	Youth (11-15 years)	246
Moderate Intensity User	Adult (≥21 years)	63
	Youth (16-20 years)	67
	Youth (11-15 years)	62
High Intensity User	Adult (≥21 years)	**4.2**
	Youth (16-20 years)	**4.5**
	Youth (11-15 years)	**4.1**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high, moderate, and low intensity users, for moderate and low intensity bystanders by inhalation exposures, and high intensity users by dermal exposures. The MOEs are above benchmark MOE for low intensity bystanders by inhalation exposures, and for low and moderate intensity users by dermal exposures.

4.2.4.8 Lubricants and Penetrating Oils

Estimates of MOEs for acute inhalation and dermal exposures for the lubricants and penetrating oils consumer use are presented in Table 4-104 and Table 4-105, respectively. Consumer inhalation exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.7.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.7.

Table 4-104. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Lubricants and Penetrating Oils Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	90	435
Moderate Intensity User	**1.4**	**7.3**
High Intensity User	**8.0E-02**	**0.4**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-105. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Lubricants and Penetrating Oils Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	446
	Youth (16-20 years)	476
	Youth (11-15 years)	435
Moderate Intensity User	Adult (≥21 years)	11
	Youth (16-20 years)	11
	Youth (11-15 years)	10
High Intensity User	Adult (≥21 years)	**0.6**
	Youth (16-20 years)	**0.6**
	Youth (11-15 years)	**0.6**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate intensity users and bystanders by inhalation exposures, and for high intensity users by dermal exposures. The MOEs are above the benchmark MOE for low and intensity users and bystanders by inhalation exposures, and for low and moderate intensity users by dermal exposures.

4.2.4.9 Adhesives

Estimates of MOEs for acute inhalation and dermal exposures for the adhesives consumer use are presented in Table 4-106 and Table 4-107, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.8.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.8.

Table 4-106. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Adhesives Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	62	299
Moderate Intensity User	**2.3**	12
High Intensity User	**0.1**	**0.5**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-107. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Adhesives Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	117
	Youth (16-20 years)	125
	Youth (11-15 years)	114
Moderate Intensity User	Adult (≥21 years)	**5.0**
	Youth (16-20 years)	**5.3**
	Youth (11-15 years)	**4.9**
High Intensity User	Adult (≥21 years)	**0.7**
	Youth (16-20 years)	**0.8**
	Youth (11-15 years)	**0.7**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate intensity users, and moderate intensity bystanders by inhalation exposures, and for high and moderate intensity users by dermal exposures. The MOEs are above the benchmark MOE for low intensity users, and low and moderate intensity bystanders by inhalation exposures, and for low intensity users by dermal exposures.

4.2.4.10 Livestock Grooming Adhesive

Estimates of MOEs for acute inhalation and dermal exposures for the livestock grooming adhesive consumer use are presented in Table 4-108 and Table 4-109, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.9.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.9.

Table 4-108. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Livestock Grooming Adhesives Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	112	539
Moderate Intensity User	12	64
High Intensity User	**0.8**	**3.0**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-109. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Livestock Grooming Adhesives Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	264
	Youth (16-20 years)	282
	Youth (11-15 years)	258
Moderate Intensity User	Adult (≥21 years)	33
	Youth (16-20 years)	36
	Youth (11-15 years)	32
High Intensity User	Adult (≥21 years)	**5.3**
	Youth (16-20 years)	**5.7**
	Youth (11-15 years)	**5.2**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high intensity users and bystanders by inhalation exposures, and for high intensity users by dermal exposures. The MOEs are above the benchmark MOE for low and moderate intensity users and bystanders by inhalation exposures, and for low and moderate intensity users by dermal exposures.

4.2.4.11 Caulks, Sealants and Column Adhesives

Estimates of MOEs for acute inhalation and dermal exposures for the caulks, sealants and column adhesives consumer use are presented in Table 4-110 and Table 4-111, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.10. Dermal exposures for the caulks, sealants and column adhesives consumer use are not expected and the area of use was assumed to be outdoors, so bystander exposure was not estimated.

Considering the overall strengths and limitations of the data, EPA's overall confidence is medium for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.10.

Table 4-110. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Caulks, Sealants and Column Adhesives Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10
	User MOE
Low Intensity User	192
Moderate Intensity User	**2.3**
High Intensity User	**7.2E-02**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-111. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Caulks, Sealants and Column Adhesives Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	42
	Youth (16-20 years)	45
	Youth (11-15 years)	41
Moderate Intensity User	Adult (≥21 years)	**1.1**
	Youth (16-20 years)	**1.2**
	Youth (11-15 years)	**1.1**
High Intensity User	Adult (≥21 years)	**0.5**
	Youth (16-20 years)	**0.5**
	Youth (11-15 years)	**0.5**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate intensity users by inhalation exposures, and high and moderate intensity users by dermal exposures. The MOEs are above the benchmark MOE for low intensity users by inhalation exposures, and for low intensity users by dermal exposures.

4.2.4.12 Outdoor Water Shield

Estimates of MOEs for acute inhalation and dermal exposures for the outdoor water shield consumer use are presented in Table 4-112 and Table 4-113, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.11.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.11

Table 4-112. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Outdoor Water Shield Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	**7.6**	29
Moderate Intensity User	**1.1**	**3.3**
High Intensity User	**8.9E-02**	**0.4**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-113. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Outdoor Water Shield Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	**0.3**
	Youth (16-20 years)	**0.4**
	Youth (11-15 years)	**0.3**
Moderate Intensity User	Adult (≥21 years)	**0.2**
	Youth (16-20 years)	**0.2**
	Youth (11-15 years)	**0.2**
High Intensity User	Adult (≥21 years)	**0.1**
	Youth (16-20 years)	**0.2**
	Youth (11-15 years)	**0.1**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for all users and high and moderate intensity bystanders by inhalation exposures, and for all users by dermal exposures. The MOEs are above the benchmark MOE for low intensity bystanders by inhalation exposures.

4.2.4.13 Aerosol Coatings and Primers

Estimates of MOEs for acute inhalation and dermal exposures for the aerosol coatings and primers consumer use are presented in Table 4-114 and Table 4-115, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.12.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.12.

Table 4-114. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Aerosol Coatings and Primers Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	522	13448
Moderate Intensity User	62	2143
High Intensity User	**5.9**	209

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-115. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Aerosol Coatings and Primers Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	30
	Youth (16-20 years)	32
	Youth (11-15 years)	30
Moderate Intensity User	Adult (≥21 years)	**8.8**
	Youth (16-20 years)	**9.4**
	Youth (11-15 years)	**8.6**
High Intensity User	Adult (≥21 years)	**3.3**
	Youth (16-20 years)	**3.5**
	Youth (11-15 years)	**3.2**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high intensity users by inhalation exposures, and high and moderate intensity users by dermal exposures. The MOEs are above the benchmark MOE for moderate and low intensity users and all bystanders by inhalation exposures, and for low intensity users by dermal exposures.

4.2.4.14 Liquid Primers and Sealants

Estimates of MOEs for acute inhalation and dermal exposures for the liquid primers and sealants consumer use are presented in Table 4-116 and Table 4-117, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.13.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.13.

Table 4-116. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Liquid Primers and Sealants Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	10600	128556
Moderate Intensity User	1163	12434
High Intensity User	36	229

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-117. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Liquid Primers and Sealants Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	**4.0**
	Youth (16-20 years)	**4.2**
	Youth (11-15 years)	**3.8**
Moderate Intensity User	Adult (≥21 years)	**0.9**
	Youth (16-20 years)	**0.9**
	Youth (11-15 years)	**0.9**
High Intensity User	Adult (≥21 years)	**0.5**
	Youth (16-20 years)	**0.6**
	Youth (11-15 years)	**0.5**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for all users by dermal exposures. The MOEs are above the benchmark MOE for all users and bystanders for inhalation exposures.

4.2.4.15 Metallic Overglaze

Estimates of MOEs for acute inhalation and dermal exposures for the metallic overglaze consumer use are presented in Table 4-118 and Table 4-117, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.14.

Considering the overall strengths and limitations of the data, EPA's overall confidence is medium for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.14.

Table 4-118. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Metallic Overglaze Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	4372	21107
Moderate Intensity User	337	1674
High Intensity User	21	81

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-119. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Metallic Overglaze Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	115
	Youth (16-20 years)	123
	Youth (11-15 years)	112
Moderate Intensity User	Adult (≥21 years)	**9.6**
	Youth (16-20 years)	10
	Youth (11-15 years)	**9.4**
High Intensity User	Adult (≥21 years)	**1.6**
	Youth (16-20 years)	**1.7**
	Youth (11-15 years)	**1.5**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for high and moderate (adult and youth age 11-15) users by dermal exposures. The MOEs are above the benchmark MOE for all users and bystanders by inhalation exposures, and moderate (youth age 16-20) and low intensity users by dermal exposures.

4.2.4.16 Wax Marble and Stone Polish

Estimates of MOEs for acute inhalation and dermal exposures for the liquid wax-based metal and stone polish consumer use are presented in Table 4-120 and Table 4-121, respectively. Consumer inhalation and dermal exposures were modeled across a range of low, moderate, and high user intensities as described in detail in Section 2.4.2.2. Inhalation exposures are presented for users and bystanders for 24-hour TWAs and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.3.15.

Considering the overall strengths and limitations of the data, EPA's overall confidence is high for the consumer inhalation estimate and medium for the dermal estimate, as discussed in Section 2.4.2.3.15.

Table 4-120. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Wax Metal and Stone Polish Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User MOE	Bystander MOE
Low Intensity User	**1.1**	**5.3**
Moderate Intensity User	**0.15**	**0.77**
High Intensity User	**1.5E-02**	**6.1E-02**

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-121. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Wax Metal and Stone Polish Consumer Use

Exposure Scenario	Consumer Receptor	Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10
		User MOE
Low Intensity User	Adult (≥21 years)	41
	Youth (16-20 years)	44
	Youth (11-15 years)	40
Moderate Intensity User	Adult (≥21 years)	**4.9**
	Youth (16-20 years)	**5.2**
	Youth (11-15 years)	**4.8**
High Intensity User	Adult (≥21 years)	**0.58**
	Youth (16-20 years)	**0.62**
	Youth (11-15 years)	**0.57**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2

The MOEs are below the benchmark MOE for all users and bystanders by inhalation exposures, and for moderate and high users by dermal exposures. The MOEs are above benchmark MOE for low intensity users by dermal exposures.

4.2.4.17 Dry-Cleaned Clothing

Estimates of MOEs for acute inhalation and dermal exposures for the dry-cleaned clothing consumer use are presented in Table 4-122 and Table 4-123, respectively. Consumer inhalation and dermal exposures were modeled as described in Section 2.4.2.4. Inhalation exposures are presented for users and bystanders for 24-hour TWAs in Section 2.4.2.4.3 and dermal exposure results are presented for users as acute ADRs in Section 2.4.2.4.2.

Considering the overall strengths and limitations of the data, EPA's overall confidence is medium to high for the consumer inhalation estimate and medium to high for the dermal estimate, as discussed in Section 2.4.2.4.2.

Table 4-122. Risk Estimation for Acute, Non-Cancer Inhalation Exposures for Dry-Cleaned Clothing Consumer Use

Exposure Scenario	Acute HEC for CNS Effects[1] (11 mg/m^3) Benchmark MOE = 10	
	User (Adult) MOE	Bystander (Youth or Child) MOE
Stay-at-home Adult and Child	156	486

[1] 24 hrs HEC based on data from Altmann et al. (1990)

Table 4-123. Risk Estimation for Acute, Non-Cancer Dermal Exposures for Dry-Cleaned Clothing Consumer Use

Acute HED for CNS Effects[1] (4.25 mg/kg/day) Benchmark MOE = 10				
Assumed dry cleaning technology	Dry Cleaning Events	Days After Dry Cleaning	User, Half-Body MOE	User, Full-Body MOE
2nd and 3rd generation	Single	1	**8.6**	**2.9**
		2	11	**3.7**
		3	15	**4.9**
4th and 5th generation	Single	1	49	16
		2	64	21
		3	83	28
4th and 5th generation	Repeat[2]	1	16	**5.2**
		2	20	**6.7**
		3	26	**8.7**

[1] HED extrapolated from inhalation exposures based on data from Altmann et al. (1990) described in Section 3.2.5.4.2
[2] Based on maximum average PCE concentration in wool after 6 dry cleaning cycles from Sherlach (2011); PCE concentration was still increasing in wool fabric after 6 cycles and had not yet reached saturation.

The MOEs are below the benchmark MOE for users dermally exposed to half-body garments, one day after a single dry cleaning event and full body garments, one to three days after a single dry cleaning event, for 2nd and 3rd generation dry cleaning technologies; and for users dermally exposures to full-body garments, one to three days after repeated dry cleaning events, for 4th and 5th generation technologies. The MOEs are above the benchmark MOE for users and bystanders by inhalation exposure; for uses dermally exposed to half-body garments, two to three days after a single dry cleaning event, for 2nd and 3rd generation technologies; for users dermally exposed to half-body garments, one to three days after single and repeat dry cleaning events, for 4th and 5th generation technologies; and for users dermally exposed to full-body garments, one to three days after a single dry cleaning event, for 4th and 5th generation technologies.

4.2.5 Human Health Risk Characterization Key Assumptions and Uncertainties

4.2.5.1 Human Health Hazard Considerations

There is medium-high confidence in the acute non-cancer POD, high confidence in the chronic non-cancer PODs selected to represent each health domain, and medium confidence in the cancer POD. Confidence is reduced for dermal PODs due to the use of route-to-route extrapolation in the absence of a dermal compartment in the PBPK model (Section 3.2.6.4). Major uncertainties include the selection of cancer endpoint for IUR selection and inconclusive human evidence for a few health domains (Section 3.2.6).

4.2.5.2 Occupational Risk Considerations

EPA estimated inhalation risk to workers and ONUs based on monitoring and/or modeling data, as reasonably available. For the majority of OES, only one source was available so the results could not be compared. Despite the absence of both types of data for most OES, overall confidence in worker inhalation estimates ranged from Medium to High for all OES (Table 2-17). For ONUs, modeling or monitoring data was available in 9 of 22 OES. For the other 13, in the absence of reasonably available data EPA applied the worker central tendency estimates to ONUs. When ONU data was not available, there is low confidence in ONU risk estimates. There is medium confidence in dermal exposure estimates, which are based on the *Dermal Exposure to Volatile Liquids Model* (Section 2.4.1.28).

There are significant uncertainties associated with PPE usage across OES. For the majority of OES, EPA assumes that workers will responsibly wear gloves and respirators and that employers implement a continuing, effective respiratory protection program according to the requirements of OSHA's Respiratory Protection Standard. This results in respiratory protection up to APF = 50 and glove protection up to PF = 20 (or PF = 10 for commercial scenarios). Respiratory protection factors can be confirmed through regular fit testing, however glove PFs represent a what-if scenario and EPA cannot confirm the actual frequency, type, and effectiveness of globe use in specific workplaces with PCE conditions of use. Risks may be underestimated by these assumptions. EPA also identified OES for which regular respirator use is not expected (Table 4-8.), and risks may be overestimated for these scenarios if even mild respiratory protection is employed.

There is also uncertainty associated with assumptions underlying the derivation of occupational HECs and applying them to various OES. The occupational HECs for CNS effects were derived from occupational epidemiological studies (Section 3.2.5.3.2), and EPA assumes a typical 5 day/week, ~250 day/year exposure scenario for these PODs. Therefore, risks may be over or underestimated when applying the occupational HEC to OES for which fewer or greater number of exposure days/year, respectively, are expected. EPA did not apply the occupational HEC for Other DOD Uses scenarios (Section 4.2.2.20) because the exposure days for these scenarios are significantly fewer than 250.

4.2.5.3 Consumer Risk Considerations

There is medium to high or high confidence in both the consumer inhalation and dermal exposure estimates (Section 2.4.2.6). All exposure estimates are based on modeling, and there is uncertainty based on the application of surrogate product categories from the Westat survey (Westat, 1987) when there was not an exact match for the COU. Professional judgment was also required for determining the most appropriate room of use, which affects the area volume and in turn inhalation exposure estimates. A key uncertainty for the dermal estimates is the accuracy of the assumption of which COUs are likely to result in exposure with impeded evaporation, and whether evaporation is truly fully impeded for those scenarios.

EPA only evaluated acute risks for consumer COUs. While the expected sparse and intermittent use frequency for the vast majority of users (Westat, 1987) indicates that only acute risks are relevant to consumer uses, there is uncertainty whether chronic risks may be of concern for consumers at the very high end of the range for frequency of use, especially if a product is used several days consecutively. Without continued use on consecutive days or in short succession, chronic hazards are unlikely due to the relatively short half-life of PCE (Section 3.2.2.1.4). Since reasonably available information was not identified to inform these and other parameters, and the absence of data leaves it uncertain how to develop a credible worst-case scenario, chronic consumer product use and chronic exposures due to continued storage of consumer products were not evaluated in this Risk Evaluation.

EPA calculated inhalation risk estimates based on ambient air concentrations and did not derive lifestage-specific internal doses. As stated in Section 4.3.1, EPA expects that the PBPK model and UF_H at least partially account for lifestage-specific differences, however younger lifestages are likely exposed to several fold higher internal dose of PCE compared to adults. Therefore, using air concentrations across all lifestages may underestimate risk, especially for infant bystanders.

4.2.5.4 Integration of Exposure and Hazard Considerations

Except for ONU risk estimates based on worker exposure values, there is at least medium confidence in all hazard and exposure inputs to risk estimates. Overall, there is medium-high confidence in the risk estimates generally. For occupational risk estimates, risk estimates are relatively close to the benchmark in many instances (less than 2-fold), and therefore refinements to exposure or hazard values could potentially result in a change to risk conclusions for certain scenarios. As a result, there is medium confidence in the occupational risk conclusions as presented in Section 4.4.2.1. For consumer risk however, MOEs for high-intensity users with identified risk are generally several fold below the benchmark and therefore there is medium-high confidence in the consumer risk conclusions as presented in Section 4.4.2.2.

EPA only estimated risks for individual exposure scenarios without consideration of aggregating exposures across routes or incorporation of potential residual background exposures from household or workplace products/articles. EPA acknowledges that risks may be underestimated by not accounting for chronic background exposures in either occupational or consumer environments, however these background exposures are likely significantly lower than the assessed exposure estimates for each exposure scenario and would therefore be unlikely to drive risk conclusions. Consideration of background exposures from consumer products is discussed in Section 2.4.2.6 and additional discussion of aggregate exposure is provided in Section 4.3.2.

4.3 Other Risk Related Considerations

4.3.1 Potentially Exposed or Susceptible Subpopulations

TSCA requires that the determination of whether a chemical substance presents an unreasonable risk include consideration of unreasonable risk to "a potentially exposed or susceptible subpopulation identified as relevant to the risk evaluation" by EPA. TSCA § 3(12) states that "the term 'potentially exposed or susceptible subpopulation' means a group of individuals within the general population identified by the Administrator who, due to either greater susceptibility or greater exposure, may be at greater risk than the general population of adverse health effects from exposure to a chemical substance or mixture, such as infants, children, pregnant women, workers, or the elderly."

EPA identified workers, ONUs, consumers, and bystanders as potentially exposed populations. EPA provided risk estimates for workers and ONUs (Sections 4.2.2 and 4.2.3) at both central tendency and high-end exposure levels for all COUs. Consumer and bystander risk estimates were provided for low, medium, and high intensities of use (Section 4.2.4), accounting for differences in duration, weight fraction, and mass used. Occupational dermal risk estimates were calculated for both average workers and women of childbearing age (see *Risk Evaluation for Perchloroethylene Supplemental File: Occupational Exposure Risk Calculator* (U.S. EPA, 2020e)) and consumer dermal risk estimates were calculated for both adult and children (see *Risk Evaluation for Perchloroethylene Consumer Dermal Risk Calculations* (U.S. EPA, 2020b). EPA determined that bystanders may include lifestages of any age. These groups exhibit differences in delivered dose accounting for differing body weight and hand size, accounting for differences in exposure, and providing risk estimates for women of childbearing age protects the susceptible subpopulation of the developing fetus. EPA also performed risk estimation for

children of employees present at dry cleaners (Section 4.2.2.13.2). Children who live or attend daycare or school above or adjacent to dry cleaners can also have elevated PCE exposures as noted in the 2012 IRIS PCE assessment (U.S. EPA, 2012c), however the risk estimates presented in Section 4.2.2.13.2 are expected to account for acute risks to that subpopulation because children present within a dry cleaning facility would be exposed to higher PCE concentrations than those nearby.

For inhalation exposures, risk estimates did not differ between sexes or across lifestages because both exposures and inhalation hazard values are expressed as an air concentration. EPA expects that variability in human physiological factors (*e.g.*, breathing rate, body weight, tidal volume) may affect internal delivered concentration or dose. EPA also identified lifestage, biological sex, genetic polymorphisms, race/ethnicity, preexisting health status, and lifestyle factors and nutrition status as factors affecting biological susceptibility. However, there is insufficient data on these potential differences in metabolism and human susceptibility to support a quantitative analysis of interindividual variability in other potentially susceptible populations. A 10x UF for human population uncertainty/variability was applied to account for interindividual variability, but whether this factor sufficiently accounts for differences in susceptibility represents a source of uncertainty. EPA conservatively assumed that maternal internal dose was equivalent to fetal exposure, and the PBPK model (Section 3.2.2.2) does not contain a fetal compartment. Therefore, while EPA did not assess risk for breast feeding infants, evaluating risk for developmental effects based on maternal internal dose is protective of this subpopulation. An individual may be a member of multiple PESS groups (perhaps including both exposure and biological susceptibility considerations) and may exhibit multiple concurrent susceptibilities.

EPA acknowledges that it was unable to directly account for all possible PESS considerations and subpopulations in the risk estimates. As previously discussed, EPA also only considered acute effects from consumer exposure. While typical use patterns are unlikely to result in any chronic effects for the vast majority of consumers, EPA cannot rule out that consumers at very high frequencies of use may be at risk for chronic hazards if use patterns are consecutive or in short succession, especially if those consumers also exhibit biological susceptibilities. EPA can also not rule out that certain subpopulations, whether due to very elevated exposure or biological susceptibility, may be at risk for hazards that were not fully supported by the weight of the scientific evidence or could not be quantified (*e.g.*, immune and blood effects). However, in these circumstances EPA assumes that these effects are likely to occur at a higher dose than more sensitive endpoints that were accounted for by risk estimates. EPA's decisions for unreasonable risk are based on high-end exposure estimates (see below in Section 4.3.2), which helps to account for individuals on the high-end of the risk distribution.

4.3.2 Aggregate and Sentinel Exposures

Section 6(b)(4)(F)(ii) of TSCA requires the EPA, as a part of the risk evaluation, to describe whether aggregate or sentinel exposures under the conditions of use were considered and the basis for their consideration. The EPA has defined aggregate exposure as "*the combined exposures to an individual from a single chemical substance across multiple routes and across multiple pathways*" (40 CFR Section 702.33). In this risk evaluation, EPA determined that aggregating dermal and inhalation exposure for risk characterization was not appropriate due to uncertainties in quantifying the relative contribution of dermal vs inhalation exposure, since dermally applied dose could evaporate and then be inhaled. Additionally, without a PBPK model containing a dermal compartment to account for toxicokinetic processes the true internal dose for any given exposure cannot be determined. Aggregating exposures could inappropriately overestimate total exposure, as simply adding exposures from different routes without an available PBPK model for those routes would compound uncertainties. It is unknown whether exposures from multiple routes would act in an additive fashion, and saturation of metabolic

processes at elevated exposures may result in a steady-state that hampers subsequent absorption relative to excretive processes. Conversely, not aggregating exposures in any manner may potentially underestimate total exposure for a given individual. EPA also did not consider aggregate exposure among individuals who may be exposed both in an occupational and consumer context because there is insufficient information reasonably available as to the likelihood of this scenario or the relative distribution of exposures from each pathway. Risk is likely to be elevated for individuals who experience PCE exposure in multiple contexts.

EPA defines sentinel exposure as "*the exposure to a single chemical substance that represents the plausible upper bound of exposure relative to all other exposures within a broad category of similar or related exposures*" (40 CFR Section 702.33). In this risk evaluation, EPA considered sentinel exposures by considering risks to populations who may have upper bound exposures – for example, workers and ONUs who perform activities with higher exposure potential, or consumers who have higher exposure potential or certain physical factors like body weight or skin surface area exposed. EPA characterized high-end exposures in evaluating exposure using both monitoring data and modeling approaches. Where statistical data are reasonably available, EPA typically uses the 95th percentile value of the reasonably available dataset to characterize high-end exposure for a given condition of use. If the 95th percentile is not available, EPA used a different percentile greater than or equal to the 90th percentile but less than or equal to the 99.9th percentile, depending on the statistics available for the distribution. If the full distribution is not known and the preferred statistics are not available, EPA estimated a maximum or bounding estimate in lieu of the high-end. For consumer and bystander exposures, EPA characterized sentinel exposure through a "high-intensity use" category based on both product and user-specific factors. In cases where sentinel exposures result in MOEs greater than the benchmark or cancer risk lower than the benchmark (*i.e.,* risks were not identified), EPA did no further analysis because sentinel exposures represent the worst-case scenario. EPA's decisions for unreasonable risk are based on high-end exposure estimates to capture individuals with sentinel exposure. In this risk evaluation, EPA considered sentinel exposure in the form of high-end scenarios for occupational exposure resulting from dermal and inhalation exposures, as these exposure routes are the most likely to result in the highest exposure given the details of the manufacturing process and the potential exposure scenarios discussed above. The calculation for dermal exposure is especially conservative given that it assumes full contact/immersion.

4.4 Risk Conclusions

4.4.1 Environmental Risk Conclusions

Aquatic Pathways

Table 4-124 displays risk quotients for each of the facilities by OES. Risks were not identified for aquatic organisms from PCE release to surface water from the Manufacturing, Importing/Repackaging, Open-Top Vapor Degreasing, Closed-Loop Vapor Degreasing, Conveyorized Degreasing, Web Degreasing, Dry Cleaning (Industrial and Commercial), Adhesives, Paints, and Coatings, Maskants for Chemical Milling, Industrial Processing Aid, Other Industrial Uses, Other Commercial Uses COUs, and Waste Handling, Disposal, Treatment, and Recycling. *Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.*

Risks from acute PCE exposures were not identified for aquatic organisms. *Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.*

Risks from chronic PCE exposures were identified for aquatic organisms based on direct releases from the Processing as a Reactant COU, and indirect releases from Incorporation into Formulations COU. *Therefore, EPA concludes there is a chronic risk to aquatic organisms from release of PCE to surface water from facilities using PCE for the COUs listed above. Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.*

Risks from PCE exposures were not identified for algae. *Based on the data quality, uncertainties and weight of the scientific evidence, confidence in the risk estimate is medium.*

Table 4-124. Facilities Showing RQs and Days of Exceedance from the Release of PCE to Surface Water as Modeled in E-FAST.
Acute risk = RQs ≥ 1, chronic and algae risk = RQs ≥ 1 and ≥ 20 days of exceedance. Shaded areas show risk.

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
OES: Manufacturing											
Axiall Corporation Westlake, LA NPDES: LA0000761	Surface Water or POTW	Direct (0% WWT removal): LA0000761 Indirect (88% WWT removal): Organic Chemicals Mfg	Surface Water	350	0.1 (max)	0	0.11	Acute	1,400	NA	7.9E-05
								Chronic	50	0	2.2E-03
								Algae	360	0	3.1E-04
						88	2.22	Acute	1,400	NA	1.6E-03
								Chronic	50	3	4.4E-02
								Algae	360	0	6.2E-03
				350	3.08E-02 (avg)	0	3.48E-02	Acute	1,400	NA	2.5E-05
								Chronic	50	0	7.0E-04
								Algae	360	0	9.7E-05
						88	0.68	Acute	1,400	NA	4.9E-04
								Chronic	50	0	1.4E-02
								Algae	360	0	1.9E-03
				20	0.54	0	0.61	Acute	1,400	NA	4.4E-04
								Chronic	50	0	1.2E-02
								Algae	360	0	1.7E-03
Greenchem West Palm Beach, FL NPDES: None (FRS 110056959634)	Surface Water or POTW	Direct and Indirect Surrogate: Organic Chemicals Mfg Receiving Facility: Unknown	Surface Water	350	0.1 (max)	0	18.48	Acute	1,400	NA	1.3E-02
								Chronic	50	25	3.7E-01
								Algae	360	4	5.1E-02
						88	2.22	Acute	1,400	NA	1.6E-03
								Chronic	50	3	4.4E-02
								Algae	360	0	6.2E-03
				350	3.08E-02 (avg)	0	5.69	Acute	1,400	NA	4.1E-03
								Chronic	50	12	1.1E-01
								Algae	360	0	1.6E-02
						88	0.68	Acute	1,400	NA	4.9E-04
								Chronic	50	0	1.4E-02
								Algae	360	0	1.9E-03
				20	0.54	0	99.82	Acute	1,400	NA	7.1E-02
								Chronic	50	4	2.0
								Algae	360	1	2.8E-01

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Occidental Chemical Corp Geismar Plant Geismar, LA NPDES: LA0002933	Surface Water	LA0002933	Surface Water	350	1.69E-03	0	6.84E-06	Acute	1,400	NA	4.9E-09
								Chronic	50	0	1.4E-07
								Algae	360	0	1.9E-08
				20	2.95E-02	0	1.19E-04	Acute	1,400	NA	8.5E-08
								Chronic	50	0	2.4E-06
								Algae	360	0	3.3E-07
Olin Blue Cube Freeport, TX NPDES: None (FRS 110066943605)	Non-POTW WWT	Receiving Facility: TX0006483	Surface Water	350	4.15E-02	88	1.91E-03	Acute	1,400	NA	1.4E-06
								Chronic	50	0	3.8E-05
								Algae	360	0	5.3E-06
				20	7.26E-01	88	3.34E-02	Acute	1,400	NA	2.4E-05
								Chronic	50	0	6.7E-04
								Algae	360	0	9.3E-05
Solvents & Chemicals Pearland, TX NPDES: Not available (TRI: 77588SLVNT4704S)	Surface Water or POTW	Direct and Indirect Surrogate: Organic Chemicals Mfg Receiving Facility: Unknown	Surface Water	350	3.0E-4 (max)	0	5.56E-2	Acute	1,400	NA	4.0E-05
								Chronic	50	0	1.1E-03
								Algae	360	0	1.5E-04
						88	6.65E-3	Acute	1,400	NA	4.8E-06
								Chronic	50	0	1.3E-04
								Algae	360	0	1.9E-05
				350	8.57E-05 (avg)	0	1.58E-02	Acute	1,400	NA	1.1E-05
								Chronic	50	0	3.2E-04
								Algae	360	0	4.4E-05
						88	1.90E-3	Acute	1,400	NA	1.4E-06
								Chronic	50	0	3.8E-05
								Algae	360	0	5.3E-06
				20	1.5E-3	0	0.28	Acute	1,400	NA	2.0E-04
								Chronic	50	0	5.6E-03
								Algae	360	0	7.8E-04

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Univar USA Inc Redmond, WA NPDES: None (FRS: 110036000000)	Surface Water or POTW	Direct and Indirect Surrogate: Organic Chemicals Mfg Receiving Facility: Unknown	Surface Water	350	0.1 (max)	0	18.48	Acute	1,400	NA	1.3E-02
								Chronic	50	25	3.7E-01
								Algae	360	4	5.1E-02
						88	2.22	Acute	1,400	NA	1.6E-03
								Chronic	50	3	4.4E-02
								Algae	360	0	6.2E-03
				350	3.08E-02 (avg)	0	5.69	Acute	1,400	NA	4.1E-03
								Chronic	50	12	1.1E-01
								Algae	360	0	1.6E-02
						88	0.68	Acute	1,400	NA	4.9E-04
								Chronic	50	0	1.4E-02
								Algae	360	0	1.9E-03
				20	0.54	0	99.82	Acute	1,400	NA	7.1E-02
								Chronic	50	4	2.0
								Algae	360	1	2.8E-01
OES: Import/Repackaging											
Chemtool Rockton, IL NPDES: IL0064564	Surface Water	IL0064564	Surface Water	250	1.20E-03	0	1.75E-03	Acute	1,400	NA	1.3E-06
								Chronic	50	0	3.5E-05
								Algae	360	0	4.9E-06
				20	0.015	0	0.0218	Acute	1,400	NA	1.6E-05
								Chronic	50	0	4.4E-04
								Algae	360	0	6.1E-05
Harvey Terminal Harvey, LA NPDES: LA0056600	Surface Water	Surrogate based on location: LA0005291	Surface Water	250	8.00E-05	0	3.24E-07	Acute	1,400	NA	2.3E-10
								Chronic	50	0	6.5E-09
								Algae	360	0	9.0E-10
				20	0.001	0	4.05E-06	Acute	1,400	NA	2.9E-09
								Chronic	50	0	8.1E-08
								Algae	360	0	1.1E-08
Hubbard-Hall Inc Waterbury, CT NPDES: None (FRS 110000317194	Non-POTW WWT	Surrogate: Industrial POTW (for receiving facility FRS 110004250541)	Surface Water	250	1.12	88	17.32	Acute	1,400	NA	1.2E-02
								Chronic	50	6	3.5E-01
								Algae	360	0	4.8E-02
				20	13.95	88	215.72	Acute	1,400	NA	1.5E-01
								Chronic	50	11	4.3
								Algae	360	1	6.0E-01

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Vopak Terminal Westwego Inc Westwego, LA NPDES: LA0124583	Surface Water	Surrogate based on location: LA0003093	Surface Water	250	4.80E-03	0	1.94E-05	Acute	1,400	NA	1.4E-08
								Chronic	50	0	3.9E-07
								Algae	360	0	5.4E-08
				20	0.06	0	2.43E-04	Acute	1,400	NA	1.7E-07
								Chronic	50	0	4.9E-06
								Algae	360	0	6.8E-07
OES: Processing as a Reactant											
Akzo Nobel Surface Chemistry LLC Morris, IL NPDES: IL0026069	Surface Water	IL0026069	Surface Water	350	1.43E-04	0	2.98E-04	Acute	1,400	NA	2.1E-07
								Chronic	50	0	6.0E-06
								Algae	360	0	8.3E-07
				20	0.0025	0	0.00521	Acute	1,400	NA	3.7E-06
								Chronic	50	0	1.0E-04
								Algae	360	0	1.5E-05
Atkemix Ten Inc Louisville, KY NPDES: KY0002780	Surface Water	KY0002780	Surface Water	350	7.39E-02	0	3.96E-03	Acute	1,400	NA	2.8E-06
								Chronic	50	0	7.9E-05
								Algae	360	0	1.1E-05
				20	1.29	0	0.0691	Acute	1,400	NA	4.9E-05
								Chronic	50	0	1.4E-03
								Algae	360	0	1.9E-04
Bayer Corporation Haledon, NJ NPDES: NJG104451	Surface Water	Surrogate: Organic Chemical Mfg SIC	Surface Water	350	2.86E-05	0	5.29E-03	Acute	1,400	NA	3.8E-06
								Chronic	50	0	1.1E-04
								Algae	360	0	1.5E-05
				20	0.0005	0	0.0924	Acute	1,400	NA	6.6E-05
								Chronic	50	0	1.9E-03
								Algae	360	0	2.6E-04
Bayer MaterialScience New Martinsville, WV NPDES: WV0005169	Surface Water	WV0005169	Surface Water	350	7.14E-04	0	8.50E-05	Acute	1,400	NA	6.1E-08
								Chronic	50	0	1.7E-06
								Algae	360	0	2.4E-07
				20	1.25E-02	0	1.49E-03	Acute	1,400	NA	1.1E-06
								Chronic	50	0	3.0E-05
								Algae	360	0	4.1E-06

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Chemtura North and South Plants Morgantown, WV NPDES: WV0004740	Surface Water	WV0004740	Surface Water	350	2.86E-05	0	4.15E-05	Acute	1,400	NA	3.0E-08
								Chronic	50	0	8.3E-07
								Algae	360	0	1.2E-07
				20	0.0005	0	0.000725	Acute	1,400	NA	5.2E-07
								Chronic	50	0	1.5E-05
								Algae	360	0	2.0E-06
Dupont-Chemours Montague Site Montague, MI NPDES: MI0000884	Surface Water	MI0000884	Still Water	350	1.68E-02	0	2.03	Acute	1,400	NA	1.5E-03
								Chronic	50	0	4.1E-02
								Algae	360	0	5.6E-03
				20	2.95E-01	0	35.07	Acute	1,400	NA	2.5E-02
								Chronic	50	0	7.0E-01
								Algae	360	0	9.7E-02
Eagle US 2 LLC - Lake Charles Complex Lake Charles, LA NPDES: LA0000761	Surface Water	LA0000761	Surface Water	350	1.33	0	1.5	Acute	1,400	NA	1.1E-03
								Chronic	50	0	3.0E-02
								Algae	360	0	4.2E-03
				20	23.27	0	26.3	Acute	1,400	NA	1.9E-02
								Chronic	50	0	5.3E-01
								Algae	360	0	7.3E-02
Flint Hills Resources Corpus Christi LLC - West Plant Corpus Christi, TX NPDES: TXU001146, TX0006289	Surface Water	TX0006289	Still Water	350	6.87E-02	0	2.96	Acute	1,400	NA	2.1E-03
								Chronic	50	0	5.9E-02
								Algae	360	0	8.2E-03
				20	1.2	0	51.65	Acute	1,400	NA	3.7E-02
								Chronic	50	20	1.0
								Algae	360	0	1.4E-01
Flint Hills Resources Pine Bend LLC Rosemount, MN NPDES: MN0070246, MN0000418	Surface Water	MN0000418	Surface Water	350	1.17E-02	0	3.31E-03	Acute	1,400	NA	2.4E-06
								Chronic	50	0	6.6E-05
								Algae	360	0	9.2E-06
				20	2.04E-01	0	0.0566	Acute	1,400	NA	4.0E-05
								Chronic	50	0	1.1E-03
								Algae	360	0	1.6E-04

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Honeywell International Inc - Geismar Complex Geismar, LA NPDES: LA0006181	Surface Water	LA0006181	Surface Water	350	2.03E-02	0	8.22E-05	Acute	1,400	NA	5.9E-08
								Chronic	50	0	1.6E-06
								Algae	360	0	2.3E-07
				20	3.56E-01	0	1.46E-03	Acute	1,400	NA	1.0E-06
								Chronic	50	0	2.9E-05
								Algae	360	0	4.1E-06
Honeywell International Inc-Baton Rouge Plant Baton Rouge, LA NPDES: LAR10E873, LA0000329	Surface Water	LA0000329	Surface Water	350	4.93E-02	0	4.87	Acute	1,400	NA	3.5E-03
								Chronic	50	0	9.7E-02
								Algae	360	0	1.4E-02
				20	8.62E-01	0	84.98	Acute	1,400	NA	6.7E-02
								Chronic	50	7	1.7
								Algae	360	0	2.4E-01
Indorama Ventures Olefins, LLC Sulphur, LA NPDES: LA0069850	Surface Water	Surrogate: Organic Chemical Mfg SIC	Surface Water	350	1.14E-05	0	2.11E-03	Acute	1,400	NA	1.5E-06
								Chronic	50	0	4.2E-05
								Algae	360	0	5.9E-06
				20	0.0002	0	0.037	Acute	1,400	NA	2.6E-05
								Chronic	50	0	7.4E-04
								Algae	360	0	1.0E-04
Keeshan And Bost Chemical Co., Inc. Manvel, TX NPDES: TX0072168	Surface Water	TX0072168	Still Water	350	5.71E-05	0	5.71	Acute	1,400	NA	4.1E-03
								Chronic	50	0	1.1E-01
								Algae	360	0	1.6E-02
				20	0.001	0	100	Acute	1,400	NA	7.1E-02
								Chronic	50	20	2.0
								Algae	360	0	2.8E-01
Phillips 66 Lake Charles Refinery Westlake, LA NPDES: LAR05P540, LA0003026	Surface Water	LA0003026	Surface Water	350	5.87E-02	0	9.26E-02	Acute	1,400	NA	6.6E-05
								Chronic	50	0	1.9E-03
								Algae	360	0	2.6E-04
				20	1.03	0	1.62	Acute	1,400	NA	1.2E-03
								Chronic	50	0	3.2E-02
								Algae	360	0	4.5E-03

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Phillips 66 Los Angeles Refinery Wilmington Plant Wilmington, CA NPDES: CA0000035	POTW	Receiving Facility: CA0053856	Still Water	350	1.08E-01	88	0.19	Acute	1,400	NA	1.4E-04
								Chronic	50	0	3.8E-03
								Algae	360	0	5.3E-04
Premcor Refining Group Inc Port Arthur Port Arthur, TX NPDES: TX0005991	Surface Water	TX0005991	Surface Water	350	1.28E-01	0	1.99	Acute	1,400	NA	1.4E-03
								Chronic	50	0	4.0E-02
								Algae	360	0	5.5E-03
				20	2.25	0	34.41	Acute	1,400	NA	2.5E-02
								Chronic	50	1	6.9E-01
								Algae	360	0	9.6E-02
Solutia Nitro Site Nitro, WV NPDES: WV0116181	Surface Water	Surrogate: WV0000868	Surface Water	350	1.71E-04	0	5.03E-05	Acute	1,400	NA	3.6E-08
								Chronic	50	0	1.0E-06
								Algae	360	0	1.4E-07
				20	0.003	0	8.82E-04	Acute	1,400	NA	6.3E-07
								Chronic	50	0	1.8E-05
								Algae	360	0	2.5E-06
Solvay - Houston Plant Houston, TX NPDES: TX0007072	Surface Water	TX0007072	Surface Water	350	2.36E-02	0	4.37	Acute	1,400	NA	3.1E-03
								Chronic	50	0	8.7E-02
								Algae	360	0	1.2E-02
				20	4.14E-01	0	75.93	Acute	1,400	NA	5.4E-02
								Chronic	50	0	1.5
								Algae	360	0	2.1E-01
OES: Incorporation into Formulation											
Lord Corp Saegertown, PA NPDES: PA0101800	Non-POTW WWT	Surrogate: Industrial POTW	Surface Water	300	5.26	88	81.34	Acute	1,400	NA	5.8E-02
								Chronic	50	81	1.6
								Algae	360	3	2.3E-01
				20	78.93	88	1220.57	Acute	1,400	NA	8.7E-01
								Chronic	50	19	24
								Algae	360	10	3.4

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Stepan Co Millsdale Road Elwood, IL NPDES: IL0002453	Surface Water	IL0002453	Surface Water	300	1.67E-03	0	7.00E-04	Acute	1,400	NA	5.0E-07
								Chronic	50	0	1.4E-05
								Algae	360	0	1.9E-06
				20	0.025	0	0.0105	Acute	1,400	NA	7.5E-06
								Chronic	50	0	2.1E-04
								Algae	360	0	2.9E-05
Weatherford Aerospace LLC Weatherford, TX NPDES: None (FRS 110000743740)	POTW	Receiving Facility: TX0047724	Surface Water	300	1.50E-03	88	2.94E-02	Acute	1,400	NA	2.1E-05
								Chronic	50	0	5.9E-04
								Algae	360	0	8.2E-05
OES: Open Top Vapor Degreasing (OTVD)											
601 Nassau St Assoc LLC North Brunswick Twp, NJ NPDES: NJG129127	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	9.39E-06	0	1.04E-03	Acute	1,400	NA	7.4E-07
								Chronic	50	0	2.1E-05
								Algae	360	0	2.9E-06
				20	1.22E-04	0	1.36E-02	Acute	1,400	NA	9.7E-06
								Chronic	50	0	2.7E-04
								Algae	360	0	3.8E-05
ASCO Valve Manufacturing Aiken, SC NPDES: SC0049026	Surface Water	SC0049026	Surface Water	260	1.42E-04	0	1.58E-02	Acute	1,400	NA	1.1E-05
								Chronic	50	0	3.2E-04
								Algae	360	0	4.4E-05
				20	1.85E-03	0	0.21	Acute	1,400	NA	1.5E-04
								Chronic	50	0	4.2E-03
								Algae	360	0	5.8E-04
Chemours - Beaumont Works Beaumont, TX NPDES: TX0004669	Surface Water	TX0004669	Surface Water	260	6.49E-03	0	9.22E-03	Acute	1,400	NA	6.6E-06
								Chronic	50	0	1.8E-04
								Algae	360	0	2.6E-05
				20	8.44E-02	0	0.12	Acute	1,400	NA	8.6E-05
								Chronic	50	0	2.4E-03
								Algae	360	0	3.3E-04

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Delphi Harrison Thermal Systems Dayton, OH NPDES: OH0009431	Surface Water	OH0009431	Surface Water	260	6.46E-03	0	1.21E-02	Acute	1,400	NA	8.6E-06
								Chronic	50	0	2.4E-04
								Algae	360	0	3.4E-05
				20	0.084	0	0.16	Acute	1,400	NA	1.1E-04
								Chronic	50	0	3.2E-03
								Algae	360	0	4.4E-04
Equistar Chemicals LP La Porte, TX NPDES: TX0119792	Surface Water	Surrogate: TX0002836	Still Water	260	1.25E-02	0	0.25	Acute	1,400	NA	1.8E-04
								Chronic	50	0	5.0E-03
								Algae	360	0	6.9E-04
				20	1.62E-01	0	3.23	Acute	1,400	NA	2.3E-03
								Chronic	50	0	6.5E-02
								Algae	360	0	9.0E-03
Fairfield Works Fairfield, AL NPDES: AL0003646	Surface Water	AL0003646	Surface Water	260	4.09E-03	0	5.20E-03	Acute	1,400	NA	3.7E-06
								Chronic	50	0	1.0E-04
								Algae	360	0	1.4E-05
				20	5.32E-02	0	6.76E-02	Acute	1,400	NA	4.8E-05
								Chronic	50	0	1.4E-03
								Algae	360	0	1.9E-04
Gayston Corp Dayton, OH NPDES: OH0127043	POTW	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	3.12E-03	0	0.35	Acute	1,400	NA	2.5E-04
								Chronic	50	6	7.0E-03
								Algae	360	0	9.7E-04
				20	4.06E-02	0	4.51	Acute	1,400	NA	3.2E-03
								Chronic	50	2	9.0E-02
								Algae	360	1	1.3E-02
Getzen Co Inc Elkhorn, WI NPDES: None (FRS110000417291)	POTW	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	3.49E-04	88	4.65E-03	Acute	1,400	NA	3.3E-06
								Chronic	50	0	9.3E-05
								Algae	360	0	1.3E-05

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GM Components Holdings LLC Lockport, NY NPDES: NY0000558	Surface Water	NY0000558	Surface Water	260	7.08E-02	0	5.97	Acute	1,400	NA	4.3E-03
								Chronic	50	0	1.2E-01
								Algae	360	0	1.7E-02
				20	9.21E-01	0	77.64	Acute	1,400	NA	5.6E-02
								Chronic	50	3	1.6
								Algae	360	0	2.2E-01
HB Fuller Co Morris, IL NPDES: IL0079758	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	7.90E-04	0	8.78E-02	Acute	1,400	NA	6.3E-05
								Chronic	50	0	1.8E-03
								Algae	360	0	2.4E-04
				20	1.03E-02	0	1.14	Acute	1,400	NA	8.1E-04
								Chronic	50	1	2.3E-02
								Algae	360	0	3.2E-03
Hyster-Yale Group, Inc Sulligent, AL NPDES: AL0069787	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	9.03E-07	0	1.00E-04	Acute	1,400	NA	7.1E-08
								Chronic	50	0	2.0E-06
								Algae	360	0	2.8E-07
				20	1.17E-05	0	1.30E-03	Acute	1,400	NA	9.3E-07
								Chronic	50	0	2.6E-05
								Algae	360	0	3.6E-06
MEMC Electronic Materials Incorporated Moore, SC NPDES: SC0036145	Surface Water	SC0036145	Surface Water	260	2.61E-04	0	8.78E-03	Acute	1,400	NA	6.3E-06
								Chronic	50	0	1.8E-04
								Algae	360	0	2.4E-05
				20	3.39E-03	0	0.11	Acute	1,400	NA	7.9E-05
								Chronic	50	0	2.2E-03
								Algae	360	0	3.1E-04
Piano Factory-Grand Haven Grand Haven, MI NPDES: MI0054399	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	7.17E-04	0	7.97E-02	Acute	1,400	NA	5.7E-05
								Chronic	50	0	1.6E-03
								Algae	360	0	2.2E-04
				20	9.32E-03	0	1.04	Acute	1,400	NA	7.4E-04
								Chronic	50	1	2.1E-02
								Algae	360	0	2.9E-03

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Rex Heat Treat Lansdale Inc Lansdale, PA NPDES: PA0052965	Surface Water	Surrogate: PA0026182	Surface Water	260	1.94E-03	0	5.23E-02	Acute	1,400	NA	3.7E-05
								Chronic	50	0	1.1E-03
								Algae	360	0	1.5E-04
				20	2.53E-02	0	0.68	Acute	1,400	NA	4.9E-04
								Chronic	50	0	1.4E-02
								Algae	360	0	1.9E-03
Styrolution America LLC Channahon, IL NPDES: IL0001619	Surface Water	IL0001619	Surface Water	260	6.37E-04	0	2.21E-04	Acute	1,400	NA	1.6E-07
								Chronic	50	0	4.4E-06
								Algae	360	0	6.1E-07
				20	8.28E-03	0	2.88E-03	Acute	1,400	NA	2.1E-06
								Chronic	50	0	5.8E-05
								Algae	360	0	8.0E-06
Trane Residential Solutions - Fort Smith Fort Smith, AR NPDES: AR0052477	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	1.31E-05	0	1.46E-03	Acute	1,400	NA	1.0E-06
								Chronic	50	0	2.9E-05
								Algae	360	0	4.1E-06
				20	1.71E-04	0	1.90E-02	Acute	1,400	NA	1.4E-05
								Chronic	50	0	3.8E-04
								Algae	360	0	5.3E-05
US Steel Fairless Hills Facility Fairless Hills, PA NPDES: PA0013463	Surface Water	PA0013463	Surface Water	260	1.01E-03	0	1.68E-04	Acute	1,400	NA	1.2E-07
								Chronic	50	0	3.4E-06
								Algae	360	0	4.7E-07
				20	1.32E-02	0	2.20E-03	Acute	1,400	NA	1.6E-06
								Chronic	50	0	4.4E-05
								Algae	360	0	6.1E-06
OES: OTVDs (not in TRI/DMR)											
4,819 OTVD Sites	POTW or non-POTW WWT	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	88	0.25	Acute	1,400	NA	1.8E-04
								Chronic	50	0	5.0E-03
								Algae	360	0	6.9E-04

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
OES: Closed-Loop Vapor Degreasing (not in TRI/DMR)											
25,423 Closed-Loop Vapor Degreaser Sites	POTW or non-POTW WWT	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	88	0.25	Acute	1,400	NA	1.8E-04
								Chronic	50	0	5.0E-03
								Algae	360	0	6.9E-04
OES: Conveyorized Degreasing (not in TRI/DMR)											
445 Conveyorized Degreaser Sites	POTW or non-POTW WWT	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	88	0.25	Acute	1,400	NA	1.8E-04
								Chronic	50	0	5.0E-03
								Algae	360	0	6.9E-04
OES: Web Degreasing (not in TRI/DMR)											
445 Web Degreaser Sites	POTW or non-POTW WWT	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	88	0.25	Acute	1,400	NA	1.8E-04
								Chronic	50	0	5.0E-03
								Algae	360	0	6.9E-04
OES: Dry Cleaning (Commercial and Industrial)											
Chase Tower Dallas, TX NPDES: TX0119784	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	9.70E-03 (high end)	0	5.51	Acute	1,400	NA	3.9E-03
								Chronic	50	0	1.1E-01
								Algae	360	0	1.5E-02
				307	9.10E-03 (central tendency)	0	5.17	Acute	1,400	NA	3.7E-03
								Chronic	50	0	1.0E-01
								Algae	360	0	1.4E-02
				20	0.14	0	79.55	Acute	1,400	NA	5.7E-02
								Chronic	50	1	1.6
								Algae	360	0	2.2E-01
San Jacinto Tower Dallas, TX NPDES: TX0127779	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	1.10E-05 (high end)	0	6.25E-03	Acute	1,400	NA	4.5E-06
								Chronic	50	0	1.3E-04
								Algae	360	0	1.7E-05
				307	1.00E-05 (central tendency)	0	5.68E-03	Acute	1,400	NA	4.1E-06
								Chronic	50	0	1.1E-04
								Algae	360	0	1.6E-05
				20	1.55E-04	0	8.81E-02	Acute	1,400	NA	6.3E-05
								Chronic	50	0	1.8E-03
								Algae	360	0	2.5E-04

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
The Martin Las Vegas, NV NPDES: NV0023558	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	1.30E-04 (high end)	0	7.39E-02	Acute	1,400	NA	5.3E-05
								Chronic	50	0	1.5E-03
								Algae	360	0	2.1E-04
				307	1.20E-02 (central tendency)	0	6.82E-02	Acute	1,400	NA	4.9E-05
								Chronic	50	0	1.4E-03
								Algae	360	0	1.9E-04
				20	1.90E-03	0	1.08	Acute	1,400	NA	7.7E-04
								Chronic	50	0	2.2E-02
								Algae	360	0	3.0E-03
The Stirling Club Las Vegas, NV NPDES: NV0023256	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	6.90E-04 (high end)	0	0.39	Acute	1,400	NA	2.8E-04
								Chronic	50	0	7.8E-03
								Algae	360	0	1.1E-03
				307	6.50E-04 (central tendency)	0	0.37	Acute	1,400	NA	2.6E-04
								Chronic	50	0	7.4E-03
								Algae	360	0	1.0E-03
				20	1.00E-02	0	5.68	Acute	1,400	NA	4.1E-03
								Chronic	50	0	1.1E-01
								Algae	360	0	1.6E-02
12,822 Commercial Dry cleaning Sites	POTW	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	307	1.60E-03 (high end)	88	0.11	Acute	1,400	NA	7.9E-05
								Chronic	50	0	2.2E-03
								Algae	360	0	3.1E-04
				289	5.55E-04 (central tendency)	88	3.78E-02	Acute	1,400	NA	2.7E-05
								Chronic	50	0	7.6E-04
								Algae	360	0	1.1E-04
Boise State University Boise, ID NPDES: IDG911006	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	2.05E-04 (high end)	0	0.12	Acute	1,400	NA	8.6E-05
								Chronic	50	0	2.4E-03
								Algae	360	0	3.3E-04
				307	1.93E-04 (central tendency)	0	0.11	Acute	1,400	NA	7.9E-05
								Chronic	50	0	2.2E-03
								Algae	360	0	3.1E-04
				20	2.97E-03	0	1.69	Acute	1,400	NA	1.2E-03
								Chronic	50	0	3.4E-02
								Algae	360	0	4.7E-03

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Unifirst Williamstown, VT NPDES: VT0000850	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	4.73E-05 (high end)	0	2.69E-02	Acute	1,400	NA	1.9E-05
								Chronic	50	0	5.4E-04
								Algae	360	0	7.5E-05
				307	4.45E-05 (central tendency)	0	2.53E-02	Acute	1,400	NA	1.8E-05
								Chronic	50	0	5.1E-04
								Algae	360	0	7.0E-05
				20	6.84E-04	0	0.39	Acute	1,400	NA	2.8E-04
								Chronic	50	0	7.8E-03
								Algae	360	0	1.1E-03
OES: Adhesives, Paints, and Coatings											
Roll Coating 60 Sites NPDES: None	POTW	Surrogate: Adhesives and Sealants Manufacturer	Surface Water	250	1.80	88	27.76	Acute	1,400	NA	2.0E-02
								Chronic	50	0	5.6E-01
								Algae	360	0	7.7E-02
Spray Coating with Water Curtain Capture 60 Sites NPDES: None	POTW	Surrogate: Adhesives and Sealants Manufacturer	Surface Water	250	1.40	88	21.59	Acute	1,400	NA	1.5E-02
								Chronic	50	0	4.3E-01
								Algae	360	0	6.0E-02
OES: Chemical Maskant											
Alliant Techsystems Operations LLC Elkton, MD NPDES: MD0000078	Surface Water	MD0000078	Surface Water	172	5.81E-06	0	5.34E-04	Acute	1,400	NA	3.8E-07
								Chronic	50	0	1.1E-05
								Algae	360	0	1.5E-06
				20	0.00005	0	4.60E-03	Acute	1,400	NA	3.3E-06
								Chronic	50	0	9.2E-05
								Algae	360	0	1.3E-05
Ducommun Aerostructures Inc Orange Facility Orange, CA NPDES: None (110070089239)	POTW	Surrogate: Metal Finishing SIC (surrogate for receiving facility CA0110604)	Surface Water	172	0.00262	88	0.12	Acute	1,400	NA	8.6E-05
								Chronic	50	0	2.4E-03
								Algae	360	0	3.3E-04

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GE Aviation Lynn, MA NPDES: MA0003905	Surface Water	MA0003905	Still Water	172	8.72E-04	0	3.70E-03	Acute	1,400	NA	2.6E-06
								Chronic	50	0	7.4E-05
								Algae	360	0	1.0E-05
				20	0.0075	0	3.18E-02	Acute	1,400	NA	2.3E-05
								Chronic	50	0	6.4E-04
								Algae	360	0	8.8E-05
McCanna Inc. Carpentersville, IL NPDES: IL0071340	Surface Water	Surrogate: Metal Finishing SIC	Surface Water	172	4.07E-04	0	0.15	Acute	1,400	NA	1.1E-04
								Chronic	50	0	3.0E-03
								Algae	360	0	4.2E-04
				20	0.0035	0	1.33	Acute	1,400	NA	9.5E-04
								Chronic	50	0	2.7E-02
								Algae	360	0	3.7E-03
Weatherford Aerospace LLC Weatherford, TX NPDES: None (FRS 110000743740)	POTW	Receiving Facility: TX0047724	Surface Water	208	0.0109	88	0.21	Acute	1,400	NA	1.5E-04
								Chronic	50	0	4.2E-03
								Algae	360	0	5.8E-04
OES: Industrial Processing Aid											
Chevron Products Co - Salt Lake Refinery *Salt Lake City, UT* NPDES: UTG070261, UT0000175	Surface Water	UT0000175	Surface Water	300	5.80E-03	0	0.18	Acute	1,400	NA	1.3E-04
								Chronic	50	0	3.6E-03
								Algae	360	0	5.0E-04
				20	0.087	0	2.69	Acute	1,400	NA	1.9E-03
								Chronic	50	0	5.4E-02
								Algae	360	0	7.5E-03
Chevron Products Co Richmond Refinery Richmond, CA NPDES: CA0005134	Surface Water	CA0005134	Surface Water	300	3.03E-03	0	0.18	Acute	1,400	NA	1.3E-04
								Chronic	50	0	3.6E-03
								Algae	360	0	5.0E-04
				20	4.55E-02	0	2.64	Acute	1,400	NA	1.9E-03
								Chronic	50	0	5.3E-02
								Algae	360	0	7.3E-03

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CHS McPherson Refinery McPherson, KS NPDES: KS0000337	Surface Water	KS0000337	Surface Water	300	0.0003	0	4.41E-02	Acute	1,400	NA	3.2E-05
								Chronic	50	0	8.8E-04
								Algae	360	0	1.2E-04
				20	0.0045	0	0.66	Acute	1,400	NA	4.7E-04
								Chronic	50	0	1.3E-02
								Algae	360	0	1.8E-03
ExxonMobil Oil Beaumont Refinery Beaumont, TX NPDES: None (FRS 110056963683)	Surface Water	TX0068934	Surface Water	300	2.42E-02	0	6.70	Acute	1,400	NA	4.8E-03
								Chronic	50	0	1.3E-01
								Algae	360	0	1.9E-02
				20	3.63E-01	0	100.55	Acute	1,400	NA	7.2E-02
								Chronic	50	2	2.0
								Algae	360	0	2.8E-01
HollyFrontier El Dorado Refining LLC El Dorado, KS NPDES: KS0000761	Surface Water	KS0000761	Surface Water	300	3.03E-03	0	0.60	Acute	1,400	NA	4.3E-04
								Chronic	50	0	1.2E-02
								Algae	360	0	1.7E-03
				20	4.55E-02	0	8.97	Acute	1,400	NA	6.4E-03
								Chronic	50	0	1.8E-01
								Algae	360	0	2.5E-02
Hunt Refining Co - Tuscaloosa Refinery Tuscaloosa, AL NPDES: AL0000973	Surface Water	AL0000973	Surface Water	300	1.34E-02	0	4.44E-02	Acute	1,400	NA	3.2E-05
								Chronic	50	0	8.9E-04
								Algae	360	0	1.2E-04
				20	2.01E-01	0	0.66	Acute	1,400	NA	4.7E-04
								Chronic	50	0	1.3E-02
								Algae	360	0	1.8E-03
Marathon Petroleum Co LP Garyville, LA NPDES: LAU009485, LA0045683	Surface Water	LA0045683	Still Water	300	9.07E-03	0	0.43	Acute	1,400	NA	3.1E-04
								Chronic	50	0	8.6E-03
								Algae	360	0	1.2E-03
				20	1.36E-01	0	6.62	Acute	1,400	NA	4.7E-03
								Chronic	50	0	1.3E-01
								Algae	360	0	1.8E-02

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Occidental Chemical Corp Niagara Plant Niagara Falls, NY NPDES: NY0003336	Surface Water and POTW	Direct (0% WWT Removal): NY0003336 Indirect (88% WWT Removal): Organic Chemicals Mfg (surrogate for NY0026336)	Still Water	300	1.74E-01	0	1.29	Acute	1,400	NA	9.2E-04
								Chronic	50	0	2.6E-02
								Algae	360	0	3.6E-03
			Surface Water	300	1.74E-01	88	3.77	Acute	1,400	NA	2.7E-03
								Chronic	50	6	7.5E-02
								Algae	360	0	1.1E-02
			Still Water	20	2.61	0	19.80	Acute	1,400	NA	1.4E-02
								Chronic	50	0	4.0E-01
								Algae	360	0	5.5E-02
Tesoro Los Angeles Refinery-Carson Operations Carson, CA NPDES: CA0000680	Surface Water and POTW	Direct (0% WWT removal): Petroleum Refining Indirect (88% WWT removal): CA0053813	Surface Water	300	2.87E-02	0	11.39	Acute	1,400	NA	8.1E-03
								Chronic	50	16	2.3E-01
								Algae	360	2	3.2E-02
			Surface Water	300	2.87E-02	88	1.39E-05	Acute	1,400	NA	9.9E-09
								Chronic	50	0	2.8E-07
								Algae	360	0	3.9E-08
			Surface Water	20	4.31E-01	0	170.63	Acute	1,400	NA	1.2E-01
								Chronic	50	7	3.4
								Algae	360	2	4.7E-01
The Dow Chemical Co Midland, MI NPDES: MI0000868	Surface Water	MI0000868	Surface Water	300	3.48E-02	0	5.51E-02	Acute	1,400	NA	3.9E-05
								Chronic	50	0	1.1E-03
								Algae	360	0	1.5E-04
				20	5.22E-01	0	0.82	Acute	1,400	NA	5.9E-04
								Chronic	50	0	1.6E-02
								Algae	360	0	2.3E-03
Valero Refining Co -Oklahoma Valero Ardmore Refinery Ardmore, OK NPDES: OK0001295	Surface Water	OK0001295	Surface Water	300	7.57E-03	0	0.49	Acute	1,400	NA	3.5E-04
								Chronic	50	0	9.8E-03
								Algae	360	0	1.4E-03
				20	1.14E-01	0	7.37	Acute	1,400	NA	5.3E-03
								Chronic	50	0	1.5E-01
								Algae	360	0	2.1E-02

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Valero Refining Co -Oklahoma Valero Ardmore Refinery Ardmore, OK NPDES: OK0001295	Surface Water	Surrogate: Organic Chemicals Mfg	Surface Water	300	9.10E-03	0	1.68	Acute	1,400	NA	1.2E-03
								Chronic	50	1	3.4E-02
								Algae	360	0	4.7E-03
				20	1.37E-01	0	25.88	Acute	1,400	NA	1.9E-02
								Chronic	50	2	5.2E-01
								Algae	360	0	7.2E-02
OES: Other Industrial Uses											
ExxonMobil Oil Corp JoiIet Refinery Channahon, IL NPDES: ILR10H432	Surface Water	ILR10H432	Surface Water	250	4.72E-03	0	1.64E-03	Acute	1,400	NA	1.2E-06
								Chronic	50	0	3.3E-05
								Algae	360	0	4.6E-06
				20	0.059	0	2.05E-02	Acute	1,400	NA	1.5E-05
								Chronic	50	0	4.1E-04
								Algae	360	0	5.7E-05
Natrium Plant New Martinsville, WV NPDES: WV0004359	Surface Water	WV0004359	Surface Water	250	3.15E-02	0	3.75E-03	Acute	1,400	NA	2.7E-06
								Chronic	50	0	7.6E-05
								Algae	360	0	1.0E-05
				20	3.94E-01	0	4.64E-02	Acute	1,400	NA	3.3E-05
								Chronic	50	0	9.3E-04
								Algae	360	0	1.3E-04
Oxy Vinyls LP - Deer Park PVC Deer Park, TX NPDES: TX0007412	Surface Water	TX0007412	Surface Water	250	0.31	0	1.00	Acute	1,400	NA	7.1E-04
								Chronic	50	0	2.0E-02
								Algae	360	0	2.8E-03
				20	3.88	0	12.55	Acute	1,400	NA	9.0E-03
								Chronic	50	0	2.5E-01
								Algae	360	0	3.5E-02
Princeton Plasma Physics Lab (FF) Princeton, NJ NPDES: NJ0023922	Surface Water	Surrogate: Industrial POTW	Surface Water	250	5.30E-04	0	6.83E-02	Acute	1,400	NA	4.9E-05
								Chronic	50	0	1.4E-03
								Algae	360	0	1.9E-04
				20	6.63E-03	0	0.85	Acute	1,400	NA	6.1E-04
								Chronic	50	0	1.7E-02
								Algae	360	0	2.4E-03

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Tree Top Inc Wenatchee Plant Wenatchee, WA NPDES: WA0051527	Surface Water	Industrial POTW	Surface Water	250	3.04E-05	0	3.92E-03	Acute	1,400	NA	2.8E-06
								Chronic	50	0	7.8E-05
								Algae	360	0	1.1E-05
				20	3.80E-04	0	4.90E-02	Acute	1,400	NA	3.5E-05
								Chronic	50	0	9.8E-04
								Algae	360	0	1.4E-04
Vesuvius USA Corp Buffalo Plant Buffalo, NY NPDES: NY0030881	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.23E-04	0	1.59E-02	Acute	1,400	NA	1.1E-05
								Chronic	50	0	3.2E-04
								Algae	360	0	4.4E-05
				20	1.54E-03	0	0.20	Acute	1,400	NA	1.4E-04
								Chronic	50	0	4.0E-03
								Algae	360	0	5.6E-04
William E. Warne Power Plant Los Angeles County, CA NPDES: CA0059188	Surface Water	CA0059188	Surface Water	250	1.13E-06	0	0.11	Acute	1,400	NA	7.9E-05
								Chronic	50	0	2.2E-03
								Algae	360	0	3.1E-04
				20	1.41E-05	0	1.41	Acute	1,400	NA	1.0E-03
								Chronic	50	0	2.8E-02
								Algae	360	0	3.9E-03
OES: Other Commercial Uses											
Union Station North Wing Office Building Denver, CO NPDES: COG315293	Surface Water	Surrogate: Industrial POTW	Surface Water	250	2.87E-03	0	0.37	Acute	1,400	NA	2.6E-04
								Chronic	50	0	7.4E-03
								Algae	360	0	1.0E-03
				20	3.59E-02	0	4.63	Acute	1,400	NA	3.3E-03
								Chronic	50	0	9.3E-02
								Algae	360	0	1.3E-02
Confluence Park Apartments Denver, CO NPDES: COG315339	Surface Water	Surrogate: Industrial POTW	Surface Water	250	0.0003	0	0.0387	Acute	1,400	NA	2.8E-05
								Chronic	50	0	7.7E-04
								Algae	360	0	1.1E-04
				20	3.75E-03	0	0.48	Acute	1,400	NA	3.4E-04
								Chronic	50	0	9.6E-03
								Algae	360	0	1.3E-03

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Wynkoop Denver LLCP St Denver, CO NPDES: COG603115	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.54E-04	0	1.98E-02	Acute	1,400	NA	1.4E-05
								Chronic	50	0	4.0E-04
								Algae	360	0	5.5E-05
				20	1.92E-03	0	0.25	Acute	1,400	NA	1.8E-04
								Chronic	50	0	5.0E-03
								Algae	360	0	6.9E-04
100 Saint Paul Denver County, CO NPDES: COG315289	Surface Water	Surrogate: Industrial POTW	Surface Water	250	4.27E-05	0	5.50E-03	Acute	1,400	NA	3.9E-06
								Chronic	50	0	1.1E-04
								Algae	360	0	1.5E-05
				20	5.34E-04	0	6.88E-02	Acute	1,400	NA	4.9E-05
								Chronic	50	0	1.4E-03
								Algae	360	0	1.9E-04
BPI-Westminster, LLC(Owner)/Arcadis (Op) Denver, CO NPDES: COG315146	Surface Water	Surrogate: Industrial POTW	Surface Water	250	3.44E-05	0	4.43E-03	Acute	1,400	NA	3.2E-06
								Chronic	50	0	8.9E-05
								Algae	360	0	1.2E-05
				20	4.30E-04	0	5.54E-02	Acute	1,400	NA	4.0E-05
								Chronic	50	0	1.1E-03
								Algae	360	0	1.5E-04
Safeway Inc Denver, CO NPDES: COG315260	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.56E-05	0	2.01E-03	Acute	1,400	NA	1.4E-06
								Chronic	50	0	4.0E-05
								Algae	360	0	5.6E-06
				20	1.95E-04	0	2.51E-02	Acute	1,400	NA	1.8E-05
								Chronic	50	0	5.0E-04
								Algae	360	0	7.0E-05
Illinois Central Railroad Thompsonville, IL NPDES: IL0070696	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.31E-05	0	1.69E-03	Acute	1,400	NA	1.2E-06
								Chronic	50	0	3.4E-05
								Algae	360	0	4.7E-06
				20	1.64E-04	0	2.11E-02	Acute	1,400	NA	1.5E-05
								Chronic	50	0	4.2E-04
								Algae	360	0	5.9E-05

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
OES: Waste Handling, Disposal, Treatment, and Recycling											
Clean Harbors Deer Park LLC La Porte, TX NPDES: TX0005941	Non-POTW WWT	Surrogate: Industrial POTW	Surface Water	250	3.49E-01	88	5.41	Acute	1,400	NA	3.9E-03
								Chronic	50	1	1.1E-01
								Algae	360	0	1.5E-02
				20	4.37	88	67.58	Acute	1,400	NA	4.8E-02
								Chronic	50	4	1.4
								Algae	360	0	1.9E-01
Clean Harbors El Dorado LLC El Dorado, AR NPDES: AR0037800	Non-POTW WWT	Surrogate: Industrial POTW	Surface Water	250	3.71E-02	88	0.57	Acute	1,400	NA	4.1E-04
								Chronic	50	0	1.1E-02
								Algae	360	0	1.6E-03
				20	4.64E-01	88	7.11	Acute	1,400	NA	5.1E-03
								Chronic	50	0	1.4E-01
								Algae	360	0	2.0E-02
Clean Harbors Recycling Services of Ohio LLC Hebron, OH NPDES: None (FRS 110070118494)	POTW	Receiving Facility: OH0021539	Surface Water	250	4.00E-05	88	2.58E-04	Acute	1,400	NA	1.8E-07
								Chronic	50	0	5.2E-06
								Algae	360	0	7.2E-07
Clean Water Of New York Inc Staten Island, NY NPDES: NY0200484	Surface Water	Surrogate: Industrial POTW SIC code	Surface Water	250	3.76E-03	0	0.48	Acute	1,400	NA	3.4E-04
								Chronic	50	0	9.6E-03
								Algae	360	0	1.3E-03
				20	0.047	0	6.06	Acute	1,400	NA	4.3E-03
								Chronic	50	0	1.2E-01
								Algae	360	0	1.7E-02
Clifford G Higgins Disposal Service Inc SLF Kingston, NJ NPDES: NJG160946	Surface Water	Surrogate: Industrial POTW SIC code	Surface Water	250	0.0002	0	2.58E-02	Acute	1,400	NA	1.8E-05
								Chronic	50	0	5.2E-04
								Algae	360	0	7.2E-05
				20	0.0025	0	0.32	Acute	1,400	NA	2.3E-04
								Chronic	50	0	6.4E-03
								Algae	360	0	8.9E-04

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Durez North Tonawanda Occidental Chemical Corporation North Tonawanda, NY NPDES: NY0001198	Surface Water	NY0001198	Surface Water	250	4.00E-05	0	2.13E-02	Acute	1,400	NA	1.5E-05
								Chronic	50	0	4.3E-04
								Algae	360	0	5.9E-05
				20	0.00050	0	0.27	Acute	1,400	NA	1.9E-04
								Chronic	50	0	5.4E-03
								Algae	360	0	7.5E-04
Heritage Thermal Services East Liverpool, OH NPDES: OH0107298	POTW	Receiving Facility: OH0024970	Surface Water	250	4.00E-07	88	5.80E-09	Acute	1,400	NA	4.1E-12
								Chronic	50	0	1.2E-10
								Algae	360	0	1.6E-11
Oiltanking Houston Inc Houston, TX NPDES: TX0091855	Surface Water	Surrogate location: TX0005941	Surface Water	250	3.32E-03	0	0.36	Acute	1,400	NA	2.6E-04
								Chronic	50	0	7.2E-03
								Algae	360	0	1.0E-03
				20	4.15E-02	0	4.54	Acute	1,400	NA	3.2E-03
								Chronic	50	0	9.1E-02
								Algae	360	0	1.3E-02
Pinewood Site Custodial Trust Pinewood, SC NPDES: SC0042170	Surface Water	Surrogate: Industrial POTW SIC code	Surface Water	250	6.00E-04	0	7.73E-02	Acute	1,400	NA	5.5E-05
								Chronic	50	0	1.6E-03
								Algae	360	0	2.2E-04
				20	0.0075	0	0.97	Acute	1,400	NA	6.9E-04
								Chronic	50	0	1.9E-02
								Algae	360	0	2.7E-03
Safety-Kleen Systems Inc Smithfield, KY NPDES: KY0098345	Non-POTW WWT	Surrogate: Industrial POTW SIC code (surrogate for receiving facility MDU000011)	Surface Water	250	1.35	88	20.88	Acute	1,400	NA	1.5E-02
								Chronic	50	9	4.2E-01
								Algae	360	0	5.8E-02
				20	16.92	88	261.65	Acute	1,400	NA	1.9E-01
								Chronic	50	13	5.2
								Algae	360	2	7.3E-01

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	WWT removal %	7Q10 SWC (ppb)[g]	COC Type	COC (ppb)	Days of Exceedance (days/year)[h]	Risk Quotient
Safety-Kleen Systems Inc, East Chicago, IN NPDES: Unknown	POTW	Receiving Facility: IN0022829	Surface Water	250	2.73E-01	88	0.48	Acute	1,400	NA	3.4E-04
								Chronic	50	7	9.6E-03
								Algae	360	3	1.3E-03
Tier Environmental LLC Bedford, OH NPDES: None (FRS 110000388232)	POTW	Surrogate: Industrial POTW SIC code	Surface Water	250	0.12	88	1.86	Acute	1,400	NA	1.3E-03
								Chronic	50	0	3.7E-02
								Algae	360	0	5.2E-03
Tradebe Treatment & Recycling LLC East Chicago, IN NPDES: None (FRS 110070334821)	Non-POTW WWT	Surrogate: Industrial POTW SIC code (surrogate for FRS 110020159852	Surface Water	250	5.44E-03	88	8.41E-02	Acute	1,400	NA	6.0E-05
								Chronic	50	0	1.7E-03
								Algae	360	0	2.3E-04
				20	0.068	88	1.05	Acute	1,400	NA	7.5E-04
								Chronic	50	0	2.1E-02
								Algae	360	0	2.9E-03

a. Facilities actively releasing PCE were identified via DMR, TRI and CDR databases for the 2016 reporting year.
b. Release media are either direct (release from active facility directly to surface water) or indirect (transfer of wastewater from active facility to a receiving POTW or non-POTW WWTP facility). A wastewater treatment removal rate of 88% is applied to all indirect releases, as well as direct releases from WWTPs.
c. If a valid NPDES of the direct or indirect releaser was not available in E-FAST, the release was modeled using either a surrogate representative facility in E-FAST (based on location) or a representative industry sector. If available in TRI, the NPDES of the receiving facility is provided.
d. E-FAST 2014 (U.S. EPA, 2014b) uses the "surface water" model for free-flowing water bodies such as rivers and streams, and the "still water" model for lakes, bays, and oceans. The surface water model uses stream flow values to calculate the concentration, whereas the still water model uses dilution factors. The dilution factor used in E-FAST is provided in parentheses.
e. Modeling was conducted with the maximum days of release per year estimated. For direct releasing facilities, a minimum of 20 days was also modeled.
f. The daily release amount was calculated from the reported annual release amount divided by the number of release days per year.
g. For releases discharging to lakes, bays, estuaries, and oceans, the acute scenario mixing zone water concentration was reported in place of the 7Q10 SWC. For discharges to free-flowing water using an industry sector flow, the 10th percentile 7Q10 is reported.
h. To determine the PDM days of exceedance for still bodies of water, the release days provided by the EPA Engineers is equal to the days of exceedance only if the predicted surface water concentration exceeds the COC. Otherwise, the days of exceedance can be assumed to be zero.

4.4.2 Human Health Risk Conclusions

4.4.2.1 Summary of Risk Estimates for Inhalation and Dermal Exposures to Workers and ONUs

Table 4-125 summarizes the risk estimates for inhalation and dermal exposures for all occupational exposure scenarios. Risk estimates that exceed the benchmark (*i.e.,* MOEs less than the benchmark MOE or cancer risks greater than the cancer risk benchmark) are highlighted by bolding the number and shading the cell both with and without assumed PPE. The PPE protection factor is listed in parentheticals beneath the risk value. The lowest APF/glove PF that eliminated risk (or APF 50/glove PF 20 if risk was not eliminated) was presented. The risk characterization is described in more detail in Section 4.2.2 and specific links to the exposure and risk characterization sections are listed in Table 4-125 in the column headed Occupational Exposure Scenario.

Of note, the risk summary below is based on the most robust and sensitive non-cancer endpoints (neurotoxicity) following acute and chronic exposures , as well as cancer following chronic exposures. For the majority of exposure scenarios, when risks were identified for the non-cancer endpoint (neurotoxicity), risks following chronic exposures were also identified for kidney (urinary markers of nephrotoxicity) and immune system toxicity.

EPA made OES-specific determinations of assumed respirator use (see Section 4.2.2.2). When respirator use was considered plausible for the use scenario, the displayed PPE protection limits in Table 4-125 shows the minimum PPE required to eliminate risk (up to APF =50, glove PF =20 for industrial, and glove PF=10 for commercial). Risk estimates are shown with PPE estimates in Table 4-125 as a what-if scenario, even if those limits are not used for unreasonable risk determination (Section 5). Footnotes indicate for which individual OES respirator use is not assumed.

Table 4-125 Summary of Risk Estimates for Inhalation and Dermal Exposures to Workers by Condition of Use

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
Manufacture/ Domestic manufacture	Domestic manufacture	Section 2.4.1.6 – Manufacturing; Section 4.2.2.3 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**1.9**	**5.4**	**6.2E-4**	19 (APF 10)	136 (APF 25)	6.2E-5 (APF 10)
					Central Tendency	154	446	5.9E-6	1,538 (APF 10)	4,462 (APF 10)	5.9E-7 (APF 10)
				Inhalation 12 hr	High-End	15	**45**	5.0E-5	155 (APF 10)	453 (APF 10)	5.0E-6 (APF 10)
					Central Tendency	161	472	3.7E-6	1,610 (APF 10)	4,715 (APF 10)	3.7E-7 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	54	158	2.1E-5	N/A	N/A	N/A
					Central Tendency	147	427	6.2E-6	N/A	N/A	N/A
				Inhalation 12 hr	High-End	73	215	1.1E-5	N/A	N/A	N/A
					Central Tendency	147	430	4.1E-6	N/A	N/A	N/A
Manufacture/ Import	Import	Section 2.4.1.7 – Repackaging; Section 4.2.2.4 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**4.1**	**12**	**2.8E-4**	41 (APF 10)	120 (APF 10)	2.8E-5 (APF 10)
					Central Tendency	11	**32**	8.3E-5	109 (APF 10)	316 (APF 10)	8.3E-6 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	11	**32**	8.3E-5	N/A	N/A	N/A

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
Processing/ Processing as a reactant/ intermediate	Intermediate in industrial gas manufacturing	Section 2.4.1.8– Processing as a Reactant; Section 4.2.2.5 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**1.9**	**5.4**	**6.2E-4**	19 (APF 10)	136 (APF 25)	6.2E-5 (APF 10)
					Central Tendency	154	446	5.9E-6	1,538 (APF 10)	4,462 (APF 10)	5.9E-7 (APF 10)
	Intermediate in basic organic chemical manufacturing			Inhalation 12 hr	High-End	15	**45**	5.0E-5	155 (APF 10)	453 (APF 10)	5.0E-6 (APF 10)
					Central Tendency	161	472	3.7E-6	1,610 (APF 10)	4,715 (APF 10)	3.7E-7 (APF 10)
	Intermediate in petroleum refineries			Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
	Reactant Use				Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	54	158	2.1E-5	N/A	N/A	N/A
					Central Tendency	147	427	6.2E-6	N/A	N/A	N/A
				Inhalation 12 hr	High-End	73	215	1.1E-5	N/A	N/A	N/A
					Central Tendency	147	430	4.1E-6	N/A	N/A	N/A
Processing/ Incorporated into formulation mixture or reaction product	Other chemical products and preparations	Section 2.4.1.9 – Incorporation into Formulation, Mixture, or Reactant Product; Section 4.2.2.6 based on Aerosol Packing for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.2**	**0.6**	**6.0E-3**	**9.8** (APF 50)	**28** (APF 50)	**1.2E-4** (APF 50)
					Central Tendency	**0.6**	**1.7**	**1.6E-3**	14 (APF 25)	**83** (APF 50)	6.3E-5 (APF 25)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**0.6**	**1.7**	**1.6E-3**	N/A	N/A	N/A
	Adhesive and sealant products (used these risk estimates for Risk Determination)	Section 2.4.1.9 – Incorporation into Formulation, Mixture, or Reactant Product; Section 4.2.2.6 based on Degreasing Solvent for inhalation risks and	Worker	Inhalation 8 hr	High-End	**1.9**	**5.6**	**4.7E-4**	19 (APF 10)	139 (APF 25)	4.7E-5 (APF 10)
					Central Tendency	**6.8**	**20**	**1.3E-4**	68 (APF 10)	198 (APF 10)	1.3E-5 (APF 10)
	Paint and coating products (used these risk estimates for Risk Determination)			Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
	Cleaning and degreasing products	Section 4.2.3.1 for dermal risks	ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**6.8**	**20**	**1.3E-4**	N/A	N/A	N/A
	Cleaning and degreasing products (used these risk estimates for Risk Determination)	Section 2.4.1.9 – Incorporation into Formulation, Mixture, or Reactant Product; Section 4.2.2.6 based on Dry Cleaning Solvent for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.4**	**1.0**	**2.6E-3**	18 (APF 50)	**52** (APF 50)	5.1E-5 (APF 50)
					Central Tendency	**1.3**	**3.7**	**6.8E-4**	13 (APF 10)	183 (APF 50)	6.8E-5 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**1.3**	**3.7**	**6.8E-4**	N/A	N/A	N/A
	Adhesive and sealant products	Section 2.4.1.9 – Incorporation into Formulation, Mixture, or Reactant Product and Section 4.2.2.6 based on Miscellaneous for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**3.5**	**10**	**2.6E-4**	35 (APF 10)	102 (APF 10)	2.6E-5 (APF 10)
					Central Tendency	13	**37**	6.8E-5	126 (APF 10)	366 (APF 10)	6.8E-6 (APF 10)
	Paint and coating products			Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	13	**37**	6.8E-5	N/A	N/A	N/A
Processing/ Incorporated into articles	Plastic and rubber products	Not assessed – after further review, EPA determined that PCE is not incorporated into plastic articles but rather is used as a degreasing solvent at plastic manufacture sites which are assessed in Sections 2.4.1.10 through 2.4.1.15									
Processing/ Repackaging	Solvent for cleaning or degreasing	Section 2.4.1.7 – Repackaging; Section 4.2.2.4 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**4.1**	**12**	**2.8E-4**	41 (APF 10)	120 (APF 10)	2.8E-5 (APF 10)
	Intermediate				Central Tendency	11	**32**	8.3E-5	109 (APF 10)	316 (APF 10)	8.3E-6 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	11	**32**	8.3E-5	N/A	N/A	N/A
Processing/ Recycling	Recycling	Section 2.4.1.26 – Waste Handling, Disposal, Treatment, and Recycling; Section 4.2.2.23 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	50	145	2.3E-5	502 (APF 10)	1,455 (APF 10)	2.3E-6 (APF 10)
					Central Tendency	1,315	3,813	6.9E-7	13,150 (APF 10)	38,134 (APF 10)	6.9E-8 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	1,315	3,813	6.9E-7	N/A	N/A	N/A
Distribution in commerce	Distribution	Activities related to distribution (*e.g.*, loading, unloading) are considered throughout the life cycle, rather than using a single distribution scenario.									
Industrial-commercial use/ Solvents (for cleaning or degreasing)	Batch vapor degreaser (*e.g.*, open-top, closed-loop)	Section 2.4.1.10 – Batch Open-Top Vapor Degreasing; Section 4.2.2.7 for inhalation risks and Section 4.2.3.2 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.2**	**0.5**	**7.5E-3**	**7.8** (APF 50)	**23** (APF 50)	**1.5E-4** (APF 50)
					Central Tendency	**2.4**	**6.9**	**3.8E-4**	24 (APF 10)	173 (APF 25)	3.8E-5 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**1.0**	**2.8**	**1.2E-3**	N/A	N/A	N/A
					Central Tendency	**8.2**	**24**	**1.1E-4**	N/A	N/A	N/A
		Section 2.4.1.11 – Batch Closed-Loop Vapor Degreasing; Section 4.2.2.8 for inhalation risks and Section 4.2.3.2 for dermal risks	Worker	Inhalation 8 hr	High-End	20	**57**	5.9E-5	198 (APF 10)	573 (APF 10)	5.9E-6 (APF 10)
					Central Tendency	69	201	1.3E-5	693 (APF 10)	2,009 (APF 10)	1.3E-6 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs		High-End	52	151	2.2E-5	N/A	N/A	N/A

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
				Inhalation 8 hr	Central Tendency	76	222	1.2E-5	N/A	N/A	N/A
	In-line vapor degreaser (*e.g.*, conveyorized, web cleaner)	Section 2.4.1.12– Conveyorized Vapor Degreasing; Section 4.2.2.9 for inhalation risks and Section 4.2.3.2 for dermal risks	Worker	Inhalation 8 hr	High-End	**2.7E-2**	**7.8E-2**	**3.5E-2**	**1.3** (APF 50)	**3.9** (APF 50)	**7.0E-4** (APF 50)
					Central Tendency	**6.4E-2**	**0.2**	**1.3E-2**	**3.2** (APF 50)	**9.3** (APF 50)	**2.7E-4** (APF 50)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**4.0E-2**	**0.1**	**2.3E-2**	N/A	N/A	N/A
					Central Tendency	**0.1**	**0.4**	**7.0E-3**	N/A	N/A	N/A
		Section 2.4.1.13 - Web Degreasing; Section 4.2.2.10 for inhalation risks and Section 4.2.3.2 for dermal risks	Worker	Inhalation 8 hr	High-End	**2.8**	**8.0**	**3.3E-4**	28 (APF 10)	201 (APF 25)	3.3E-05 (APF 10)
					Central Tendency	**8.2**	**24**	**1.1E-4**	82 (APF 10)	237 (APF 10)	1.1E-05 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**4.3**	**12**	**2.1E-4**	N/A	N/A	N/A
					Central Tendency	16	**45**	5.5E-5	N/A	N/A	N/A
	Cold cleaner	Section 2.4.1.14– Cold Cleaning; Section 4.2.2.11 based on inhalation* exposure monitoring data for inhalation risks and Section 4.2.3.2 for dermal risks	Worker	Inhalation 8 hr	High-End	**1.2**	**3.5**	**9.7E-4**	12 (APF 10)	176 (APF 50)	9.7E-5 (APF 10)
					Central Tendency	**3.6**	**10**	**2.5E-4**	36 (APF 10)	104 (APF 10)	2.4E-5 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	Monitoring data for ONUs not reasonably available. ONUs assessed using model.					
					Central Tendency						
			Worker	Inhalation 8 hr	High-End	**3.3**	**9.4**	**2.6E-4**	33 (APF 10)	236 (APF 25)	2.6E-5 (APF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		Section 2.4.1.14– Cold Cleaning; Section 4.2.2.11 based on inhalation* exposure modeling for inhalation risks and Section 4.2.3.2 for dermal risks			Central Tendency	2,086	6,048	4.1E-7	20,857 (APF 10)	60,485 (APF 10)	4.1E-8 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**6.4**	**19**	**1.3E-4**	N/A	N/A	N/A
					Central Tendency	4,029	11,685	2.1E-7	N/A	N/A	N/A
	Aerosol spray degreaser/cleaner	Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants; Section 4.2.2.12 [c] based on inhalation* exposure monitoring data for inhalation risks and Section 4.2.3.3 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.7**	**1.9**	**1.8E-3**	17 (APF 25)	**97** (APF 50)	7.0E-5 (APF 25)
					Central Tendency	**3.5**	**10**	**2.6E-4**	35 (APF 10)	103 (APF 10)	2.6E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	Monitoring data for ONUs not reasonably available. ONUs assessed using model.					
					Central Tendency						
		Section 2.4.1.15 - Aerosol Degreasing and Aerosol Lubricants; Section 4.2.2.12 [c] based on inhalation* exposure modeling for inhalation risks and Section 4.2.3.3 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.3**	**0.8**	**3.1E-3**	15 (APF 50)	**42** (APF 50)	6.3E-5 (APF 50)
					Central Tendency	**0.9**	**2.6**	**9.4E-4**	23 (APF 25)	132 (APF 50)	9.4E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**6.8**	**20**	**1.4E-4**	N/A	N/A	N/A
					Central Tendency	50	145	2.0E-5	N/A	N/A	N/A
	Dry cleaning solvent	Section 2.4.1.16 – Dry Cleaning and Spot Cleaning	Worker	Inhalation 8 hr	High-End	**0.3**	**0.9**	**4.7E-3**	15 (APF 50)	**43** (APF 50)	9.3E-5 (APF 50)
	Spot cleaner				Central Tendency	**2.3**	**6.7**	**4.0E-4**	23 (APF 10)	169 (APF 25)	4.0E-5 (APF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		Post-2006 Dry Cleaning (including spot cleaning); Section 4.2.2.13 [c] based on inhalation* exposure monitoring data for inhalation risks and Section 4.2.3.4 for dermal risks		Dermal	High-End	**0.8**	**1.4**	**4.4E-3**	**7.9** (PF 10)	**14** (PF 10)	**4.4E-4** (PF 10)
					Central Tendency	**2.4**	**4.9**	**1.0E-3**	12 (PF 5)	**49** (PF 10)	**1.0E-4** (PF 0)
			ONUs	Inhalation 8 hr	High-End	14	**42**	9.5E-5	N/A	N/A	N/A
					Central Tendency			6.5E-5	N/A	N/A	N/A
			Children of Employees	Inhalation 8 hr	High-End	**3.7**	N/A	N/A	N/A	N/A	N/A
					Central Tendency		N/A	N/A	N/A	N/A	N/A
		Section 2.4.1.16– Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning (including spot cleaning); Section 4.2.2.13 [c] based on inhalation* exposure modeling for inhalation risks and Section 4.2.3.4 for dermal risks	Worker	Inhalation 12 hr	High-End	**0.1**	**0.3**	**8.1E-3**	**5.6** (APF 50)	**16** (APF 50)	**1.6E-4** (APF 50)
					Central Tendency	**2.4**	**6.9**	**3.8E-4**	24 (APF 10)	173 (APF 25)	3.8E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.4**	**4.4E-3**	**7.9** (PF 10)	**14** (PF 10)	**4.4E-4** (PF 10)
					Central Tendency	**2.4**	**4.9**	**1.0E-3**	12 (PF 5)	**49** (PF 10)	**1.0E-4** (PF 10)
			ONUs	Inhalation 12 hr	High-End	**2.1**	**6.2**	**4.3E-4**	N/A	N/A	N/A
					Central Tendency	30	**89**	2.9E-5	N/A	N/A	N/A
			Children of Employees	Inhalation 12 hr	High-End	**0.6**	N/A	N/A	N/A	N/A	N/A
					Central Tendency	**8.0**	N/A	N/A	N/A	N/A	N/A
		Section 2.4.1.16– Dry Cleaning and Spot Cleaning 4th/5th Gen Only Dry Cleaning (including spot cleaning); Section 4.2.2.13 [c] based on inhalation* exposure monitoring data	Worker	Inhalation 8 hr	High-End	**0.9**	**2.6**	**1.5E-3**	22 (APF 25)	130 (APF 50)	6.1E-5 (APF 25)
					Central Tendency	**5.1**	**15**	**1.8E-4**	51 (APF 10)	148 (APF 10)	1.8E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.4**	**4.4E-3**	**7.9** (PF 10)	**14** (PF 10)	**4.4E-4** (PF 10)
					Central Tendency	**2.4**	**4.9**	**1.0E-3**	12 (PF 5)	**49** (PF 10)	**1.0E-4** (PF 10)
			ONUs		High-End	41	118	3.4E-5	N/A	N/A	N/A

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		for inhalation risks and Section 4.2.3.4 for dermal risks		Inhalation 8 hr	Central Tendency	358	1,039	2.6E-6	N/A	N/A	N/A
			Children of Employees	Inhalation 12 hr	High-End	11	N/A	N/A	N/A	N/A	N/A
					Central Tendency	93	N/A	N/A	N/A	N/A	N/A
Industrial-commercial use/ Lubricants and greases	Lubricants and greases (aerosol lubricants)	Section 2.4.1.15 - Aerosol Degreasing and Aerosol Lubricants; Section 4.2.2.12[c] based on inhalation* exposure monitoring data for inhalation risks and Section 4.2.3.3 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.7**	**1.9**	**1.8E-3**	17 (APF 25)	**97** (APF 50)	7.0E-5 (APF 25)
					Central Tendency	**3.5**	**10**	**2.6E-4**	35 (APF 10)	103 (APF 10)	2.6E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	Monitoring data for ONUs not reasonably available. ONUs assessed using model.					
					Central Tendency						
		Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants; Section 4.2.2.12[c] based on inhalation* exposure modeling for inhalation risks and Section 4.2.3.3 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.3**	**0.8**	**3.1E-3**	15 (APF 50)	**42** (APF 50)	6.3E-5 (APF 50)
					Central Tendency	**0.9**	**2.6**	**9.4E-4**	23 (APF 25)	132 (APF 50)	9.4E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**6.8**	**20**	**1.4E-4**	N/A	N/A	N/A
					Central Tendency	50	145	2.0E-5	N/A	N/A	N/A
	Lubricants and greases (penetrating lubricants, cutting tool coolants)	Section 2.4.1.20– Metalworking Fluids; Section 4.2.2.17[c] for inhalation risks and Section 4.2.3.6 for dermal risks	Worker	Inhalation 8 hr	High-End	239	692	4.9E-6	2,387 (APF 10)	6,923 (APF 10)	4.9E-7 (APF 10)
					Central Tendency	869	2,521	1.0E-6	8,692 (APF 10)	25,208 (APF 10)	1.0E-7 (APF 10)
				Dermal	High-End	12	**26**	**2.5E-4**	60 (PF 5)	128 (PF 5)	5.0E-5 (PF 5)
					Central Tendency	36	**77**	6.4E-5	181 (PF 5)	384 (PF 5)	1.3E-5 (PF 5)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	869	2,521	1.0E-6	N/A	N/A	N/A
Industrial-commercial use/ Adhesives and sealants	Solvent-based adhesives and sealants	Section 2.4.1.17– Adhesive, Sealants, Paints, and Coatings; Section 4.2.2.14 based on Adhesives for inhalation risks and Section 4.2.3.7 for dermal risks	Worker	Inhalation 8 hr	High-End	**6.2**	**18**	**1.9E-4**	62 (APF 10)	179 (APF 10)	1.9E-5 (APF 10)
					Central Tendency	57	164	1.6E-5	565 (APF 10)	1,639 (APF 10)	1.6E-6 (APF 10)
				Dermal Commercial use	High-End	**1.0**	**2.1**	**3.0E-3**	**9.8** (PF 10)	**21** (PF 10)	**3.0E-4** (PF 10)
					Central Tendency	**3.0**	**6.3**	**7.8E-4**	15 (PF 5)	**63** (PF 10)	7.8E-5 (PF 10)
				Dermal Industrial use	High-End	**1.5**	**3.2**	**2.0E-3**	15 (PF 10)	**64** (PF 20)	9.9E-5 (PF 20)
					Central Tendency	**4.5**	**9.6**	**5.1E-4**	23 (PF 5)	192 (PF 20)	5.1E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	57	164	1.6E-5	N/A	N/A	N/A
Industrial-commercial use/ Paints and coatings including paint and coating removers	Solvent-based paints and coatings, including for chemical milling	Section 2.4.1.17– Adhesive, Sealants, Paints, and Coatings; Section 4.2.2.14 based on Paints/ Coatings for inhalation risks and Section 4.2.3.7 for dermal risks	Worker	Inhalation 8 hr	High-End	**1.1**	**3.2**	**1.1E-3**	11 (APF 10)	159 (APF 50)	4.3E-5 (APF 25)
					Central Tendency	21	**62**	4.2E-5	214 (APF 10)	621 (APF 10)	4.2E-6 (APF 10)
				Dermal Commercial use	High-End	**1.0**	**2.1**	**3.0E-3**	**9.8** (PF 10)	**21** (PF 10)	**3.0E-4** (PF 10)
					Central Tendency	**3.0**	**6.3**	**7.8E-4**	15 (PF 5)	**63** (PF 10)	7.8E-5 (PF 10)
				Dermal Industrial use	High-End	**1.5**	**3.2**	**2.0E-3**	15 (PF 10)	**64** (PF 20)	9.9E-5 (PF 20)
					Central Tendency	**4.5**	**9.6**	**5.1E-4**	23 (PF 5)	192 (PF 20)	5.1E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	21	**62**	4.2E-5	N/A	N/A	N/A
		Section 2.4.1.18 – Maskant for Chemical Milling; Section 4.2.2.15 for inhalation risks and	Worker	Inhalation 8 hr	High-End	**8.8E-2**	**0.3**	**1.3E-2**	**4.4** (APF 50)	**13** (APF 50)	**2.7E-4** (APF 50)
					Central Tendency	**2.2**	**6.5**	**4.1E-4**	22 (APF 10)	162 (APF 25)	4.1E-5 (APF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		Section 4.2.3.2 for dermal risks		Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**2.3**	**6.7**	**5.1E-4**	N/A	N/A	N/A
					Central Tendency	**4.8**	**14**	**1.9E-4**	N/A	N/A	N/A
Industrial-commercial use/ Processing aids, not otherwise listed	Pesticide, fertilizer and other agricultural chemical manufacturing	Section 2.4.1.19 – Industrial Processing Aid; Section 4.2.2.16 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**4.2**	**12**	**2.8E-4**	42 (APF 10)	123 (APF 10)	2.8E-5 (APF 10)
					Central Tendency	83	242	1.1E-5	833 (APF 10)	2,417 (APF 10)	1.1E-6 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	83	242	1.1E-5	N/A	N/A	N/A
Industrial-commercial use/ Processing aids, specific to petroleum production	Catalyst regeneration in petrochemical manufacturing	Section 2.4.1.19 – Industrial Processing Aid; Section 4.2.2.16 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**4.2**	**12**	**2.8E-4**	42 (APF 10)	123 (APF 10)	2.8E-5 (APF 10)
					Central Tendency	83	242	1.1E-5	833 (APF 10)	2,417 (APF 10)	1.1E-6 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	83	242	1.1E-5	N/A	N/A	N/A
Industrial-commercial use/ Other uses	Textile processing	Section 2.4.1.22 – Other Industrial Uses; Section 2.4.1.23 based on Textile Processing for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.3**	**0.8**	**4.3E-3**	14 (APF 50)	**40** (APF 50)	8.5E-5 (APF 50)
					Central Tendency	**4.0**	**12**	**2.3E-4**	40 (APF 10)	116 (APF 10)	2.3E-5 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**4.0**	**12**	**2.3E-4**	N/A	N/A	N/A
	Wood furniture manufacturing	Section 2.4.1.23 – Other Industrial Uses; Section 4.2.2.20 based on Wood Furniture Manufacturing for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.1**	**0.3**	**1.0E-2**	**5.6** (APF 50)	**16** (APF 50)	**2.1E-4** (APF 50)
					Central Tendency	**0.7**	**2.0**	**1.3E-3**	17 (APF 25)	**98** (APF 50)	5.4E-5 (APF 25)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**0.7**	**2.0**	**1.3E-3**	N/A	N/A	N/A
	Laboratory chemicals	Section 2.4.1.25 – Laboratory Chemicals; Section 4.2.2.22 for inhalation risks[c] and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**4.2**	**12**	**2.8E-4**	42 (PF 10)	122 (PF 10)	2.8E-5 (PF 10)
					Central Tendency			**2.2E-4**			2.2E-5 (PF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**4.2**	**12**	**2.2E-4**	N/A	N/A	N/A
	Foundry applications	Section 2.4.1.23 – Other Industrial Uses; Section 4.2.2.20 based on Foundry Applications for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**2.1E-2**	**6.0E-2**	**5.6E-2**	**1.0** (APF 50)	**3.0** (APF 50)	**1.1E-3** (APF 50)
					Central Tendency	**0.3**	**1.0**	**2.7E-3**	17 (APF 50)	**49** (APF 50)	5.3E-5 (APF 50)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**0.3**	**1.0**	**2.7E-3**	N/A	N/A	N/A

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
	Other DOD uses	Section 2.4.1.23 – Other Industrial Uses; Section 4.2.2.20 based on Other DOD uses for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	**2.2**	**43**	**1.2E-04**	22 (APF 10)	431 (APF 10)	1.2E-05 (APF 10)
					Central Tendency	**4.3**	**52**	8.0E-05	43 (APF 10)	517 (APF 10)	8.0E-06 (APF 10)
				Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
					Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**4.3**	**52**	8.0E-05	N/A	N/A	N/A
Industrial-commercial use/ Cleaning and furniture care products	Cleaners and degreasers (other)	Section 2.4.1.21 – Wipe Cleaning and Metal/Stone Polishes; Section 4.2.2.18[c] for inhalation risks and Section 4.2.3.5 for dermal risks	Worker	Inhalation 8 hr	High-End	**2.2E-2**	**6.4E-2**	**5.3E-2**	**1.1** (APF 50)	**3.2** (APF 50)	**1.1E-3** (APF 50)
					Central Tendency	**3.8E-2**	**0.1**	**2.4E-2**	**1.9** (APF 50)	**5.5** (APF 50)	**4.8E-4** (APF 50)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**3.8E-4** (PF 10)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**0.2**	**0.6**	**5.4E-3**	N/A	N/A	N/A
					Central Tendency	229	664	4.0E-6	N/A	N/A	N/A
		Section 2.4.1.22 – Other Spot Cleaning/Spot Removers (Including Carpet Cleaning); Section 4.2.2.19[c] for inhalation risks and Section 4.2.3.5 for dermal risks	Worker	Inhalation 8 hr	High-End	**1.5**	**4.3**	**7.9E-4**	15 (APF 10)	108 (APF 25)	7.9E-5 (APF 10)
					Central Tendency	**3.3**	**9.6**	**2.8E-4**	33 (APF 10)	239 (APF 25)	2.8E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**3.8E-4** (PF 10)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	167	483	7.0E-6	N/A	N/A	N/A
					Central Tendency			5.4E-6			
		Section 2.4.1.24 – Other Commercial Uses;	Worker	Inhalation 8 hr	High-End	44	128	2.7E-5	441 (APF10)	1,279 (APF 10)	2.7E-6 (APF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		Section 4.2.2.21 Based on Mold Release[c] for inhalation risks and Section 4.2.3.5 for dermal risks			Central Tendency	88	256	1.0E-5	882 (APF10)	2,558 (APF 10)	1.0E-6 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**3.8E-4** (PF 10)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	88	256	1.0E-5	N/A	N/A	N/A
	Dry cleaning solvent	Section 2.4.1.16 – Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning (including spot cleaning); Section 4.2.2.13[c] based on inhalation* exposure monitoring data for inhalation risks and Section 4.2.3.4 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.3**	**0.9**	**4.7E-3**	15 (APF 50)	**43** (APF 50)	9.3E-5 (APF 50)
	Spot cleaner				Central Tendency	**2.3**	**6.7**	**4.0E-4**	23 (APF 10)	169 (APF 25)	4.0E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.4**	**4.4E-3**	**7.9** (PF 10)	**14** (PF 10)	**4.4E-4** (PF 10)
					Central Tendency	**2.4**	**4.9**	**1.0E-3**	12 (PF 5)	**49** (PF 10)	**1.0E-4** (PF 10)
			ONUs	Inhalation 8 hr	High-End	14	**42**	9.5E-5	N/A	N/A	N/A
					Central Tendency		**64**	6.5E-5	N/A	N/A	N/A
		Section 2.4.1.16 – Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning (including spot cleaning); Section 4.2.2.13[c] based on inhalation* exposure modeling for inhalation risks and Section 4.2.3.4 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.1**	**0.3**	**8.1E-3**	**5.6** (APF 50)	**16** (APF 50)	**1.6E-4** (APF 50)
					Central Tendency	**2.4**	**6.9**	**3.8E-4**	24 (APF 10)	173 (APF 25)	3.8E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.4**	**4.4E-3**	**7.9** (PF 10)	**14** (PF 10)	**4.4E-4** (PF 10)
					Central Tendency	**2.4**	**4.9**	**1.0E-3**	12 (PF 5)	**49** (PF 10)	**1.0E-4** (PF 10)
			ONUs	Inhalation 8 hr	High-End	**2.1**	**6.2**	**4.3E-4**	N/A	N/A	N/A
					Central Tendency	30	**89**	2.9E-5	N/A	N/A	N/A
		Section 2.4.1.16 – Dry Cleaning and Spot	Worker	Inhalation 8 hr	High-End	**0.9**	**2.6**	**1.5E-3**	22 (APF 25)	130 (APF 50)	6.1E-5 (APF 25)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		Cleaning 4th/5th Gen Only Dry Cleaning (including spot cleaning); Section 4.2.2.13[c] based on inhalation* exposure monitoring data for inhalation risks and Section 4.2.3.4 for dermal risks			Central Tendency	**5.1**	**15**	**1.8E-4**	51 (APF 10)	148 (APF 10)	1.8E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.4**	**4.4E-3**	**7.9** (PF 10)	**14** (PF 10)	**4.4E-4** (PF 10)
					Central Tendency	**2.4**	**4.9**	**1.0E-3**	12 (PF 5)	**49** (PF 10)	**1.0E-4** (PF 10)
			ONUs	Inhalation 8 hr	High-End	41	118	3.4E-5	N/A	N/A	N/A
					Central Tendency	358	1,039	2.6E-6	N/A	N/A	N/A
	Automotive care products (*e.g.*, engine degreaser and brake cleaner)	Section 2.4.1.15 – Aerosol Degreasing and Aerosol Lubricants; Section 4.2.2.12[c] based on inhalation* exposure monitoring data for inhalation risks and Section 4.2.3.3 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.7**	**1.9**	**1.8E-3**	17 (APF 25)	**97** (APF 50)	7.0E-5 (APF 25)
	Aerosol cleaner				Central Tendency	**3.5**	**10**	**2.6E-4**	35 (APF 10)	103 (APF 10)	2.6E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	Monitoring data for ONUs not reasonably available. ONUs assessed using model.					
					Central Tendency						
		Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants; Section 4.2.2.12[c] based on inhalation* exposure modeling for inhalation risks and Section 4.2.3.3 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.3**	**0.8**	**3.1E-3**	15 (APF 50)	**42** (APF 50)	6.3E-5 (APF 50)
					Central Tendency	**0.9**	**2.6**	**9.4E-4**	23 (APF 25)	132 (APF 50)	9.4E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**6.8**	**20**	**1.4E-4**	N/A	N/A	N/A
					Central Tendency	50	145	2.0E-5	N/A	N/A	N/A
	Non-aerosol cleaner	Section 2.4.1.21 – Wipe Cleaning and Metal/Stone	Worker	Inhalation 8 hr	High-End	**2.2E-2**	**6.4E-2**	**5.3E-2**	**1.1** (APF 50)	**3.2** (APF 50)	**1.1E-3** (APF 50)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		Polishes; Section 4.2.2.18[c] for inhalation risks and Section 4.2.3.5 for dermal risks			Central Tendency	**3.8E-2**	**0.1**	**2.4E-2**	**1.9** (APF 50)	**5.5** (APF 50)	**4.8E-4** (APF 50)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**3.8E-4** (PF 10)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**0.2**	**0.6**	**5.4E-3**	N/A	N/A	N/A
					Central Tendency	229	664	4.0E-6	N/A	N/A	N/A
Commercial use/ Other uses	Inks and ink removal products	Section 2.4.1.24– Other Commercial Uses; Section 4.2.2.21 based on Printing[c] for inhalation risks and Section 4.2.3.5 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.4**	**1.1**	**3.2E-3**	19 (APF 50)	**54** (APF 50)	6.3E-5 (APF 50)
					Central Tendency	**3.0**	**8.8**	**3.0E-4**	30 (APF 10)	221 (APF 25)	3.0E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**3.8E-4** (PF 10)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**3.0**	**8.8**	**3.0E-4**	N/A	N/A	N/A
		Section 2.4.1.24– Other Commercial Uses; Section 4.2.2.21 based on Photocopying[c] for inhalation risks and Section 4.2.3.5 for dermal risks	Worker	Inhalation 8 hr	High-End	10,000	29,000	1.2E-7	100,000 (APF 10)	290,000 (APF 10)	1.2E-8 (APF 10)
					Central Tendency	26,667	77,333	3.4E-8	266,667 (APF 10)	773,333 (APF 10)	3.4E-9 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**3.8E-4** (PF 10)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	26,667	77,333	3.4E-8	N/A	N/A	N/A
	Welding	Section 2.4.1.15 – Aerosol Degreasing and Aerosol Lubricants and Section 4.2.2.12[b, c] Based on inhalation* exposure monitoring data	Worker	Inhalation 8 hr	High-End	**0.7**	**1.9**	**1.8E-3**	17 (APF 25)	**97** (APF 50)	7.0E-5 (APF 25)
					Central Tendency	**3.5**	**10**	**2.6E-4**	35 (APF 10)	103 (APF 10)	2.6E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
		for inhalation risks and Section 4.2.3.3 for dermal risks			Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	Monitoring data for ONUs not reasonably available. ONUs assessed using model.					
					Central Tendency						
		Section 2.4.1.15– Aerosol Degreasing and Aerosol Lubricants; Section 4.2.2.12[c] based on inhalation* exposure modeling for inhalation risks and Section 4.2.3.3 for dermal risks	Worker	Inhalation 8 hr	High-End	**0.3**	**0.8**	**3.1E-3**	15 (APF 50)	**42** (APF 50)	6.3E-5 (APF 50)
					Central Tendency	**0.9**	**2.6**	**9.4E-4**	23 (APF 25)	132 (APF 50)	9.4E-5 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.7E-3**	16 (PF 20)	**34** (PF 20)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.1**	**9.6E-4**	12 (PF 5)	103 (PF 20)	9.6E-5 (PF 10)
			ONUs	Inhalation 8 hr	High-End	**6.8**	**20**	**1.4E-4**	N/A	N/A	N/A
					Central Tendency	50	145	2.0E-5	N/A	N/A	N/A
	Photographic film	Section 2.4.1.24 – Other Commercial Uses; Section 4.2.2.21 based on Photographic Film[c] for inhalation risks and Section 4.2.3.5 for dermal risks	Worker	Inhalation 8 hr	High-End	**8.9E-2**	**0.3**	**1.3E-2**	**4.4** (APF 50)	**13** (APF 50)	**2.6E-4** (APF 50)
					Central Tendency	**0.8**	**2.3**	**1.1E-3**	20 (APF 25)	115 (APF 50)	4.6E-5 (APF 25)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**1.9E-4** (PF 20)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	**0.8**	**2.3**	**1.1E-3**	N/A	N/A	N/A
	Mold cleaning, release and protectant products	Section 2.4.1.24– Other Commercial Uses; Section 4.2.2.21 based on Mold Release[c] for inhalation risks and Section 4.2.3.5 for dermal risks	Worker	Inhalation 8 hr	High-End	44	128	2.7E-5	441 (APF10)	1,279 (APF 10)	2.7E-6 (APF 10)
					Central Tendency	88	256	1.0E-5	882 (APF10)	2,558 (APF 10)	1.0E-6 (APF 10)
				Dermal	High-End	**0.8**	**1.7**	**3.8E-3**	**7.9** (PF 10)	**17** (PF 10)	**3.8E-4** (PF 10)
					Central Tendency	**2.4**	**5.0**	**9.8E-4**	12 (PF 5)	**50** (PF 10)	9.8E-5 (PF 10)

Life Cycle Stage/ Category	Subcategory	Occupational Exposure Scenario and Exposure and Risk Section Numbers	Population	Exposure Route and Duration	Exposure Level	Risk Estimates for No PPE			Risk Estimates with PPE		
						Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})	Acute Non-cancer (benchmark MOE = 10)	Chronic Non-cancer (benchmark MOE = 100)	Cancer (benchmark = 10^{-4})
			ONUs	Inhalation 8 hr	Worker Central Tendency[a]	88	256	1.0E-5	N/A	N/A	N/A
Disposal/ Disposal	Industrial pre-treatment	Section 2.4.1.26– Waste Handling, Disposal, Treatment, and Recycling; Section 4.2.2.23 for inhalation risks and Section 4.2.3.1 for dermal risks	Worker	Inhalation 8 hr	High-End	50	145	2.3E-5	5,020 (APF 10)	1,455 (APF 10)	2.3E-6 (APF 10)
	Industrial wastewater treatment										
	Publicly owned treatment works (POTW)										
	Underground injection				Central Tendency	1,315	3,813	6.9E-7	13,150 (APF 10)	38,134 (APF 10)	6.9E-8 (APF 10)
	Municipal solid waste landfill			Dermal	High-End	**1.2**	**2.6**	**2.5E-3**	12 (PF 10)	**51** (PF 20)	**1.2E-4** (PF 20)
	Hazardous waste landfill										
	Other land disposal				Central Tendency	**3.6**	**7.7**	**6.4E-4**	18 (PF 5)	154 (PF 20)	6.4E-5 (PF 10)
	Municipal waste incinerator		ONUs	Inhalation 8 hr	Worker Central Tendency[a]	1,315	3,813	6.9E-7	N/A	N/A	N/A
	Hazardous waste incinerator										
	Off-site waste transfer										

N/A = not assessed because ONUs are not assumed to be wearing PPE

* exposure scenarios with both inhalation exposure monitoring data and inhalation exposure modeling present risk calculations for both exposure results, note that all dermal exposures were modeled

[a] EPA is unable to estimate ONU exposures separately from workers for this OES. EPA used worker central tendency values as a surrogate to assess risk for ONUs; however, the statistical representativeness of this value for ONUs is unknown.

[b] Identified welding products were anti-spatter aerosol products; therefore, the assessment is included with the assessment of other aerosol products.

[c] EPA believes that small commercial facilities using PCE for aerosol degreasing and lubrication, dry cleaning, metalworking fluid, wipe cleaning, spot cleaning, or other commercial uses are unlikely to have a respiratory protection program. Therefore, the use of respirators is unlikely for workers in these facilities.

[d] Risk estimates for Laboratory Chemicals are based on only a single data point, resulting in low confidence for the quantitative assessment. Risk determination for Laboratory Chemicals are therefore based on the qualitative assumption that the potential for exposure is low due to the expected use of a fume hood.

4.4.2.2 Summary of Risk Estimates for Inhalation and Dermal Exposures to Consumers and Bystanders

Table 4-126 summarizes the risk estimates for inhalation and dermal exposures for all consumer exposure scenarios. Risk estimates that exceed the benchmark (*i.e.,* MOEs less than the benchmark MOE) are highlighted by bolding the number and shading the cell. The risk characterization is described in more detail in Section 4.2.2 and specific links to the exposure and risk characterization sections are listed in Table 4-126 in the column headed Consumer Exposure Scenario.

Dermal risk estimates for all three consumer age groups (11-15 years, 16 – 20 years) and adults (≥21) are presented for each exposure scenario in Section 4.2.4. Overall, the differences in the MOEs between age groups are approximately 10% or less and none of the exposure scenarios have MOEs close enough to the benchmark MOE to result in different risk results depending on the age group selected. Table 4-126 presents dermal exposures for the most sensitive age group (11-15 years).

Table 4-126 Summary of Risk Estimates for CNS effects from Acute Inhalation and Dermal Exposures to Consumers by Conditions of Use

Category	Sub Category	Consumer Exposure Scenario	Exposure Route and Duration	Scenario Description	User MOE (benchmark MOE = 10)	Bystander MOE (benchmark MOE = 10)
Cleaning and furniture care products	Cleaners and degreasers (other)	Section 2.4.2.3.1- Aerosol Degreasers (includes: marine cleaner, degreaser, coil cleaner, electric motor cleaner, parts cleaner, cable cleaner, stainless steel polish, electrical/energized cleaner, wire and ignition demoisturants, electric motor cleaner; brake cleaners) Section 4.2.4.1 Aerosol Cleaners for Motors, Coils, Electrical Parts, Cables, Stainless Steel and marine Equipment, and Wire and Ignition Demoisturants	Inhalation 24-hr	Low Intensity User	**7.7**	39
				Moderate Intensity User	**0.2**	**0.8**
				High Intensity User	**1.3E-02**	**5.2E-02**
			Dermal[1]	Low Intensity User	587	N/A
				Moderate Intensity User	**9.8**	N/A
				High Intensity User	**1.0**	N/A
	Dry cleaning solvent	Section 2.4.2.4.2 and Section 2.4.2.4.3- Dry-Cleaned Articles Section 4.2.4.17 Dry-Cleaned Clothing	Inhalation 24-hr	Stay-at-home Adult and Child	156	486
			Dermal[1]	Assumed dry cleaning Technology (Events, days after cleaning)	User, Half-Body MOE	User, Full-Body MOE
				2nd and 3rd generation (single, 1 day)	**8.6**	**2.9**
				2nd and 3rd generation (single, 2 day)	11	**3.7**
				2nd and 3rd generation (single, 3 day)	15	**4.9**
				4nd and 5th generation (single, 1 day)	49	16
				4nd and 5th generation (single, 2 day)	64	21
				4nd and 5th generation (single, 3 day)	83	28
				4nd and 5th generation (repeat, 1 day)	16	**5.2**
				4nd and 5th generation (repeat, 2 day)	20	**6.7**

Category	Sub Category	Consumer Exposure Scenario	Exposure Route and Duration	Scenario Description	User MOE (benchmark MOE = 10)	Bystander MOE (benchmark MOE = 10)
				4nd and 5th generation (repeat, 3 day)	26	**8.7**
	Automotive care products (*e.g.*, engine degreaser and brake cleaner)	Section 2.4.2.3.1 - Brake Cleaner Section 4.2.4.2 Aerosol Brake Cleaners	Inhalation 24-hr	Low Intensity User	**2.0**	**7.1**
				Moderate Intensity User	**0.2**	**0.8**
				High Intensity User	**4.5E-02**	**0.2**
			Dermal[1]	Low Intensity User	360	N/A
				Moderate Intensity User	11	N/A
				High Intensity User	**1.2**	N/A
		Section 2.4.2.3.2 - Parts Cleaner Section 4.2.4.3 Parts Cleaners	Inhalation 24-hr	Low Intensity User	31	174
				Moderate Intensity User	**0.6**	**3.3**
				High Intensity User	**7.1E-02**	**0.4**
			Dermal[1]	Low Intensity User	142	N/A
				Moderate Intensity User	12	N/A
				High Intensity User	**2.0**	N/A
	Aerosol cleaner	Section 2.4.2.3.3 - Mold Cleaner, Weld Splatter Protectant Section 4.2.4.4 Mold Cleaners, and Weld Splatter Protectants	Inhalation 24-hr	Low Intensity User	15	77
				Moderate Intensity User	**0.3**	**1.6**
				High Intensity User	**1.3E-02**	**5.2E-02**
			Dermal[1]	Low Intensity User	178	N/A
				Moderate Intensity User	**3.7**	N/A
				High Intensity User	**0.6**	N/A
		Section 2.4.2.3.4 - Vandalism Mark & Stain Remover Section 4.2.4.5 - Vandalism Mark & Stain Removers	Inhalation 24-hr	Low Intensity User	**7.7**	39
				Moderate Intensity User	**0.6**	**3.2**
				High Intensity User	**6.5E-02**	**0.3**
			Dermal[1]	Low Intensity User	787	N/A
				Moderate Intensity User	53	N/A
				High Intensity User	**6.6**	N/A
	Non-aerosol cleaner	Section 2.4.2.3.5 - Marble and Stone Polish (liquid)	Inhalation 24-hr	Low Intensity User	**3.3**	17
				Moderate Intensity User	**6.8E-02**	**0.4**

Category	Sub Category	Consumer Exposure Scenario	Exposure Route and Duration	Scenario Description	User MOE (benchmark MOE = 10)	Bystander MOE (benchmark MOE = 10)
		Section 4.2.4.6 Liquid Marble and Stone Polish		High Intensity User	**1.2E-02**	**5.0E-02**
			Dermal[1]	Low Intensity User	294	N/A
				Moderate Intensity User	**4.6**	N/A
				High Intensity User	**0.5**	N/A
Lubricants and greases	Lubricants and greases (*e.g.*, penetrating lubricants, cutting tool coolants, aerosol lubricants)	Section 2.4.2.3.6-Cutting Fluid Section 4.2.4.7 Cutting Fluid	Inhalation 24-hr	Low Intensity User	**8.1**	39
				Moderate Intensity User	**1.3**	**6.7**
				High Intensity User	**0.1**	**0.6**
			Dermal[1]	Low Intensity User	246	N/A
				Moderate Intensity User	62	N/A
				High Intensity User	**4.1**	N/A
		Section 2.4.2.3.7- Spray Lubricant and Penetrating Oil Section 4.2.4.8 Lubricants and Penetrating Oils	Inhalation 24-hr	Low Intensity User	90	435
				Moderate Intensity User	**1.4**	**7.3**
				High Intensity User	**8.0E-02**	**0.4**
			Dermal[1]	Low Intensity User	435	N/A
				Moderate Intensity User	10	N/A
				High Intensity User	**0.6**	N/A
Adhesives and sealant chemicals	Adhesives for arts and crafts	Section 2.4.2.3.8-Adhesives (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant) Section 4.2.4.9 Adhesives	Inhalation 24-hr	Low Intensity User	62	29
				Moderate Intensity User	**2.3**	12
				High Intensity User	**0.1**	**0.5**
			Dermal[1]	Low Intensity User	114	N/A
				Moderate Intensity User	**4.9**	N/A
				High Intensity User	**0.7**	N/A
		Section 2.4.2.3.9-Livestock Grooming Adhesive Section 4.2.4.10 Livestock Grooming Adhesive	Inhalation 24-hr	Low Intensity User	112	539
				Moderate Intensity User	12	64
				High Intensity User	**0.8**	**3.0**
			Dermal[1]	Low Intensity User	258	N/A
				Moderate Intensity User	32	N/A
				High Intensity User	**5.2**	N/A

Category	Sub Category	Consumer Exposure Scenario	Exposure Route and Duration	Scenario Description	User MOE (benchmark MOE = 10)	Bystander MOE (benchmark MOE = 10)
	Light repair adhesives	Section 2.4.2.3.10-Column Adhesive, Caulk and Sealant Section 4.2.4.11 Caulks, Sealants and Column Adhesives	Inhalation 24-hr	Low Intensity User	192	N/E
				Moderate Intensity User	**2.3**	N/E
				High Intensity User	**7.2E-02**	N/E
			Dermal[1]	Low Intensity User	41	N/A
				Moderate Intensity User	**1.1**	N/A
				High Intensity User	**0.5**	N/A
Paints and coatings	Solvent-based paints and coatings	Section 2.4.2.3.11-Outdoor Water Shield (liquid) Section 4.2.4.12 Outdoor Water Shield	Inhalation 24-hr	Low Intensity User	**7.6**	29
				Moderate Intensity User	**1.1**	**3.3**
				High Intensity User	**8.9E-02**	**0.4**
			Dermal[1]	Low Intensity User	**0.3**	N/A
				Moderate Intensity User	**0.2**	N/A
				High Intensity User	**0.1**	N/A
		Section 2.4.2.3.12 - Coatings and primers (aerosol) Section 4.2.4.13 Aerosol Coatings and Primers	Inhalation 24-hr	Low Intensity User	522	13448
				Moderate Intensity User	62	2143
				High Intensity User	**5.9**	209
			Dermal[1]	Low Intensity User	30	N/A
				Moderate Intensity User	**8.6**	N/A
				High Intensity User	**3.2**	N/A
		Section 2.4.2.3.13 - Rust Primer and Sealant (liquid) Section 4.2.4.14 Liquid Primers and Sealants	Inhalation 24-hr	Low Intensity User	10600	128556
				Moderate Intensity User	1163	12434
				High Intensity User	36	229
			Dermal[1]	Low Intensity User	**3.8**	N/A
				Moderate Intensity User	**0.9**	N/A
				High Intensity User	**0.5**	N/A
		Section 2.4.2.3.14-Metallic Overglaze Section 4.2.4.15 Metallic Overglaze	Inhalation 24-hr	Low Intensity User	4372	21107
				Moderate Intensity User	337	1674
				High Intensity User	21	81
			Dermal[1]	Low Intensity User	112	N/A

Category	Sub Category	Consumer Exposure Scenario	Exposure Route and Duration	Scenario Description	User MOE (benchmark MOE = 10)	Bystander MOE (benchmark MOE = 10)
				Moderate Intensity User	**9.4**	N/A
				High Intensity User	**1.5**	N/A
Other Uses	Metal (*e.g.*, stainless steel) and stone polishes	Section 2.4.2.3.15-Marble and Stone Polish (wax) Section 4.2.4.16 Wax Marble and Stone Polish	Inhalation 24-hr	Low Intensity User	**1.1**	**5.3**
				Moderate Intensity User	**0.2**	**0.8**
				High Intensity User	**1.5E-02**	**6.1E-02**
			Dermal[1]	Low Intensity User	40	N/A
				Moderate Intensity User	**4.8**	N/A
				High Intensity User	**0.6**	N/A
	Inks and ink removal products	Ink removal combined under Aerosol Cleaner (vandalism and stain remover); use in printing inks discussed as "other use"	Inhalation 24-hr	Low Intensity User	**7.7**	39
				Moderate Intensity User	**0.6**	**3.2**
				High Intensity User	**6.5E-02**	**0.3**
			Dermal[1]	Low Intensity User	787	N/A
				Moderate Intensity User	53	N/A
				High Intensity User	**6.6**	N/A
	Welding	Identified welding products were anti-spatter aerosol products; therefore, the assessment is included with the assessment of other aerosol products combined under Aerosol Cleaner (weld splatter protectant)	Inhalation 24-hr	Low Intensity User	15	77
				Moderate Intensity User	**0.3**	**1.6**
				High Intensity User	**1.3E-02**	**5.2E-02**
			Dermal[1]	Low Intensity User	178	N/A
				Moderate Intensity User	**3.7**	N/A
				High Intensity User	**0.6**	N/A
	Mold cleaning, release and protectant products	Combined under Aerosol Cleaner (mold cleaner)	Inhalation 24-hr	Low Intensity User	15	77
				Moderate Intensity User	**0.3**	**1.6**
				High Intensity User	**1.3E-02**	**5.2E-02**
			Dermal[1]	Low Intensity User	178	N/A
				Moderate Intensity User	**3.7**	N/A
				High Intensity User	**0.6**	N/A

[1] Dermal exposure presented here are the youth age group (11-15 years). Three age groups are presented for each COU in section 4.2.4. Overall, the differences in the MOEs between age groups are approximately 10% or less.

N/A = not assessed because bystanders are assumed to not have dermal contact with liquid PCE

N/E = not evaluated because dermal exposures to consumers are not expected for these uses because for the caulks, sealants and column adhesives consumer use the area of use was assumed to be outdoors, so bystander exposure was not estimated.

5 RISK DETERMINATION

5.1 Overview

In each risk evaluation under TSCA section 6(b), EPA determines whether a chemical substance presents an unreasonable risk of injury to health or the environment, under the conditions of use. These determinations do not consider costs or other non-risk factors. In making these determinations, EPA considers relevant risk-related factors, including, but not limited to: the effects of the chemical substance on health and human exposure to such substance under the conditions of use (including cancer and non-cancer risks); the effects of the chemical substance on the environment and environmental exposure under the conditions of use; the population exposed (including any potentially exposed or susceptible subpopulations (PESS)); the severity of hazard (including the nature of the hazard, the irreversibility of the hazard); and uncertainties. EPA also takes into consideration the Agency's confidence in the data used in the risk estimate. This includes an evaluation of the strengths, limitations, and uncertainties associated with the information used to inform the risk estimates and the risk characterization. This approach is in keeping with the Agency's final rule, *Procedures for Chemical Risk Evaluation Under the Amended Toxic Substances Control Act* (82 FR 33726).[26]

This section describes the final unreasonable risk determinations for the conditions of use in the scope of the risk evaluation. The final unreasonable risk determinations are based on the risk estimates in the final Risk Evaluation, which may differ from the risk estimates in the draft Risk Evaluation due to peer review and public comments. Therefore, the final unreasonable risk determinations of some conditions of use may differ from those in the draft Risk Evaluation.

5.1.1 Human Health

EPA's risk evaluation identified non-cancer adverse effects from acute and chronic inhalation and dermal exposures to PCE, and cancer from chronic inhalation and dermal exposures to PCE. The health risk estimates for all conditions of use are in Section 4.4.2 (Table 4-125 and Table 4-126).

For the PCE risk evaluation, EPA identified as Potentially Exposed or Susceptible Subpopulations: workers and ONUs, consumers and bystanders, developing fetus (and by extension, women of childbearing age), and those with pre-existing health conditions, higher body fat content, or particular genetic polymorphisms.

EPA evaluated exposures to workers, ONUs, consumer users, and bystanders, using reasonably available monitoring and modeling data for inhalation and dermal exposures, as applicable. For example, EPA assumed that ONUs and bystanders do not have direct contact with PCE; therefore, non-cancer effects and cancer from dermal exposures to PCE are not expected and were not evaluated. The description of the data used for human health exposure is in Section 2.4. Uncertainties in the analysis are discussed in Section 4.4 and considered in the unreasonable risk determination for each condition of use presented below, including the fact that the dermal model used for occupational exposures does not address variability in exposure duration and frequency.

[26] This risk determination is being issued under TSCA section 6(b) and the terms used, such as unreasonable risk, and the considerations discussed are specific to TSCA. Other statutes have different authorities and mandates and may involve risk considerations other than those discussed here.

EPA did not evaluate hazards or exposures to the general population, and as such the unreasonable risk determinations for relevant conditions of use do not account for exposures to the general population. Additional details regarding the general population are in Section 1.4.2.

5.1.1.1 Non-Cancer Risk Estimates

The risk estimates of non-cancer effects (MOEs) refers to adverse health effects associated with health endpoints other than cancer, including to the body's organ systems, such as reproductive/developmental effects, cardiac and lung effects, and kidney and liver effects. The MOE is the point of departure (POD) (an approximation of the no-observed adverse effect level (NOAEL) or benchmark dose level (BMDL)) for a specific health endpoint divided by the exposure concentration for the specific scenario of concern. Section 3.2 presents the PODs for acute and chronic non-cancer effects for PCE and Section 4.2 presents the MOEs for acute and chronic non-cancer effects.

The MOEs are compared to a benchmark MOE. The benchmark MOE accounts for the total uncertainty in a POD, including, as appropriate: (1) the variation in sensitivity among the members of the human population (*i.e.*, intrahuman/intraspecies variability); (2) the uncertainty in extrapolating animal data to humans (*i.e.*, interspecies variability); (3) the uncertainty in extrapolating from data obtained in a study with less-than-lifetime exposure to lifetime exposure (*i.e.*, extrapolating from subchronic to chronic exposure); and (4) the uncertainty in extrapolating from a lowest observed adverse effect level (LOAEL) rather than from a NOAEL. A lower benchmark MOE (*e.g.*, 30) indicates greater certainty in the data (because fewer of the default UFs relevant to a given POD as described above were applied). A higher benchmark MOE (*e.g.*, 1000) would indicate more uncertainty for specific endpoints and scenarios. However, these are often not the only uncertainties in a risk evaluation. The benchmark MOE for acute non-cancer risks for PCE is 100 (accounting for intraspecies and LOAEL to NOAEL variability). The benchmark MOE for chronic non-cancer risks for PCE is 10 (accounting for interspecies and intraspecies variability). Additional information regarding the benchmark MOE is in Section 4.3.

5.1.1.2 Cancer Risk Estimates

Cancer risk estimates represent the incremental increase in probability of an individual in an exposed population developing cancer over a lifetime (excess lifetime cancer risk (ELCR)) following exposure to the chemical. Standard cancer benchmarks used by EPA and other regulatory agencies are an increased cancer risk above benchmarks ranging from 1 in 1,000,000 to 1 in 10,000 (*i.e.*, $1x10^{-6}$ to $1x10^{-4}$) depending on the subpopulation exposed. Generally, EPA considers $1x10^{-6}$ to $1x10^{-4}$ as the appropriate benchmark for the general population, consumer users, and non-occupational PESS.[27]

EPA, consistent with 2017 NIOSH guidance,[28] used $1x10^{-4}$ as the benchmark for the purposes of the unreasonable risk determinations for individuals in industrial and commercial work environments. It is important to note that $1x10^{-4}$ is not a bright line and EPA has discretion to make unreasonable risk determinations based on other cancer risk benchmarks as appropriate.

[27] As an example, when EPA's Office of Water in 2017 updated the Human Health Benchmarks for Pesticides, the benchmark for a "theoretical upper-bound excess lifetime cancer risk" from pesticides in drinking water was identified as 1 in 1,000,000 to 1 in 10,000 over a lifetime of exposure (EPA. Human Health Benchmarks for Pesticides: Updated 2017 Technical Document (pp.5). (EPA 822-R -17 -001). Washington, DC: U.S. Environmental Protection Agency, Office of Water January 2017. https://www.epa.gov/sites/production/files/2015-10/documents/hh-benchmarks-techdoc.pdf). Similarly, EPA's approach under the Clean Air Act to evaluate residual risk and to develop standards is a two-step approach that "includes a presumptive limit on maximum individual lifetime [cancer] risk (MIR) of approximately 1 in 10 thousand" and consideration of whether emissions standards provide an ample margin of safety to protect public health "in consideration of all health information, including the number of persons at risk levels higher than approximately 1 in 1 million, as well as other relevant factors" (54 FR 38044, 38045, September 14, 1989).

[28] NIOSH Current intelligence bulletin 68: NIOSH chemical carcinogen policy (Whittaker et al. 2016).

5.1.1.3 Determining Unreasonable Risk of Injury to Health

Calculated risk estimates (MOEs or cancer risk estimates) can provide a risk profile by presenting a range of estimates for different health effects for different conditions of use. A calculated MOE that is less than the benchmark MOE supports a determination of unreasonable risk of injury to health, based on non-cancer effects. Similarly, a calculated cancer risk estimate that is greater than the cancer benchmark supports a determination of unreasonable risk of injury to health from cancer. Whether EPA makes a determination of unreasonable risk depends upon other risk-related factors, such as the endpoint under consideration, the reversibility of effect, exposure-related considerations (*e.g.*, duration, magnitude, or frequency of exposure, or population exposed), and the confidence in the information used to inform the hazard and exposure values. A calculated MOE greater than the benchmark MOE or a calculated cancer risk estimate less than the benchmark, alone do not support a determination of no unreasonable risk, since EPA may consider other risk-based factors when making an unreasonable risk determination.

When making an unreasonable risk determination based on injury to health of workers (who are one example of PESS), EPA also makes assumptions regarding workplace practices and exposure controls, including engineering controls or use of personal protective equipment (PPE). EPA's decisions for unreasonable risk to workers are based on high-end exposure estimates, in order to capture not only exposures for PESS but also to account for the uncertainties related to whether or not workers are using PPE. However, EPA does not assume that ONUs use PPE. For each condition of use of PCE with an identified risk for workers, EPA assumes, as a baseline, the use of a respirator with an APF of 25 or 50. Similarly, EPA assumes the use of gloves with PF of 10 and 20 in industrial/commercial settings. However, EPA assumes that for some conditions of use, the use of appropriate respirators is not a standard industry practice, based on professional judgement given the burden associated with the use of supplied-air respirators, including the expense of the equipment and the necessity of fit-testing and training for proper use. Similarly, EPA does not assume that as a standard industry practice that workers in some commercial facilities use gloves. Once EPA has applied the appropriate PPE assumption for a particular condition of use in each unreasonable risk determination, in those instances when EPA assumes PPE is used, EPA also assumes that the PPE is used in a manner that achieves the stated APF or PF.

In the PCE risk characterization, neurotoxicity was identified as the most robust and sensitive endpoint for non-cancer adverse effect from acute inhalation and dermal exposures and as the most robust and sensitive endpoint for non-cancer adverse effects from chronic inhalation and dermal exposures for all conditions of use. Additional risks associated with other adverse effects (*e.g.*, kidney, liver, immune system and developmental toxicity) were identified for acute and chronic exposures. Determining unreasonable risk by using neurotoxicity will also include the unreasonable risk from other endpoints resulting from acute or chronic inhalation and dermal exposures.

In accordance with EPA's Guidelines for Carcinogen Risk Assessment, in this risk evaluation EPA concluded that PCE is considered likely to be carcinogenic to workers and ONUs by all routes of exposure and EPA calculated cancer risk estimates with a linear model. The cancer analysis is described in Section 3.2. EPA considered cancer risks estimates from chronic dermal or inhalation exposures in the unreasonable risk determination.

When making a determination of unreasonable risk, the Agency has a higher degree of confidence where uncertainty is low. Similarly, EPA has high confidence in the hazard and exposure characterizations when, for example, the basis for the characterizations is measured or monitoring data or a robust model

and the hazards identified for risk estimation are relevant for conditions of use. Where EPA has made assumptions in the scientific evaluation, whether or not those assumptions are protective is also a consideration. Additionally, EPA considers the central tendency and high-end exposure levels when determining the unreasonable risk. High-end risk estimates (*e.g.*, 95th percentile) are generally intended to cover individuals or sub-populations with greater exposure (PESS) and central tendency risk estimates are generally estimates of average or typical exposure.

EPA may make a determination of no unreasonable risk for conditions of use where the substance's hazard and exposure potential, or where the risk-related factors described previously, lead the Agency to determine that the risks are not unreasonable.

5.1.2 Environment

EPA calculated a risk quotient (RQ) to compare environmental concentrations against an effect level. The environmental concentration is determined based on the levels of the chemical released to the environment (*e.g.*, surface water, sediment, soil, biota) under the conditions of use, based on the fate properties, release potential, and reasonably available environmental monitoring data. The effect level is calculated using concentrations of concern that represent hazard data for aquatic organisms. Section 4.1 provides more detail regarding the risk quotient for PCE.

5.1.2.1 Determining Unreasonable Risk of Injury to the Environment

An RQ equal to 1 indicates that the exposures are the same as the concentration that causes effects. An RQ less than 1, when the exposure is less than the effect concentration, supports a determination that there is no unreasonable risk of injury to the environment. An RQ greater than 1, when the exposure is greater than the effect concentration, supports a determination that there is unreasonable risk of injury to the environment. Consistent with EPA's human health evaluations, other risk-based factors may be considered (*e.g.*, confidence in the hazard and exposure characterization, duration, magnitude, uncertainty) for purposes of making an unreasonable risk determination.

EPA considered the effects on the aquatic organisms. EPA provides estimates for environmental risk in Section 4.1 and Table 4-124. The risk estimates, the environmental effects of PCE, the exposures, physical-chemical properties of PCE, and consideration of uncertainties support EPA's determination that there is no unreasonable risk to the environment from all conditions of use of PCE.

5.2 Risk Determinations for PCE

Table 5-1. Categories and Subcategories of Conditions of Use Included in the Scope of the Risk Evaluation

Life Cycle Stage	Category [a]	Subcategory [b]	Unreasonable Risk	Detailed Risk Determination
Manufacture	Domestic manufacture	Domestic manufacture	Yes	Section 5.2.1.1
	Import	Import	Yes	Section 5.2.1.2
Processing	Processing as a reactant or intermediate	Intermediate in industrial gas manufacturing	Yes	Section 5.2.1.3
		Intermediate in basic organic chemical manufacturing		
		Intermediate in petroleum refineries		
		Reactant use		
	Incorporated into formulation, mixture or reaction product	Cleaning and degreasing products	Yes	Section 5.2.1.4
		Adhesive and sealant products	Yes	Section 5.2.1.5
		Paint and coating products	Yes	Section 5.2.1.6
		Other chemical products and preparations	Yes	Section 5.2.1.7
	Repackaging	Solvent for cleaning or degreasing	Yes	Section 5.2.1.8
		Intermediate		
	Recycling	Recycling	Yes	Section 5.2.1.9
Distribution in commerce	Distribution	Distribution	No	Section 5.2.1.10
Industrial/ Commercial use	Solvents (for cleaning or degreasing) Solvents (for cleaning or degreasing)	Batch vapor degreaser (open-top)	Yes	Section 5.2.1.11
		Batch vapor degreaser (closed-loop)	Yes	Section 5.2.1.12
		In-line vapor degreaser (conveyorized)	Yes	Section 5.2.1.13
		In-line vapor degreaser (web cleaner)	Yes	Section 5.2.1.14
		Cold cleaner	Yes	Section 5.2.1.15
		Aerosol spray degreaser/cleaner	Yes	Section 5.2.1.16
	Lubricants and greases	Lubricants and greases (aerosol lubricants)	Yes	Section 5.2.1.17
		Lubricants and greases (*e.g.*, penetrating lubricants, cutting tool coolants)	No	Section 5.2.1.18

	Adhesive and sealant chemicals	Solvent-based adhesives and sealants	Yes	Section 5.2.1.19
	Paints and coatings including paint and coating removers	Solvent-based paints and coatings	Yes	Section 5.2.1.20
		Maskant for chemical milling	Yes	Section 5.2.1.21
	Processing aids, not otherwise listed	Pesticide, fertilizer and other agricultural chemical manufacturing	Yes	Section 5.2.1.22
	Processing aids, specific to petroleum production	Catalyst regeneration in petrochemical manufacturing	Yes	Section 5.2.1.23
	Cleaning and furniture care products	Cleaners and degreasers (other) (wipe cleaning)	Yes	Section 5.2.1.24
		Cleaners and degreasers (other) (Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	Yes	Section 5.2.1.25
		Cleaners and degreasers (other) (Mold Release)	Yes	Section 5.2.1.26
		Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning	Yes	Section 5.2.1.27
		Dry Cleaning and Spot Cleaning $4^{th}/5^{th}$ Gen Only Dry Cleaning	Yes	Section 5.2.1.28
		Automotive care products (*e.g.*, engine degreaser and brake cleaner)	Yes	Section 5.2.1.29
		Non-aerosol cleaner	Yes	Section 5.2.1.30
	Other uses	Metal (*e.g.*, stainless steel) and stone polishes	Yes	Section 5.2.1.31
		Laboratory chemicals	Yes	Section 5.2.1.32
		Welding	Yes	Section 5.2.1.33
		Textile processing (other)	Yes	Section 5.2.1.34
		Wood furniture manufacturing	Yes	Section 5.2.1.35
		Foundry applications	Yes	Section 5.2.1.36
		Specialty Department of Defense uses	Yes	Section 5.2.1.37
Commercial Use	Other uses	Inks and ink removal products (based on printing)	Yes	Section 5.2.1.38

		Inks and ink removal products (based on photocopying)	Yes	Section 5.2.1.39
		Photographic film	Yes	Section 5.2.1.40
		Mold cleaning, release and protectant products	Yes	Section 5.2.1.41
Consumer use	Cleaning and furniture care products	Cleaners and degreasers (other)	Yes	Section 5.2.1.42
		Dry cleaning solvent	Yes	Section 5.2.1.43
		Automotive care products (brake cleaner)	Yes	Section 5.2.1.44
		Automotive care products (parts cleaner)	Yes	Section 5.2.1.45
		Aerosol cleaning (vandalism mark and stain remover)	Yes	Section 5.2.1.46
		Non-aerosol cleaner (*e.g.*, marble and stone polish)	Yes	Section 5.2.1.47
	Lubricants and greases	Lubricants and greases (cutting tool coolants)	Yes	Section 5.2.1.48
		Lubricants and greases (lubricants and penetrating oil)	Yes	Section 5.2.1.49
	Adhesives and sealant chemicals	Adhesives for arts and crafts (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant)	Yes	Section 5.2.1.50
		Adhesives for arts and crafts (livestock grooming adhesive)	Yes	Section 5.2.1.51
		Adhesives for arts and crafts (column adhesive, caulk, and sealant)	Yes	Section 5.2.1.52
	Paints and coatings	Solvent-based paints and coatings (outdoor water shield (liquid))	Yes	Section 5.2.1.53
		Solvent-based paints and coatings (coatings and primers (aerosol))	Yes	Section 5.2.1.54
		Solvent-based paints and coatings (rust primer and sealant (liquid))	Yes	Section 5.2.1.55
		Solvent-based paints and coatings (metallic overglaze)	Yes	Section 5.2.1.56
	Other uses	Metal (*e.g.*, stainless steel) and stone polishes	Yes	Section 5.2.1.57

		Inks and ink removal products	Yes	Section 5.2.1.58
		Welding	Yes	Section 5.2.1.59
		Mold cleaning, release and protectant products	Yes	Section 5.2.1.60
Disposal	Disposal	Industrial pre-treatment	Yes	Section 5.2.1.61
		Industrial wastewater treatment		
		Publicly owned treatment works (POTW)		
		Underground injection		
		Municipal landfill		
		Hazardous landfill		
		Other land disposal		
		Municipal waste incinerator		
		Hazardous waste incinerator		
		Off-site waste transfer		
		Off-site waste transfer		

[a] These categories of conditions of use appear in the Life Cycle Diagram, reflect CDR codes, and broadly represent conditions of use of PCE in industrial and/or commercial settings and of consumer uses.
[b] These subcategories reflect more specific uses of PCE.
** Although EPA has identified both industrial and commercial uses here for purposes of distinguishing scenarios in this document, the Agency interprets the authority over "any manner or method of commercial use" under TSCA section 6(a)(5) to reach both.

5.2.1 Detailed Unreasonable Risk Determinations by Condition of Use

5.2.1.1 Manufacturing – Domestic Manufacturing – Manufacturing (Domestic manufacture)

Section 6(b)(4)(A) unreasonable risk determination for domestic manufacture of PCE: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the domestic manufacture of PCE presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in

Section 5.1., EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 50, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer effects from chronic dermal exposures at the high-end do not support an unreasonable risk determination.
- Inhalation exposures were assessed during manufacturing using monitoring data submitted by the Halogenated Solvents Industry Alliance (HSIA).
- Dermal exposures were assessed using modeled data.
- Of the six facilities identified as manufacturing PCE for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the domestic manufacture of PCE.

5.2.1.2 Manufacturing – Import – Import (Import)

Section 6(b)(4)(A) unreasonable risk determination for import of PCE: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the import of PCE presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1., EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer effects from chronic dermal exposures at the high-end do not support an unreasonable risk determination.

- For ONUs, the risk estimates of non-cancer effects from acute inhalation exposures and of cancer effects from chronic inhalation exposures at the central tendency do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA also considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Inhalation exposures were assessed based on monitoring data using the repackaging occupational exposure scenario.
- Dermal exposures were assessed using modeled data.
- Of the four facilities identified as importing/repacking PCE for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the import of PCE.

5.2.1.3 Processing – Processing as a reactant or intermediate – Intermediate in industrial gas manufacturing; intermediate in basic organic chemical manufacturing; intermediate in petroleum refineries; reactant use (Processing as a reactant/intermediate)

Section 6(b)(4)(A) unreasonable risk determination for processing of PCE as a reactant/intermediate: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the processing of PCE as a reactant/intermediate presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1., EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer from chronic dermal exposures at the high-end do not support an unreasonable risk determination.

- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Inhalation exposures were assessed using PCE personal breathing zone monitoring data collected at facilities manufacturing PCE as a surrogate for facilities processing PCE as reactant.
- Dermal exposures were assessed using modeled data.
- Of the 18 facilities identified as processing PCE as a reactant for which releases to water were assessed, two facilities had releases indicating risk to aquatic organisms.
- All of the facilities for which water releases were assessed that were identified as processing PCE as a reactant had NPDES permits and exceedances occurred using the direct release to surface water scenario. However, as indicated in Section 2.3.4.3 and Section 4.1.5, there were major limitations in the model associated with uncertainties, such as the lack of flow data based on representative industry sector. The exposures, physical-chemical properties of PCE, and considerations of uncertainties support EPA's determination that there is no unreasonable risk to the environment for the use of PCE in processing of PCE as a reactant/intermediate.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the processing of PCE as a reactant/intermediate.

5.2.1.4 Processing – Incorporation into formulation, mixture, or reaction products – Cleaning and degreasing products (formulation, mixture, or reaction products for cleaning and degreasing products)

Section 6(b)(4)(A) unreasonable risk determination for processing of PCE into formulation, mixture, or reaction product for cleaning and degreasing products: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high-end, chronic inhalation exposures at the central tendency and high-end, and chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the processing of PCE into formulation, mixture, or reaction products for cleaning and degreasing products presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- Two exposure scenarios assessed for Incorporation into Formulation, Mixture, or Reactant Product (processing of formulation of a degreasing solvent and processing of formulation of a

dry cleaning solvent) apply to this condition of use. EPA made its determination based on the processing of a dry cleaning solvent scenario, which was more representative of the condition of use.

- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute inhalation exposures at the high-end and chronic inhalation exposures at the central tendency and high-end support an unreasonable risk determination. Similarly, when assuming use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer from chronic dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the three facilities identified as using PCE for incorporation into formulations for which releases to water were assessed, a single facility had releases indicating risk to aquatic organisms.
- The facility for which water releases were assessed that was identified as processing PCE into a formulation had NPDES permits and exceedances occurred using the indirect release to surface water scenario. However, as indicated in Section 2.3.4.3 and Section 4.1.5, there were major limitations in the model associated with uncertainties, such as the lack of flow data based on representative industry sector. The exposures, the physical-chemical properties of PCE, and consideration of uncertainties support EPA's determination that there is no unreasonable risk to the environment for the use of PCE in processing – incorporation into a formulation, mixture, or reaction products.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the processing of PCE into formulation, mixture, or reaction product for cleaning and degreasing products.

5.2.1.5 Processing – Incorporation into formulation, mixture or reaction product – Adhesive and sealant products (formulation, mixture, or reaction product for adhesive and sealant products)

Section 6(b)(4)(A) unreasonable risk determination for processing of PCE into formulation, mixture, or reaction product for adhesive and sealant products: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and

chronic inhalation exposures and of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the processing of PCE into formulation, mixture, or reaction product for adhesive and sealant products presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- Two exposure scenarios assessed for Incorporation into Formulation, Mixture, or Reactant Product (processing of formulation of a degreasing solvent and processing of formulation of a miscellaneous) apply to this condition of use. EPA made its determination based on the degreasing solvent scenario, which was more representative of the condition of use.
- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer from chronic dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the three facilities identified as using PCE for incorporation into formulations for which releases to water were assessed, a single facility had releases indicating risk to aquatic organisms.
- The facility for which water releases were assessed that was identified as processing PCE into a formulation had NPDES permits and exceedances occurred using the indirect release to surface water scenario. However, as indicated in Section 2.3.4.3 and Section 4.1.5, there were major limitations in the model associated with uncertainties, such as the lack of flow data based on representative industry sector. The exposures, physical-chemical properties of PCE, and consideration of uncertainties support EPA's determination that there is no unreasonable risk to the environment for the use of PCE in processing – incorporation into a formulation, mixture, or reaction products.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the processing of PCE into formulation, mixture, or reaction product for adhesive and sealant products.

5.2.1.6 Processing – Incorporation into formulation, mixture or reaction product – Paint and coating products (formulation, mixture, or reaction product for paint and coating products)

Section 6(b)(4)(A) unreasonable risk determination for processing of PCE into formulation, mixture, or reaction product for paint and coating products: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the processing of PCE into formulation, mixture, or reaction product for paint and coating products presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- Two exposure scenarios assessed for Incorporation into Formulation, Mixture, or Reactant Product (processing of formulation of a degreasing solvent and processing of formulation of a miscellaneous) apply to this condition of use. EPA made its determination based on the degreasing solvent scenario, which was more representative of the condition of use.
- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer from chronic dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the three facilities identified as using PCE for incorporation into formulations for which releases to water were assessed, a single facility had releases indicating risk to aquatic organisms.
- The facility for which water releases were assessed that was identified as processing PCE into a formulation had NPDES permits and exceedances occurred using the indirect release to surface water scenario. However, as indicated in Section 2.3.4.3 and Section 4.1.5, there were major limitations in the model associated with uncertainties, such as the lack of flow data based on representative industry sector. The exposures, physical-chemical properties of PCE, and consideration of uncertainties support EPA's determination that there is no unreasonable risk to

the environment for the use of PCE in processing – incorporation into a formulation, mixture, or reaction products.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the processing of PCE into formulation, mixture, or reaction product for paint and coating products.

5.2.1.7 Processing – Incorporation into formulation, mixture or reaction product – Other chemical products and preparations (formulation, mixture, or reaction product for other chemical products and preparations)

Section 6(b)(4)(A) unreasonable risk determination for processing of PCE into formulation, mixture, or reaction product for other chemical products and preparations: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high-end, chronic inhalation exposures at the central tendency and high-end, and chronic dermal exposures at the high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and cancer effects from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the processing of PCE into formulation, mixture, or reaction product for other chemical products and preparations presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1., EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- EPA made its determination based on the aerosol packing scenario assessed for Incorporation into Formulation, Mixture, or Reactant Product, which used personal breathing zone monitoring data.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute inhalation exposures at the high end, chronic inhalation exposures at the central tendency and high-end, and of cancer effects from chronic inhalation exposures at the high-end support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposure at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer effects from chronic dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation

exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the three facilities identified as using PCE for incorporation into formulations for which releases to water were assessed, a single facility had releases indicating risk to aquatic organisms.
- The facility for which water releases were assessed that was identified as processing PCE into a formulation had NPDES permits and exceedances occurred using the indirect release to surface water scenario. However, as indicated in Section 2.3.4.3 and Section 4.1.5, there were major limitations in the model associated with uncertainties, such as the lack of flow data based on representative industry sector. The exposures, physical-chemical properties of PCE, and consideration of uncertainties support EPA's determination that there is no unreasonable risk to the environment for the use of PCE in processing – incorporation into a formulation, mixture, or reaction products.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the processing of PCE into formulation, mixture, or reaction product for other chemical products and preparations.

5.2.1.8 Processing – Repackaging – Solvents (for cleaning or degreasing); intermediate (repackaging)

Section 6(b)(4)(A) unreasonable risk determination for processing of PCE by repackaging: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposure at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the processing of PCE by repackaging presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:
- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer

effects from chronic dermal exposures at the high-end do not support an unreasonable risk determination.
- For ONUs, the risk estimates of non-cancer effects from acute inhalation exposures and of cancer effects from chronic inhalation exposures at the central tendency do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Inhalation exposures were assessed based on monitoring data using the repackaging occupational exposure scenario.
- Dermal exposures were assessed using modeled data.
- Of the four facilities identified as importing/repacking PCE for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the processing of PCE by repackaging.

5.2.1.9 Processing – Recycling

Section 6(b)(4)(A) unreasonable risk determination for the recycling of PCE: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the recycling of PCE presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1., EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer from chronic dermal exposures at the high-end do not support an unreasonable risk determination.

- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the 13 facilities identified as engaged in waste handling, disposal, treatment, and recycling of PCE for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the recycling of PCE.

5.2.1.10 Distribution in Commerce – Distribution – Distribution

Section 6(b)(4)(A) unreasonable risk determination for distribution in commerce of PCE: Does not present an unreasonable risk of injury to health (workers and ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For the purposes of the unreasonable risk determination, distribution in commerce of PCE is the transportation associated with the moving of PCE in commerce. EPA is assuming that workers and ONUs will not be handling PCE because the loading and unloading activities are associated with other conditions of use and EPA assumes transportation of PCE is in compliance with existing regulations for the transportation of hazardous materials (49 CFR 172). Emissions are therefore minimal during transportation, so there is limited exposure (with the exception of spills and leaks, which are outside the scope of the risk evaluation). Based on the limited emissions and exposures from the transportation of chemicals, EPA determines there is no unreasonable risk of injury to health (workers and ONUs) or to the environment (aquatic organisms) from the distribution in commerce of PCE.

5.2.1.11 Industrial/Commercial Use – Solvents (for cleaning or degreasing) – Batch vapor degreaser (open-top) (solvent for open-top batch vapor degreasing)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a solvent for open-top batch vapor degreasing: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation at the high-end and chronic dermal exposures at the central tendency and high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high-end, chronic inhalation exposures at the central tendency and high-end, and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a solvent for open-top batch vapor degreasing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end support an unreasonable risk determination. Similarly, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposure at the high-end do not support an unreasonable risk determination.
- Inhalation exposures for workers and ONUs were assessed using monitoring data from NIOSH investigations at five sites using PCE as a degreasing solvent in OTVDs. Due to the large variety in shop types that may use PCE as a vapor degreasing solvent, it is unclear how representative these data are of a "typical" shop.
- Dermal exposures were assessed using modeled data.
- Of the 4,836 facilities identified as using PCE as a solvent for open-top batch vapor degreasing for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE as a solvent for open-top batch vapor degreasing.

5.2.1.12 Industrial/Commercial Use – Solvents (for cleaning or degreasing) – Batch vapor degreaser (closed-loop) (Solvent for closed-loop batch vapor degreasing)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a solvent for closed-loop batch vapor degreasing: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposure at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that industrial and commercial use of PCE as a solvent for closed-loop batch vapor degreasing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of

PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For workers, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposure at the central tendency and high-end and of cancer from chronic dermal exposure at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- Inhalation exposures for workers and ONUs were assessed using monitoring data from NIOSH investigations at two sites using PCE as a degreasing solvent in closed-loop batch vapor degreasers. Due to the large variety in shop types that may use PCE as a vapor degreasing solvent, it is unclear how representative these data are of a "typical" shop.
- Dermal exposures were assessed using modeled data.
- Of the 25,423 facilities identified as using PCE as a solvent for closed-loop batch vapor degreasing for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE as a solvent for closed-loop batch vapor degreasing.

5.2.1.13 Industrial/Commercial Use – Solvents (for cleaning or degreasing) – In-line vapor degreaser (conveyorized) (Solvent for in-line conveyorized vapor degreasing)

Section 6(b)(4)(A) unreasonable risk determination for industrial and commercial use of PCE as a solvent for in-line conveyorized vapor degreasing: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and chronic dermal exposures at the central tendency and high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation exposures at the central tendency and high-end and dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the central tendency and high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a solvent for in-line conveyorized vapor degreasing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the central tendency and high-end support an unreasonable risk determination. Similarly, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposure at the high-end do not support an unreasonable risk determination.
- EPA assessed inhalation exposures during conveyorized degreasing using the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model. Workers' risk estimates are based on concentrations in the near-field where the conveyorized degreasing work occurs, and ONU exposures are based on concentrations in the far-field, away from the conveyorized degreaser.
- Dermal exposures were assessed using modeled data.
- Of the 445 facilities identified as using PCE as a solvent for in-line conveyorized vapor degreasing for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE as a solvent for in-line conveyorized vapor degreasing.

5.2.1.14 Industrial/Commercial Use – Solvents (for cleaning or degreasing) – In-line vapor degreaser (web degreaser) (Solvent for in-line web cleaner vapor degreasing)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a solvent for in-line web cleaner vapor degreasing: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high-end, chronic inhalation exposures at the central tendency and high-end, and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a solvent for in-line web cleaner vapor degreasing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For workers, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposure at the central tendency and high-end and of cancer from chronic dermal exposure at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at

the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.

- EPA assessed inhalation exposures during web degreasing using the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model. Workers' estimates are based on concentrations in the near-field where the web degreasing work occurs, and ONU exposures are based on concentrations in the far-field, away from the web degreaser.
- Dermal exposures were assessed using modeled data.
- Of the 445 facilities identified as using PCE as a solvent for in-line web cleaner vapor degreasing for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE as a solvent for in-line web cleaner vapor degreasing.

5.2.1.15 Industrial/Commercial Use – Solvents (for cleaning or degreasing) – Cold cleaner (Solvent for cold cleaning)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a solvent for cold cleaning: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a solvent for cold cleaning presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For workers, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- Inhalation exposures for workers were assessed using monitoring data supplemented by the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model. The estimates based on monitoring data only include values for workers as monitoring data for ONUs were not identified. To account for lack of

monitoring data for ONUs, EPA considered risk estimates from exposure modeling when determining ONU risk.
- EPA's inhalation exposure modeling is based on a near-field/far-field approach. Worker estimates are based on concentrations in the near-field where the cold cleaning work occurs, and ONU exposures are based on concentrations in the far-field away from the cold cleaning machine.
- Dermal exposures were assessed using modeled data.
- Release data for cold cleaning are included with the release estimates for batch open-top vapor degreasing. Of the 4,836 facilities identified as using PCE as a solvent for open-top batch vapor degreasing for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE as a solvent for cold cleaning.

5.2.1.16 Industrial/Commercial Use – Solvents (for cleaning or degreasing) – Aerosol spray degreaser/cleaner (Solvent for aerosol spray degreaser/cleaner)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a solvent for aerosol spray degreaser/cleaner: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a solvent for aerosol spray degreaser/cleaner presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):
- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- Inhalation exposures for workers were assessed using monitoring data supplemented by the Brake Servicing Near-Field/Far-Field inhalation Exposure Model. The estimates based on monitoring data only include values for workers as monitoring data for ONUs were not identified. To account for lack of monitoring data for ONUs, EPA considered risk estimates from exposure modeling when determining ONU risk.
- EPA's inhalation exposure modeling is based on a near-field/far-field approach, where a vapor generation source located inside the near-field diffuses into the surrounding environment.

Workers are assumed to be exposed to PCE vapor concentrations in the near-field, while ONUs are exposed at concentrations in the far-field.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA does not expect releases containing PCE to water from facilities that use PCE as a solvent for aerosol spray degreaser/cleaner.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE as a solvent for aerosol spray degreaser/cleaner.

5.2.1.17 Industrial/Commercial Use – Lubricants and greases – Lubricants and greases (aerosol lubricants) (Solvent for aerosol lubricants)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a solvent for aerosol lubricants: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a solvent for aerosol lubricants presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):
- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- Inhalation exposures for workers were assessed using monitoring data supplemented by the Brake Servicing Near-Field/Far-Field inhalation Exposure Model. The estimates based on monitoring data only include values for workers as monitoring data for ONUs were not identified. To account for lack of monitoring data for ONUs, EPA considered risk estimates from exposure modeling when determining ONU risk.
- EPA's inhalation exposure modeling is based on a near-field/far-field approach, where a vapor generation source located inside the near-field diffuses into the surrounding environment. Workers are assumed to be exposed to PCE vapor concentrations in the near-field, while ONUs are exposed at concentrations in the far-field.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA does not expect releases containing PCE to water from facilities that use PCE as a solvent for aerosol lubricants.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE as a solvent for aerosol lubricants.

5.2.1.18 Industrial/Commercial Use – Lubricants and greases – Lubricants and greases (e.g., penetrating lubricants, cutting tool coolants) (Solvent for penetrating lubricants and cutting tool coolants)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a solvent for penetrating lubricants and cutting tool coolants: Does not present an unreasonable risk of injury to health (workers and ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation or dermal exposures at the central tendency and high-end, assuming use of dermal PPE and without assuming use of respirators. In addition, for workers, EPA found that there was no unreasonable risk of cancer from chronic inhalation or chronic dermal exposures at the central tendency and high-end, assuming use of dermal PPE and without assuming use of respirators. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the at the central tendency and high-end. No environmental risks were identified for this condition of use.

EPA's determination that the industrial and commercial use of PCE as a solvent for penetrating lubricants and cutting tool coolants does not present an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- EPA made its determination based on the metalworking fluids occupational exposure scenario.
- EPA assumes workers are unlikely to wear respiratory protection for this condition of use.
- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute and chronic dermal exposures and of cancer from chronic dermal exposures at the high-end do not support the unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Release data for metalworking fluids are included with the release estimates for batch open-top vapor degreasing. Of the 4,836 facilities identified as using PCE as a solvent for open-top batch vapor degreasing for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is no unreasonable risk of injury to health (workers

and ONUs) or to the environment (aquatic organisms) from the industrial and commercial use of PCE as a solvent for penetrating lubricants and cutting tool coolants.

5.2.1.19 Industrial/Commercial Use – Adhesives and sealants – Solvent-based adhesives and sealants

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE solvent-based adhesives and sealants: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in solvent-based adhesives and sealants presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures and of cancer from chronic dermal exposures at the high-end, support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- EPA identified inhalation exposure monitoring data related to the use of PCE-based adhesives, sealants, paints, and coatings. The results in the monitoring data only include values for workers, as monitoring data for ONUs were not identified. To account for this uncertainty when using monitoring data, EPA considered the central tendency estimate when determining ONU risk. Due to the large variety in shop types that may use PCE-based adhesives and coatings, it is unclear how representative these data are of a "typical" site using these products.
- Dermal exposures were assessed using modeled data.
- Of the two facilities identified as using PCE in solvent-based adhesives and sealants for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE in solvent-based adhesives and sealants.

5.2.1.20 Industrial/Commercial Use – Paints and coatings – Solvent-based paints and coatings (Solvent-based paints and coatings)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in solvent-based paints and coatings: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic inhalation and dermal exposures at the high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in solvent-based paints and coatings presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from chronic inhalation exposures at the high-end support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- For ONUs, the risk estimates of non-cancer effects from acute inhalation exposures and of cancer from chronic inhalation exposures at the central tendency do not support an unreasonable risk determination.
- EPA identified inhalation exposure monitoring data related to the use of PCE-based adhesives, sealants, paints, and coatings. The results in the monitoring data only include values for workers as monitoring data for ONUs were not identified. ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical substance but the relative exposure of ONUs to workers in these cases were not quantifiable. To account for this uncertainty when using monitoring data, EPA considered the central tendency estimate when determining ONU risk. Due to the large variety in shop types that may use PCE-based adhesives and coatings, it is unclear how representative these data are of a "typical" site using these products.
- Dermal exposures were assessed using modeled data.
- Of the two facilities identified as using PCE in solvent-based paints and coatings for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in solvent-based paints and coatings.

5.2.1.21 Industrial/Commercial Use – Paints and coatings – Maskant for Chemical Milling

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in maskants for chemical milling: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation at the high-end and from chronic dermal exposures at the central tendency and high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures at the central tendency and high-end, and of cancer from chronic inhalation exposures at the central tendency and high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in maskants for chemical milling presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end support an unreasonable risk determination. Similarly, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures, and of cancer from chronic dermal exposures at the high-end, support an unreasonable risk determination.
- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end does not support an unreasonable risk determination.
- EPA's inhalation exposure estimate is based on personal monitoring data samples, including 86 data points from multiple sources. Monitoring data for workers and ONUs at sites performing maskant operations was obtained from OSHA facility inspections, NIOSH studies, data submitted by public commenters, and data provided to EPA from DoD.
- Dermal exposures were assessed using modeled data.
- Of the five facilities assessed as using PCE in maskants for chemical milling for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in maskants for chemical milling.

5.2.1.22 Industrial/Commercial Use – Processing aids, not otherwise listed – Pesticide, fertilizer and other agricultural chemical manufacturing

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a processing aid in pesticide, fertilizer and other agricultural chemical manufacturing: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the central tendency and high-end, even when assuming use of PPE. Additionally, for workers, EPA found that there was unreasonable risk of cancer from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a processing aid in pesticide, fertilizer and other agricultural chemical manufacturing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end, and of cancer from chronic dermal exposures at the high-end, support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end, do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the twelve facilities identified as using PCE as an industrial processing aid for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE as a processing aid in pesticide, fertilizer and other agricultural chemical manufacturing.

5.2.1.23 Industrial/Commercial Use – Processing aids, specific to petroleum production – Catalyst regeneration in petrochemical manufacturing

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE as a processing aid in catalyst regeneration in petrochemical manufacturing: **Presents an unreasonable risk of injury to health (workers)**; does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. Additionally, for workers, EPA found that there was unreasonable risk of cancer from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE as a processing aid in catalyst regeneration in petrochemical manufacturing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end, and of cancer from chronic dermal exposure at the high-end, support an unreasonable risk determination.
- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures at the high-end, and of cancer from chronic inhalation exposures at the high-end, do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the twelve facilities identified as using PCE as an industrial processing aid for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE as a processing aid in catalyst regeneration in petrochemical manufacturing.

5.2.1.24 Industrial/Commercial Use – Cleaning and furniture care products – Cleaners and degreasers (other) (wipe cleaning)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in wipe cleaning: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures at the high-end, and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in wipe cleaning presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- EPA identified inhalation exposure monitoring data from NIOSH investigations at two sites using PCE for wipe cleaning and stone/metal polish. EPA separately calculated risk estimates for ONUs and workers based on monitoring data. Due to the large variety in shop types that may use PCE as a wipe cleaning solvent, it is unclear how representative these data are of a "typical" shop. EPA does not have a model for estimating exposures from wipe cleaning; therefore, the assessment is based on the identified monitoring data.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA does not expect releases containing PCE to water from facilities that use PCE in wipe cleaning.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in wipe cleaning.

5.2.1.25 Industrial/Commercial Use – Cleaning and furniture care products – Cleaners and degreasers (other) (Other Spot Cleaning/Spot Removers (Including Carpet Cleaning))

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in other spot cleaning/spot removers (including carpet cleaning): **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk of injury to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation at the central tendency and high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in other spot cleaning/spot removers (including carpet cleaning) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- EPA separately calculated risk estimates for ONUs and workers based on monitoring data. EPA identified inhalation exposure monitoring data from a single NIOSH investigation at a garment manufacturer. Worker samples were determined to be any sample taken on a person while directly handling PCE. ONUs samples were determined to be any sample taken on a person in the same location as the PCE use but not handling PCE. ONU exposure data did not distinguish central tendency and high-end. There is some uncertainty in how representative this data are of exposure at other facilities performing carpet cleaning or spot remover tasks.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other industrial uses" and from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE in other spot cleaning/spot removers (including carpet cleaning).

5.2.1.26 Industrial/Commercial Use – Cleaning and furniture care products – Cleaners and degreasers (other) (Mold Release)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in mold release: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end, without assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic

inhalation exposures or of cancer from chronic inhalation at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in mold release presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- For workers, the risk estimates for non-cancer effects from acute and chronic inhalation exposures, and of cancer from chronic inhalation exposures, do not support an unreasonable risk determination.
- Inhalation exposures for workers were assessed using monitoring data. While data for this condition of use are area samples, not worker breathing zone samples, EPA did not identify available data on potential ONU inhalation exposures from this commercial use. ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical substance; however, the relative exposure of ONUs to workers in these cases cannot be quantified. To account for this uncertainty, EPA considered the central tendency estimate when determining ONU risk.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other industrial uses" and from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE in mold release.

5.2.1.27 Industrial/Commercial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in dry cleaning and spot cleaning post-2006 dry cleaning: **Presents an unreasonable risk of injury to health (workers, ONUs, and children of workers present at dry cleaners);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high-end, chronic (neurotoxicity) inhalation exposures at the central tendency and high-end, and cancer from chronic inhalation exposures at the high-end. For children of workers present at dry cleaners,

EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures at the central tendency and high-end. For aquatic organisms, EPA found that there was no unreasonable risk.

EPA's determination that the industrial and commercial use of PCE in dry cleaning and spot cleaning post-2006 dry cleaning presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- EPA made its determination on workers using monitoring data. Because the monitoring data only contained one data point representing an ONU for this scenario, EPA made its determination on ONUs using modeled data. Modeled ONU exposures are based on concentrations in the far-field which corresponds to any area outside the near-field zones.
- EPA separately evaluated risks to consumers from dry-cleaned articles as part of the condition of use, Consumer Use – Cleaning and furniture care products – Dry cleaning solvent, in Section 5.2.1.43.
- Dermal exposures were assessed using modeled data.
- Of the facilities identified as using PCE in dry cleaning for which releases to water were assessed, including two industrial and five commercial dry cleaning modeled releases (one of which was based on data from 12,822 facilities), no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers, ONUs, and children of workers present at dry cleaners) from the industrial and commercial use of PCE in dry cleaning and spot cleaning post-2006 dry cleaning.

5.2.1.28 Industrial/Commercial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning $4^{th}/5^{th}$ Gen Only Dry Cleaning

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in dry cleaning and spot cleaning $4^{th}/5^{th}$ gen only dry cleaning: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs and children of workers present at dry cleaners); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation at the central tendency. For children of workers present at dry cleaners, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation

exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in dry cleaning and spot cleaning $4^{th}/5^{th}$ gen only dry cleaning presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- EPA based its risk determination on monitoring data. When comparing the model results to the fourth/fifth generation monitoring data results for workers, the model high-end and central tendency are both an order of magnitude greater than the monitoring data. This is expected as the model captures exposures from facilities with third and fourth/fifth generation machines.
- EPA separately evaluated risks to consumers from dry-cleaned articles as part of the condition of use, Consumer Use – Cleaning and furniture care products – Dry cleaning solvent, in Section 5.2.1.43.
- Dermal exposures were assessed using modeled data.
- Of the facilities identified as using PCE in dry cleaning for which releases to water were assessed, including two industrial and five commercial dry cleaning modeled releases (one of which was based on data from 12,822 facilities), no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE in dry cleaning and spot cleaning $4^{th}/5^{th}$ gen only dry cleaning.

5.2.1.29 Industrial/Commercial Use – Cleaning and furniture care products – Automotive care products (e.g., engine degreaser and brake cleaner)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in automotive care products (*e.g.*, engine degreaser and brake cleaner): **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures at the high-end, and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in automotive care products (*e.g.*, engine degreaser and brake cleaner) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- Inhalation exposures for workers were assessed using monitoring data supplemented by the Brake Servicing Near-Field/Far-Field inhalation Exposure Model. The estimates based on monitoring data only include values for workers as monitoring data for ONUs were not identified. To account for lack of monitoring data for ONUs, EPA considered risk estimates from exposure modeling when determining ONU risk.
- EPA's inhalation exposure modeling is based on a near-field/far-field approach, where a vapor generation source located inside the near-field diffuses into the surrounding environment. Workers are assumed to be exposed to PCE vapor concentrations in the near-field, while ONUs are exposed at concentrations in the far-field.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA does not expect releases containing PCE to water from facilities that use PCE in automotive care products (*e.g.*, engine degreaser and brake cleaner).

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in automotive care products (*e.g.*, engine degreaser and brake cleaner).

5.2.1.30 Industrial/Commercial Use – Cleaning and furniture care products – Non-aerosol cleaner

Section 6(b)(4)(A) unreasonable risk determination of PCE for the industrial and commercial use in non-aerosol cleaner: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in non-aerosol cleaner presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the

environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- Inhalation exposure for workers and ONUs were assessed using monitoring data from NIOSH investigations at two sites using PCE for wipe cleaning and metal/stone polish. EPA separately calculated risk estimates for ONUs and workers based on monitoring data. Due to the large variety in shop types that may use PCE as a wipe cleaning solvent, it is unclear how representative these data are of a "typical" shop. EPA does not have a model for estimating exposures from wipe cleaning; therefore, the assessment is based on the identified monitoring data.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA does not expect releases containing PCE to water from facilities that use PCE in non-aerosol cleaner.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in non-aerosol cleaner.

5.2.1.31 Industrial/Commercial Use – Other uses – Metal (e.g., stainless steel) and stone polishes

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in metal (*e.g.*, stainless steel) and stone polishes: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in metal (*e.g.*, stainless steel) and stone polishes presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- Inhalation exposures for workers and ONUs were assessed using monitoring data from NIOSH investigations at two sites using PCE for wipe cleaning and metal/stone polish. EPA separately calculated risk estimates for ONUs and workers based on monitoring data. Due to the large variety in shop types that may use PCE as a wipe cleaning solvent, it is unclear how

representative these data are of a "typical" shop. EPA does not have a model for estimating exposures from wipe cleaning; therefore, the assessment is based on the identified monitoring data.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA does not expect releases containing PCE to water from facilities that use PCE in metal (*e.g.*, stainless steel) and stone polishes.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in metal (*e.g.*, stainless steel) and stone polishes.

5.2.1.32 Industrial/Commercial Use – Other uses – Laboratory chemicals

Section 6(b)(4)(A) unreasonable risk determination for the industrial/commercial use of PCE in laboratory chemicals: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposure at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that industrial and commercial use of PCE in laboratory chemicals presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):
- For workers, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposure at the central tendency and high-end and of cancer from chronic dermal exposure at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposure at the high-end do not support an unreasonable risk determination.
- While EPA quantitatively and qualitatively assessed worker inhalation exposures to PCE during industrial and commercial use in laboratory chemicals, EPA has low confidence in the quantitative assessment. Due to the expected safety practices when using chemicals in a laboratory setting, PCE is expected to be applied in small amounts under a fume hood, thus reducing the potential for inhalation exposures. Based on the low confidence in the quantitative assessment and the expected limited exposure to use of PCE in laboratory chemicals, inhalation exposures to workers and ONUs do not support an unreasonable risk determination.
- Dermal exposures were assessed using modeled data.

- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other industrial uses" and from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the industrial and commercial use of PCE in laboratory chemicals.

5.2.1.33 Industrial/Commercial Use – Other uses – Welding

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in welding: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and chronic dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in welding presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- Inhalation exposures for workers were assessed using monitoring data supplemented by the Brake Servicing Near-Field/Far-Field inhalation Exposure Model. The estimates based on monitoring data only include values for workers as monitoring data for ONUs were not identified. To account for lack of monitoring data for ONUs, EPA considered risk estimates from exposure modeling when determining ONU risk.
- EPA's inhalation exposure modeling is based on a near-field/far-field approach, where a vapor generation source located inside the near-field diffuses into the surrounding environment. Workers are assumed to be exposed to PCE vapor concentrations in the near-field, while ONUs are exposed at concentrations in the far-field.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA does not expect releases containing PCE to water from facilities that use PCE in welding.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in welding.

5.2.1.34 Industrial/Commercial Use – Other uses – Textile processing (other) (Other textile processing)

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in other textile processing: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures at the high-end and from chronic dermal exposures at the central tendency and high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in other textile processing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Inhalation exposures were assessed using monitoring data from OSHA facility inspections.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other industrial uses" and from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in other textile processing.

5.2.1.35 Industrial/Commercial Use – Other uses – Wood furniture manufacturing

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in wood furniture manufacturing: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high-end and from chronic inhalation and chronic dermal exposures at the central tendency and high end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures at the central tendency, and of cancer from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in wood furniture manufacturing presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation and of cancer from chronic inhalation exposures at the high-end support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators when APF of 25 and gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Inhalation exposures were assessed using monitoring data from OSHA facility inspections.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other industrial uses" and from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in wood furniture manufacturing.

5.2.1.36 Industrial/Commercial Use – Other uses – Foundry applications

Section 6(b)(4)(A) unreasonable risk determination for the industrial and commercial use of PCE in foundry applications: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and chronic dermal exposures at the central tendency and high-end, even when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation at the central tendency and high-end and from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures at the central tendency, and of cancer from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in foundry applications presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation and of cancer from chronic inhalation exposures at the high-end support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators when APF of 25 and gloves with PF of 10, the risk estimates of non-cancer effects from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Inhalation exposures were assessed using monitoring data from OSHA facility inspections.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other industrial uses" and from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in foundry applications.

5.2.1.37 Industrial/Commercial Use – Other uses – Specialty Department of Defense Uses (Oil Analysis and Water Pipe Repair)

Section 6(b)(4)(A) unreasonable risk determination for industrial and commercial use of PCE in specialty Department of Defense uses: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the central tendency and high-end, when assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic dermal exposures at the high-end, when assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the industrial and commercial use of PCE in specialty Department of Defense uses presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer effects from chronic dermal exposures at the central tendency and high-end and of cancer from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination. Similarly, when assuming the use of gloves with PF of 10, the risk estimates of non-cancer from acute dermal exposures at the high-end do not support an unreasonable risk determination.
- EPA did not separately calculate risk estimates for ONUs and workers. There is uncertainty in the ONU risk estimate since the data did not distinguish between worker and ONU inhalation exposure estimates. ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical substance; however, the relative exposure of ONUs to workers in these cases cannot be quantified. To account for this uncertainty, EPA considered the central tendency estimate when determining ONU risk.
- Inhalation exposures were assessed using monitoring data for oil analysis and water pipe repair provided by the DoD.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other industrial uses" and from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the industrial and commercial use of PCE in specialty Department of Defense uses.

5.2.1.38 Commercial Use – Other uses – Inks and ink removal products (based on printing)

Section 6(b)(4)(A) unreasonable risk determination for commercial use of PCE in other inks and ink removal products (based on printing): **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the commercial use of PCE in inks and ink removal products (based on printing) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- EPA did not separately calculate risk estimates for ONUs and workers. There is uncertainty in the ONU risk estimate since the data did not distinguish between worker and ONU inhalation exposure estimates. ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical substance; however, the relative exposure of ONUs to workers in these cases cannot be quantified. To account for this uncertainty, EPA considered the central tendency estimate when determining ONU risk.
- Inhalation exposures were assessed using monitoring data.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the commercial use of PCE in inks and ink removal products (based on printing).

5.2.1.39 Commercial Use – Other uses – Inks and ink removal products (based on photocopying)

Section 6(b)(4)(A) unreasonable risk determination for commercial use of PCE for other uses – inks and ink removal products (based on photocopying): **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic dermal exposures and of cancer from chronic dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the commercial use of PCE in inks and ink removal products (based on photocopying) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- For workers, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination.
- EPA did not separately calculate risk estimates for ONUs and workers. There is uncertainty in the ONU risk estimate since the data did not distinguish between worker and ONU inhalation exposure estimates. ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical substance; however, the relative exposure of ONUs to workers in these cases cannot be quantified. To account for this uncertainty, EPA considered the central tendency estimate when determining ONU risk.
- Inhalation exposures were assessed using monitoring data.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the commercial use of PCE in ink and ink removal products (based on photocopying).

5.2.1.40 Commercial Use – Other uses – Photographic film

Section 6(b)(4)(A) unreasonable risk determination for commercial use of PCE for photographic film: **Presents an unreasonable risk of injury to health (workers and ONUs);** does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. In addition, for workers, EPA found that there was unreasonable risk of cancer from chronic inhalation and dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from

chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the commercial use of PCE for photographic film presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- EPA did not separately calculate risk estimates for ONUs and workers. There is uncertainty in the ONU risk estimate since the data did not distinguish between worker and ONU inhalation exposure estimates. ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical substance; however, the relative exposure of ONUs to workers in these cases cannot be quantified. To account for this uncertainty, EPA considered the central tendency estimate when determining ONU risk.
- Inhalation exposures were assessed using monitoring data.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers and ONUs) from the commercial use of PCE for photographic film.

5.2.1.41 Commercial Use – Other uses – Mold cleaning, release and protectant products

Section 6(b)(4)(A) unreasonable risk determination for commercial use of PCE in mold cleaning, release and protectant products: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic dermal exposures and of cancer from chronic dermal exposures at the central tendency and high-end, without assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures or of cancer from chronic inhalation exposures at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the commercial use of PCE in mold cleaning, release and protectant products presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- EPA assumes workers are unlikely to wear respiratory or dermal protection for this condition of use.
- For workers, the risk estimates of non-cancer effects from acute and chronic inhalation exposures and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination.
- EPA did not separately calculate risk estimates for ONUs and workers. There is uncertainty in the ONU risk estimate since the data did not distinguish between worker and ONU inhalation exposure estimates. ONU inhalation exposures are expected to be lower than inhalation exposures for workers directly handling the chemical substance; however, the relative exposure of ONUs to workers in these cases cannot be quantified. To account for this uncertainty, EPA considered the central tendency estimate when determining ONU risk.
- Inhalation exposures were assessed using monitoring data.
- Dermal exposures were assessed using modeled data.
- EPA did not have release data available for this specific condition of use. EPA used data from seven facilities to assess "other commercial uses." None of the facilities identified had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the commercial use of PCE in mold cleaning, release and protectant products.

5.2.1.42 Consumer Use – Cleaning and furniture care products – Cleaners and degreasers (other)

Section 6(b)(4)(A) unreasonable risk determination for the consumer use of PCE in cleaners and degreasers (other): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use, and from acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in cleaners and degreasers (other) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in cleaners and degreasers (other) were based on modeled risk estimates of 15 aerosol products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of

PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in cleaners and degreasers (other).

5.2.1.43 Consumer Use – Cleaning and furniture care products – Dry cleaning solvent

Section 6(b)(4)(A) unreasonable risk determination for the consumer use of PCE as a dry cleaning solvent: **Presents an unreasonable risk of injury to health (consumers);** does not present an unreasonable risk of injury to health (bystanders).

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from half-body acute dermal exposures 1 day after dry cleaning for 2nd and 3rd generation dry cleaning technologies. For bystanders, EPA found there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures.

EPA's determination that the consumer use of PCE as a dry cleaning solvent presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For consumers, the risk estimates of non-cancer effects from acute inhalation exposures do not support an unreasonable risk determination.
- Risk estimates for consumer use of PCE as a dry cleaning solvent due to off-gassing from recently dry cleaned articles was evaluated for two scenarios: direct dermal contact with clothing to consumers and inhalation exposure to bystanders (stay-at-home adult and child) from article storage in a home closet.
- Modeling was used to estimate dermal and inhalation exposures. Measurements of PCE concentrations in indoor air from storage of recently dry cleaned articles are in good agreement with modeling results. No direct measurements were found for consumer dermal exposure to PCE from dry cleaned fabrics
- Inhalation exposures to consumers and bystanders were evaluated with the Multi-Chamber Concentration and Exposure Model (MCCEM). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the type (generation) of dry cleaning machine used, residual PCE remaining in dry cleaned clothing, fabric type, frequency of dry cleaning events, and number of dry cleaned articles stored.
- Dermal exposures to consumers were evaluated with the CEM (Dermal Dose from Skin Contact with Article). Dermal exposures to consumers result from direct contact with residual PCE in recently dry cleaned articles. The magnitude of dermal exposures depends on several factors, including fabric type, number and proximity of dry cleaning events, total number of dry cleaned articles, total article surface area, the type (generation) of dry cleaning machine used, and number of days elapsed since the fabric was dry cleaned.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers) from the consumer use of PCE as a dry cleaning solvent.

5.2.1.44 Consumer Use – Cleaning and furniture care products – Automotive care products (Brake cleaner)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in automotive care products (brake cleaner): **Presents an unreasonable risk of injury to health (consumers and bystanders)**.

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use, and from acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use.

EPA's determination that the consumer use of PCE in automotive care products (brake cleaner) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in automotive care products (brake cleaner) were based on modeled risk estimates of 14 aerosol products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in automotive care products (brake cleaner).

5.2.1.45 Consumer Use – Cleaning and furniture care products – Automotive care products (Parts cleaner)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in automotive care products (parts cleaner): **Presents an unreasonable risk of injury to health (consumers and bystanders)**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use, and from acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of

non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in automotive care products (parts cleaner) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in automotive care products (parts cleaner) were based on modeled risk estimates of one liquid product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in automotive care products (parts cleaner).

5.2.1.46 Consumer Use – Cleaning and furniture care products – Aerosol cleaner (Vandalism Mark & Stain Remover)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in cleaning and furniture care products – aerosol cleaner (vandalism mark & stain remover): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use, and from acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in aerosol cleaner (vandalism mark and stain remover) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in aerosol cleaner (vandalism mark and stain remover) were based on modeled risk estimates of one aerosol product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on

several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in aerosol cleaner (vandalism mark and stain remover).

5.2.1.47 Consumer Use – Cleaning and furniture care products – Non-aerosol cleaner (e.g., marble and stone polish)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in non-aerosol cleaner (*e.g.*, marble and stone polish): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use, and from acute dermal exposures at the moderate and high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in non-aerosol cleaner (*e.g.*, marble and stone polish) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in non-aerosol cleaner (*e.g.*, marble and stone polish) were based on modeled risk estimates of three liquid products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in non-aerosol cleaner (*e.g.*, marble and stone polish).

5.2.1.48 Consumer Use – Lubricants and greases – Lubricants and greases (cutting fluid)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in lubricants and greases (cutting fluid): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use, and from acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in lubricants and greases (cutting fluid) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in lubricants and greases (cutting fluid) were based on modeled risk estimates of one liquid product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in lubricants and greases (cutting fluid).

5.2.1.49 Consumer Use – Lubricants and greases – Lubricants and greases (Lubricants and Penetrating Oils)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in lubricants and greases (lubricants and penetrating oils): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use, and from acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of

non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in lubricants and greases (lubricants and penetrating oils) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in lubricants and greases (lubricants and penetrating oils) were based on modeled risk estimates of nine aerosol products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in lubricants and greases (lubricants and penetrating oils).

5.2.1.50 Consumer Use – Adhesives and sealant chemicals – Adhesives for arts and crafts (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in adhesives for arts and crafts (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation and acute dermal exposures at the moderate and high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high intensity use.

EPA's determination that the consumer use of PCE in adhesives for arts and crafts (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in adhesives for arts and crafts (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant) were based on modeled risk estimates of 15 liquid products.

- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in adhesives for arts and crafts (includes industrial adhesive, arts and crafts adhesive, gun ammunition sealant)

5.2.1.51 Consumer Use – Adhesives and sealant chemicals – Adhesives for arts and crafts (Livestock Grooming Adhesive)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in adhesives and sealant chemicals – adhesives for arts and crafts (livestock grooming adhesive): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation and acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high intensity use.

EPA's determination that the consumer use of PCE in adhesives for adhesives for arts and crafts (livestock grooming adhesive) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in adhesives for adhesives for arts and crafts (livestock grooming adhesive) were based on modeled risk estimates of one aerosol product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in adhesives for arts and crafts (livestock grooming adhesive).

5.2.1.52 Consumer Use – Adhesives and sealant chemicals – Adhesives for arts and crafts (Column Adhesive, Caulk and Sealant)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in adhesives for arts and crafts (column adhesive, caulk and sealant): **Presents an unreasonable risk of injury to health (consumers);** does not present an unreasonable risk of injury to health (bystanders)**.**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation and acute dermal exposures at the moderate and high intensity use. Bystander exposure was not estimated.

EPA's determination that the consumer use of PCE in adhesives for arts and crafts (column adhesive, caulk and sealant) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Acute inhalation exposure for bystanders was not evaluated, as the consumer area of use was assumed to be similar conditions as outside the home.
- Risk estimates for the consumer use of PCE in adhesives for arts and crafts (column adhesive, caulk and sealant) were based on modeled risk estimates of 16 gel/liquid products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers) from the consumer use of PCE in arts and crafts (column adhesive, caulk and sealant).

5.2.1.53 Consumer Use – Paints and coatings – Solvent-based paints and coatings (Outdoor water shield (liquid))

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in solvent-based paints and coatings (outdoor water shield (liquid)): **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation and acute dermal exposures at the low, moderate, and high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in adhesives for arts and crafts (outdoor water shield (liquid)) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in solvent-based paints and coatings (outdoor water shield (liquid)) were based on modeled risk estimates of one liquid product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in solvent-based paints and coatings (outdoor water shield (liquid)).

5.2.1.54 Consumer Use – Paints and coatings – Solvent-based paints and coatings (Coatings and primers (aerosol))

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in solvent-based paints and coatings (coatings and primers (aerosol)): **Presents an unreasonable risk of injury to health (consumers);** does not present an unreasonable risk of injury to health (bystanders).

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the high intensity use, and from acute dermal exposures at the moderate and high intensity use. For bystanders, EPA there was found no unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use.

EPA's determination that the consumer use of PCE in solvent-based paints and coatings (coatings and primers (aerosol)) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in solvent-based paints and coatings (coatings and primers (aerosol)) were based on modeled risk estimates of 10 aerosol products.

- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers) from the consumer use of PCE in solvent-based paints and coatings (coatings and primers (aerosol)).

5.2.1.55 Consumer Use – Paints and coatings – Solvent-based paints and coatings (Rust Primer and Sealant (liquid))

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in paints and coatings – solvent-based paints and coatings (rust primer and sealant (liquid)): **Presents an unreasonable risk of injury to health (consumers);** does not present an unreasonable risk of injury to health (bystanders).

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute dermal exposures at the low, moderate, and high intensity use. For bystanders, EPA found there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use.

EPA's determination that the consumer use of PCE in solvent-based paints and coatings (rust primer and sealant (liquid)) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For consumers, the risk estimates of non-cancer effects from acute inhalation exposures do not support an unreasonable risk determination.
- Risk estimates for the consumer use of PCE in solvent-based paints and coatings (rust primer and sealant (liquid)) were based on modeled risk estimates of 9 liquid products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers) from the consumer use of PCE in solvent-based paints and coatings (rust primer and sealant (liquid)).

5.2.1.56 Consumer Use – Paints and coatings – Solvent-based paints and coatings (Metallic Overglaze)

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in solvent-based paints and coatings (metallic overglaze): **Presents an unreasonable risk of injury to health (consumers);** does not present an unreasonable risk of injury to health (bystanders).

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute dermal exposures at the high intensity use. For bystanders, EPA found there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use.

EPA's determination that the consumer use of PCE in solvent-based paints and coatings (metallic overglaze) presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- For consumers, the risk estimates of non-cancer effects from acute inhalation exposures do not support an unreasonable risk determination.
- Risk estimates for the consumer use of PCE in solvent-based paints and coatings (metallic overglaze) were based on modeled risk estimates of one liquid product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers) from the consumer use of PCE in solvent-based paints and coatings (metallics overglaze).

5.2.1.57 Consumer Use – Other Uses – Metal (e.g., stainless steel) and stone polishes

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in metal (*e.g.*, stainless steel) and stone polishes: **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use, and from acute dermal exposures at the moderate and high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use.

EPA's determination that the consumer use of PCE in metal (*e.g.,* stainless steel) and stone polishes presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in metal (*e.g.,* stainless steel) and stone polishes were based on modeled risk estimates of one liquid wax product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in metal (*e.g.,* stainless steel) and stone polishes.

5.2.1.58 Consumer Use – Other Uses – Inks and ink removal products

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in other uses – inks and ink removal products: **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the low, moderate, and high intensity use, and from acute dermal exposures at the high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in inks and ink removal products presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in aerosol cleaner (vandalism mark and stain remover) were based on modeled risk estimates of one aerosol product.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Permeability). Dermal exposures to consumers result from dermal contact involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, concentration of PCE in product used, permeability coefficient, and dermal exposure duration. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in inks and ink removal products.

5.2.1.59 Consumer Use – Other Uses – Welding

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in welding: **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation and acute dermal exposures at the moderate and high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in welding presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in aerosol cleaner (mold cleaner, weld splatter protectant) were based on modeled risk estimates of four aerosol products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in welding.

5.2.1.60 Consumer Use – Other Uses – Mold cleaning, release and protectant products

Section 6(b)(4)(A) unreasonable risk determination for consumer use of PCE in mold cleaning, release and protectant products: **Presents an unreasonable risk of injury to health (consumers and bystanders).**

For consumers, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation and acute dermal exposures at the moderate and high intensity use. For bystanders, EPA found there was unreasonable risk of non-cancer effects (neurotoxicity) from acute inhalation exposures at the moderate and high intensity use.

EPA's determination that the consumer use of PCE in mold cleaning, release and protectant products presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects to the benchmarks (Table 4-126) and other considerations. As explained in Section 5.1, EPA also considered the health effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2):

- Risk estimates for the consumer use of PCE in aerosol cleaner (mold cleaner, weld splatter protectant) were based on modeled risk estimates of four aerosol products.
- Inhalation exposures to consumers and bystanders were evaluated with the Consumer Exposure Model Version 2.1 (CEM 2.1). The magnitude of inhalation exposures to consumers and bystanders depends on several factors, including the concentration of PCE in products used, use patterns (including frequency, duration, amount of product used, room of use, and local ventilation), and application methods.
- Dermal exposures to consumers were evaluated with the CEM (Fraction Absorbed). Dermal exposures to consumers result from dermal contact not involving impeded evaporation while using the product. The magnitude of dermal exposures depends on several factors, including skin surface area, film thickness, concentration of PCE in product used, dermal exposure duration, and estimated fractional absorption. The potential for dermal exposures to PCE is limited by several factors including physical-chemical properties of PCE, such as high vapor pressure.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (consumers and bystanders) from the consumer use of PCE in mold cleaning, release and protectant products.

5.2.1.61 Disposal

Section 6(b)(4)(A) unreasonable risk determination for the disposal of PCE: **Presents an unreasonable risk of injury to health (workers);** does not present an unreasonable risk of injury to health (ONUs); does not present an unreasonable risk to the environment (aquatic organisms).

For workers, EPA found that there was unreasonable risk of non-cancer effects (neurotoxicity) from chronic dermal exposures at the high-end, even when assuming use of PPE. For ONUs, EPA found that there was no unreasonable risk of non-cancer effects (neurotoxicity) from acute and chronic inhalation exposures and of cancer from chronic inhalation exposure at the central tendency. For aquatic organisms, EPA found that there was no unreasonable risk of injury.

EPA's determination that the disposal of PCE presents an unreasonable risk is based on the comparison of the risk estimates for non-cancer effects and cancer to the benchmarks (Table 4-125) and the comparison of environmental concentration to the effect level (Table 4-124). As explained in Section 5.1, EPA also considered the health effects of PCE, the environmental effects of PCE, the exposures for the condition of use, and the uncertainties in the analysis (Section 4.2), including uncertainties related to the exposures for ONUs:

- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from chronic dermal exposures at the high-end support an unreasonable risk determination.
- For workers, when assuming the use of gloves with PF of 20, the risk estimates of non-cancer effects from acute dermal exposures and of cancer from chronic dermal exposures at the high-end do not support an unreasonable risk determination.
- For workers, when assuming use of respirators with APF of 25, the risk estimates of non-cancer effects from acute and chronic inhalation exposures at the high-end and of cancer from chronic inhalation exposures at the high-end do not support an unreasonable risk determination.
- Based on EPA's analysis, the data for worker and ONU inhalation exposures could not be distinguished; however, ONU inhalation exposures are assumed to be lower than inhalation exposures for workers directly handling the chemical substance. To account for this uncertainty, EPA considered the workers' central tendency risk estimates from inhalation exposures when determining ONUs' unreasonable risk.
- Dermal exposures were assessed using modeled data.
- Of the 13 facilities identified as engaged in waste handling, disposal, treatment, and recycling of PCE for which releases to water were assessed, no facilities had releases indicating risk to aquatic organisms.

In summary, the risk estimates, the health effects of PCE, the exposures, and consideration of uncertainties support EPA's determination that there is unreasonable risk of injury to health (workers) from the disposal of PCE.

5.3 Changes to the Unreasonable Risk Determination from Draft Risk Evaluation to Final Risk Evaluation

In this final Risk Evaluation, EPA made changes to the unreasonable risk determination for PCE following the publication of the draft Risk Evaluation, as a result of the analysis following peer review and public comments. There are four changes: addition of a determination on the industrial and commercial use of PCE in specialty Department of Defense uses, because the condition of use was not represented under an existing condition of use; the combination of industrial and commercial uses to streamline the risk determination; clarification of the processing as a reactant/intermediate condition of use; and, the addition of clearer unreasonable risk determinations for conditions of use evaluated with multiple exposure scenarios. Details of these changes are below.

In the Draft Risk Evaluation, EPA used monitoring data provided by the Department of Defense from its Defense Occupational and Environmental Health Readiness System – Industrial Hygiene (DOEHRS-IH). For the monitoring data received, two processes, oil analysis and water pipe repair, were not clearly described by the conditions of use assessed in the Draft Risk Evaluation. In this final Risk Evaluation,

EPA has made a determination on these uses under the condition of use "Industrial/Commercial Use – Other uses – Specialty Department of Defense Uses (Oil Analysis and Water Piper Repair)."

EPA uses representative Occupational Exposure Scenarios and Consumer Exposure Scenarios to generate risk estimates. Sometimes the same Exposure Scenario is used for several conditions of use, and sometimes unreasonable risk determinations are based on multiple exposure scenarios. In the Draft Risk Evaluation, EPA separately made determinations for industrial and commercial uses, when many of the uses were represented by the same Occupational Exposure Scenario (*e.g.*, the industrial and commercial use of PCE in dry cleaning and spot cleaning post-2006 dry cleaning). Although EPA identified both industrial and commercial uses for purposes of distinguishing scenarios, the Agency interprets the authority over "any manner or method of commercial use" under TSCA section 6(a)(5) to reach both. In the Final Risk Evaluation, EPA has combined into one risk determination similarly assessed industrial and commercial uses, unless a condition of use was assessed as occurring only in either an industrial or commercial setting. Therefore, whereas the draft Risk Evaluation presented 40 industrial and commercial risk determinations, the Final Risk Evaluation shows 31.

In the Draft Risk Evaluation, the processing of PCE as a reactant/intermediate condition of use included the subcategory "residual or byproduct reused as a reactant." In this Final Risk Evaluation, EPA changed the subcategory "residual or byproduct reused as a reactant" to "reactant use" to clarify that it has made a determination for the processing of PCE for reactant use.

In the Draft Risk Evaluation, EPA made one determination for three conditions of use (consumer use of PCE in inks and ink removal products, welding, and mold cleaning products). However, in this Final Risk Evaluation, EPA better adheres to the conditions of use as they were presented in the Problem Formulation and has made three separate unreasonable risk determinations for these three conditions of use.

Overall, the Draft Risk Evaluation had 68 unreasonable risk determinations, whereas the Final Risk Evaluation determination has 61 unreasonable risk determinations.

Table 5-2. Crosswalk of Use Unreasonable Risk Determinations

Unreasonable Risk Determinations in Final Risk Evaluation	Unreasonable Risk Determinations in Draft Risk Evaluation
• Processing – Processing as a reactant or intermediate – Intermediate in industrial gas manufacturing; intermediate in basic organic chemical manufacturing; intermediate in petroleum refineries; reactant use	• Processing – Processing as a reactant or intermediate – Intermediate in industrial gas manufacturing; intermediate in basic organic chemical manufacturing; intermediate in petroleum refineries; residual or byproduct reused as a reactant
• Industrial/Commercial Use – Solvents (for cleaning or degreasing) – Aerosol spray degreaser/cleaner (Solvent for aerosol spray degreaser/cleaner)	• Industrial Use – Solvents (for cleaning or degreasing) – Aerosol spray degreaser/cleaner • Commercial Use – Cleaning and furniture care products – Aerosol cleaner
• Industrial/Commercial Use – Lubricants and greases – Lubricants and greases (aerosol lubricants) (Solvent for aerosol lubricants)	• Industrial Use – Lubricants and greases – Lubricants and greases (aerosol lubricants) • Commercial Use – Lubricants and greases – Lubricants and greases (aerosol lubricants)
• Industrial/Commercial Use – Lubricants and greases – Lubricants and greases (*e.g.*, penetrating lubricants, cutting tool coolants)	• Industrial – Lubricants and greases – Lubricants and greases (*e.g.*, penetrating lubricants, cutting tool coolants) • Commercial Use – Lubricants and greases – Lubricants and greases (*e.g.*, penetrating lubricants, cutting tool coolants)

Unreasonable Risk Determinations in Final Risk Evaluation	Unreasonable Risk Determinations in Draft Risk Evaluation
(Solvent for penetrating lubricants and cutting tool coolants)	
• Industrial/Commercial Use – Adhesives and sealants – Solvent-based adhesives and sealants	• Industrial Use – Adhesives and sealants – Solvent-based adhesives and sealants • Commercial Use – Adhesives and sealant chemicals – Light repair adhesives
• Industrial/Commercial Use – Paints and coatings – Solvent-based paints and coatings	• Industrial Use – Paints and coatings – Solvent-based paints and coatings • Commercial Use – Paints and coatings – Solvent-based paints and coatings
• Industrial/Commercial Use – Cleaning and furniture care products – Cleaners and degreasers (other) (Other Spot Cleaning/Spot Removers (Including Carpet Cleaning))	• Industrial Use – Other uses – Textile processing (spot cleaning) • Commercial Use – Cleaning and furniture care products – Cleaners and degreasers (other) (Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)) • Commercial Use – Other uses – Carpet cleaning
• Industrial/Commercial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning	• Industrial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning • Commercial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning Post-2006 Dry Cleaning
• Industrial/Commercial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning 4th/5th Gen Only Dry Cleaning	• Industrial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning 4th/5th Gen Only Dry Cleaning • Commercial Use – Cleaning and furniture care products – Dry Cleaning and Spot Cleaning 4th/5th Gen Only Dry Cleaning
• Industrial/Commercial Use – Other uses – Laboratory chemicals	• Industrial Use – Other uses – Laboratory chemicals • Commercial Use – Other uses – Laboratory chemicals
• Industrial/Commercial Use – Other uses – Specialty Department of Defense Uses (Oil Analysis and Water Pipe Repair)	• Industrial/Commercial Use – Other uses
• Consumer Use – Other Uses – Inks and ink removal products • Consumer Use – Other Uses – Welding • Consumer Use – Other Uses – Mold cleaning, release and protectant products	• Consumer Use – Other Uses – Inks and ink removal products; welding; mold cleaning, release and protectant products

5.4 Unreasonable Risk Determination Conclusion

5.4.1 No Unreasonable Risk Determinations

TSCA section 6(b)(4) requires EPA to conduct risk evaluations to determine whether chemical substances present unreasonable risk under their conditions of use. In conducting risk evaluations, "EPA will determine whether the chemical substance presents an unreasonable risk of injury to health or the environment under each condition of use within the scope of the risk evaluation…" 40 CFR 702.47. Pursuant to TSCA section 6(i)(1), a determination of "no unreasonable risk" shall be issued by order and considered to be final agency action. Under EPA's implementing regulations, "[a] determination made by EPA that the chemical substance, under one or more of the conditions of use within the scope of the risk evaluations, does not present an unreasonable risk of injury to health or the environment will be issued by order and considered to be a final Agency action, effective on the date of issuance of the order." 40 CFR 702.49(d).

EPA has determined that the following conditions of use of PCE do not present an unreasonable risk of injury to health or the environment:

- Distribution in commerce (Section 5.2.1.10, Section 4, Section 3, Section 2)
- Industrial and commercial use in lubricants and greases as solvent for penetrating lubricants and cutting tool coolants (Section 5.2.1.18, Section 4, Section 3, Section 2)

This subsection of the final Risk Evaluation therefore constitutes the order required under TSCA section 6(i)(1), and the "no unreasonable risk" determinations in this subsection are considered to be final agency action effective on the date of issuance of this order. All assumptions that went into reaching the determinations of no unreasonable risk for these conditions of use, including any considerations excluded for these conditions of use, are incorporated into this order.

The support for each determination of "no unreasonable risk" is set forth in Section 5.2 of the final Risk Evaluation, "Detailed Unreasonable Risk Determinations by Condition of Use." This subsection also constitutes the statement of basis and purpose required by TSCA section 26(f).

5.4.2 Unreasonable Risk Determinations

EPA has determined that the following conditions of use of PCE present an unreasonable risk of injury to health or the environment:

- Manufacturing (domestic manufacturing)
- Manufacturing (import)
- Processing: as a reactant/intermediate
- Processing: incorporation into formulation, mixture or reaction product in cleaning and degreasing products
- Processing: incorporation into formulation, mixture or reaction product – adhesive and sealant products
- Processing: incorporation into formulation, mixture or reaction product – paint and coating products
- Processing: incorporation into formulation, mixture or reaction product – other chemical products and preparations
- Processing: Repackaging
- Processing: Recycling
- Industrial and commercial use as solvent for open-top batch vapor degreaser
- Industrial and commercial use as solvent for closed-loop batch vapor degreaser
- Industrial and commercial use as solvent for in-line conveyorized vapor degreaser
- Industrial and commercial use as solvent for in-line web cleaner vapor degreaser
- Industrial and commercial use as solvent for cold cleaning
- Industrial and commercial use as solvent for aerosol spray degreaser/cleaner
- Industrial and commercial use as a lubricant and grease in aerosol lubricants
- Industrial and commercial use as an adhesive and sealant in solvent-based adhesives and sealants
- Industrial and commercial use in paints and coatings as solvent-based paints and coatings
- Industrial and commercial use in paints and coatings as a maskant for chemical milling

- Industrial and commercial use as a processing aid in pesticide, fertilizer and other agricultural chemical manufacturing
- Industrial and commercial use as a processing aid in catalyst regeneration in petrochemical manufacturing
- Industrial and commercial use in cleaning and furniture care products in wipe cleaning
- Industrial and commercial use in cleaning and furniture care products in other spot cleaning and spot removers, including carpet cleaning
- Industrial and commercial use in cleaning and furniture care products for mold release
- Industrial and commercial use in cleaning and furniture care products in dry cleaning and spot cleaning post-2006 dry cleaning
- Industrial and commercial use in cleaning and furniture care products in dry cleaning and spot cleaning $4^{th}/5^{th}$ gen only dry cleaning
- Industrial and commercial use in cleaning and furniture care products in automotive care products (*e.g.*, engine degreaser and brake cleaner)
- Industrial and commercial use in cleaning and furniture care products in non-aerosol cleaner
- Industrial and commercial use in metal (*e.g.*, stainless steel) and stone polishes
- Industrial and commercial use in laboratory chemicals
- Industrial and commercial use in welding
- Industrial and commercial use in other textile processing
- Industrial and commercial use in wood furniture manufacturing
- Industrial and commercial use in foundry applications
- Industrial and commercial use in specialty Department of Defense uses (oil analysis and water pipe repair)
- Commercial use in inks and ink removal products (based on printing)
- Commercial use in inks and ink removal products (based on photocopying)
- Commercial use for photographic film
- Commercial use in mold cleaning, release and protectant products
- Consumer use in cleaning and furniture care products in cleaners and degreasers (other)
- Consumer use in cleaning and furniture care products in dry cleaning solvent
- Consumer use in cleaning and furniture care products in automotive care products (brake cleaner)
- Consumer use in cleaning and furniture care products in automotive care products (parts cleaner)
- Consumer use in cleaning and furniture care products in aerosol cleaner (vandalism mark and stain remover)
- Consumer use in cleaning and furniture care products in non-aerosol cleaner (*e.g.*, marble and stone polish)
- Consumer use in lubricants and greases (cutting oils)
- Consumer use in lubricants and greases (lubricants and penetrating oils)
- Consumer use in adhesives for arts and crafts (including industrial adhesive, arts and crafts adhesive, gun ammunition sealant)
- Consumer use in adhesives for arts and crafts (livestock grooming adhesive)
- Consumer use in adhesives for arts and crafts (column adhesive, caulk and sealant)

- Consumer use in paints and coatings as solvent-based paints and coatings (outdoor water shield (liquid))
- Consumer use in paints and coatings as solvent-based paints and coatings (coatings and primers (aerosol))
- Consumer use in paints and coatings as solvent-based paints and coatings (rust primer and sealant (liquid))
- Consumer use in paints and coatings as solvent-based paints and coatings (metallic overglaze)
- Consumer use in metal (*e.g.*, stainless steel) and stone polishes
- Consumer use in inks and ink removal products
- Consumer use in welding
- Consumer use in mold cleaning, release and protectant products
- Disposal

EPA will initiate TSCA section 6(a) risk management actions on these conditions of use as required under TSCA section 6(c)(1). Pursuant to TSCA section 6(i)(2), the "unreasonable risk" determinations for these conditions of use are not considered final agency action.

REFERENCES

Abbas, R; Fisher, JW. (1997). A physiologically based pharmacokinetic model for trichloroethylene and its metabolites, chloral hydrate, trichloroacetate, dichloroacetate, trichloroethanol, and trichloroethanol glucuronide in B6C3F1 mice. Toxicol Appl Pharmacol 147: 15-30. http://dx.doi.org/10.1006/taap.1997.8190

A. C. Products. (2017). Maskants and their use in aerospace: Regulatory compliance of the industry. (EPA-HQ-OPPT-2016-0732-0077). Washington, D.C.: AC Products. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0077

Adgate, JL; Church, TR; Ryan, AD; Ramachandran, G; Fredrickson, AL; Stock, TH; Morandi, MT; Sexton, K. (2004). Outdoor, indoor, and personal exposure to VOCs in children. Environ Health Perspect 112: 1386-1392. http://dx.doi.org/10.1289/ehp.7107

Ahmad, N; Benoit, D; Brooke, L; Call, D; Carlson, A; Defoe, D; Huot, J; Moriarity, A; Richter, J; Shubat, P; Veith, G; Wallbridge, C. (1984). Aquatic toxicity tests to characterize the hazard of volatile organic chemicals in water: A toxicity data summary--Parts I and II (pp. 103 p.). (EPA 600/3-84-009). Duluth, MN: U.S. EPA.

Alberati-Giani, D; Malherbe, P; Kohler, C; Lang, G; Kiefer, V; Lahm, HW; Cesura, AM. (1995). Cloning and characterization of a soluble kynurenine aminotransferase from rat brain: Identity with kidney cysteine conjugate [beta]-lyase. J Neurochem 64: 1448-1455. http://dx.doi.org/10.1046/j.1471-4159.1995.64041448.x

Altmann, L; Böttger, A; Wiegand, H. (1990). Neurophysiological and psychophysical measurements reveal effects of acute low-level organic solvent exposure in humans. Int Arch Occup Environ Health 62: 493-499. http://dx.doi.org/10.1007/BF00381179

Altmann, L; Neuhann, HF; Krämer, U; Witten, J; Jermann, E. (1995). Neurobehavioral and neurophysiological outcome of chronic low-level tetrachloroethene exposure measured in neighborhoods of dry cleaning shops. Environ Res 69: 83-89. http://dx.doi.org/10.1006/enrs.1995.1028

Andersen, A; Barlow, L; Engeland, A; Kjaerheim, K; Lynge, E; Pukkala, E. (1999). Work-related cancer in the Nordic countries [Supplemental Data]. Scand J Work Environ Health 25: 1-116.

Andrys, C; Hanovcova, I; Chylkova, V; Tejral, J; Eminger, S; Prochazkova, J. (1997). Immunological monitoring of dry-cleaning shop workers - exposure to tetrachloroethylene. Cent Eur J Public Health 5: 136-142.

Anttila, A; Pukkala, E; Sallmen, M; Hernberg, S; Hemminki, K. (1995). Cancer incidence among Finnish workers exposed to halogenated hydrocarbons. J Occup Environ Med 37: 797-806. http://dx.doi.org/10.1097/00043764-199507000-00008

Apol, AG. (1981). Health hazard evaluation report no. HETA 81-105-831, Labels West, Inc., Redmond, Washington. (HETA 81-105-831). Cincinnati, OH: National Institute for Occupational Safety and Health.

Aranyi, C; O'Shea, WJ; Graham, JA; Miller, FJ. (1986). The effects of inhalation of organic chemical air contaminants on murine lung host defenses. Fundam Appl Toxicol 6: 713-720. http://dx.doi.org/10.1016/0272-0590(86)90184-3

Aschengrau, A; Gallagher, LG; Winter, MR; Vieira, VM; Janulewicz, PA; Webster, TF; Ozonoff, DM. (2016a). No association between unintentional head injuries and early-life exposure to tetrachloroethylene (PCE)-contaminated drinking water. J Occup Environ Med 58: 1040-1045. http://dx.doi.org/10.1097/JOM.0000000000000850

Aschengrau, A; Janulewicz, PA; White, RF; Vieira, VM; Gallagher, LG; Getz, KD; Webster, TF; Ozonoff, DM. (2016b). Long-term neurotoxic effects of early-life exposure to tetrachloroethylene-contaminated drinking water. 82: 169-179. http://dx.doi.org/10.1016/j.aogh.2016.01.013

Aschengrau, A; Ozonoff, D; Paulu, C; Coogan, P; Vezina, R; Heeren, T; Zhang, Y. (1993). Cancer risk and tetrachloroethylene-contaminated drinking water in Massachusetts. Arch Environ Health 48: 284-292. http://dx.doi.org/10.1080/00039896.1993.9936715

Aschengrau, A; Paulu, C; Ozonoff, D. (1998). Tetrachloroethylene-contaminated drinking water and the risk of breast cancer. Environ Health Perspect 106: 947-953.

Aschengrau, A; Rogers, S; Ozonoff, D. (2003). Perchloroethylene-contaminated drinking water and the risk of breast cancer: Additional results from Cape Cod, Massachusetts, USA. Environ Health Perspect 111: 167-173. http://dx.doi.org/10.1289/ehp.4980

Aschengrau, A; Weinberg, JM; Janulewicz, PA; Gallagher, LG; Winter, MR; Vieira, VM; Webster, TF; Ozonoff, DM. (2009). Prenatal exposure to tetrachloroethylene-contaminated drinking water and the risk of congenital anomalies: A retrospective cohort study. Environ Health 8: 44. http://dx.doi.org/10.1186/1476-069X-8-44

Aschengrau, A; Weinberg, JM; Janulewicz, PA; Romano, ME; Gallagher, LG; Winter, MR; Martin, BR; Vieira, VM; Webster, TF; White, RF; Ozonoff, DM. (2011). Affinity for risky behaviors following prenatal and early childhood exposure to tetrachloroethylene (PCE)-contaminated drinking water: A retrospective cohort study. Environ Health 10: 102. http://dx.doi.org/10.1186/1476-069X-10-102

ATSDR. (1997). Toxicological profile for tetrachloroethylene [ATSDR Tox Profile] (pp. 1-472). (RISKLINE/1998010008). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=265&tid=48

ATSDR. (2014). Toxicological profile for tetrachloroethylene (Draft for public comment). Atlanta, GA: US Department of Health and Human Services, Public Health Service. http://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=265&tid=48

ATSDR. (2019). Toxicological profile for tetrachloroethylene. Atlanta, GA: U.S. Department of Health and Human Services. https://www.atsdr.cdc.gov/ToxProfiles/tp18.pdf

Azimi, M; Bahrami, MR; Rezaei Hachesu, V; Zavar Reza, J; Mihanpour, H; Zare Sakhvidi, MJ; Mostaghaci, M. (2017). Primary DNA Damage in Dry Cleaners with Perchlorethylene Exposure. Int J Occup Environ Med 8: 224-231. http://dx.doi.org/10.15171/ijoem.2017.1089

Bagnell, PC; Ellenberger, HA. (1977). Obstructive jaundice due to a chlorinated hydrocarbon in breast milk. Can Med Assoc J 117: 1047-1048.

Band, PR; Le, ND; Fang, R; Deschamps, M; Gallagher, RP; Yang, P. (2000). Identification of occupational cancer risks in British Columbia: A population-based case-control study of 995 incident breast cancer cases by menopausal status, controlling for confounding factors. J Occup Environ Med 42: 284-310. http://dx.doi.org/10.1097/00043764-200003000-00010

Barrows, ME; Petrocelli, SR; Macek, KJ; Carroll, JJ. (1980). Bioconcentration and elimination of selected water pollutants by bluegill sunfish (Lepomis macrochirus). In R Haque (Ed.), (pp. 379-392). Ann Arbor, MI: Ann Arbor Science.

Bartsch, H; Malaveille, C; Barbin, A; Planche, G. (1979). Mutagenic and alkylating metabolites of halo-ethylenes, chlorobutadienes and dichlorobutenes produced by rodent or human liver tissues: Evidence for oxirane formation by P450-linked microsomal mono-oxygenases. Arch Toxicol 41: 249-277. http://dx.doi.org/10.1007/BF00296896

Barul, C; Fayossé, A; Carton, M; Pilorget, C; Woronoff, AS; Stücker, I; Luce, D; group, Is. (2017). Occupational exposure to chlorinated solvents and risk of head and neck cancer in men: a population-based case-control study in France. Environ Health 16: 77. http://dx.doi.org/10.1186/s12940-017-0286-5

Batterman, S; Jia, C; Hatzivasilis, G. (2007). Migration of volatile organic compounds from attached garages to residences: A major exposure source. Environ Res 104: 224-240. http://dx.doi.org/10.1016/j.envres.2007.01.008

Beaudreuil, S; Lasfargues, G; Laueriere, L; El Ghoul, Z; Fourquet, F; Longuet, C; Halimi, JM; Nivet, H; Buchler, M. (2005). Occupational exposure in ANCA-positive patients: A case-control study. Kidney Int 67: 1961-1966. http://dx.doi.org/10.1111/j.1523-1755.2005.00295.x

Beliles, RP; Brusick, DJ; Mecler, FJ. (1980). Teratogenic-mutagenic risk of workplace contaminants: trichloroethylene, perchloroethylene, and carbon disulfide. (210-77-0047). Cincinnati, OH: National Institute for Occupation Safety and Health.

Benane, S; Blackman, C; House, D. (1996). Effect of perchloroethylene and its metabolites on intercellular communication in clone 9 rat liver cells. J Toxicol Environ Health 48: 427-437.

Bergamaschi, E; Mutti, A; Bocchi, MC; Alinovi, R; Olivetti, G; Ghiggeri, GM; Franchini, I. (1992). Rat model of perchloroethylene-induced renal dysfunctions. Environ Res 59: 427-439. http://dx.doi.org/10.1016/S0013-9351(05)80046-5

Berger, T; Horner, CM. (2003). In vivo exposure of female rats to toxicants may affect oocyte quality. Reprod Toxicol 17: 273-281. http://dx.doi.org/10.1016/S0890-6238(03)00009-1

Berman, E; Schlicht, M; Moser, VC; Macphail, RC. (1995). A multidisciplinary approach to toxicological screening: I. Systemic toxicity. J Toxicol Environ Health 45: 127-143. http://dx.doi.org/10.1080/15287399509531986

Besson, H; Brennan, P; Becker, N; Nieters, A; De Sanjosé, S; Font, R; Maynadié, M; Foretova, L; Cocco, PL; Staines, A; Vornanen, M; Boffetta, P. (2006). Tobacco smoking, alcohol drinking and non-Hodgkin's lymphoma: A European multicenter case-control study (Epilymph). Int J Cancer 119: 901-908. http://dx.doi.org/10.1002/ijc.21913

Blair, A; Decoufle, P; Grauman, D. (1979). Causes of death among laundry and dry cleaning workers. Am J Public Health 69: 508-511.

Blair, A; Petralia, SA; Stewart, PA. (2003). Extended mortality follow-up of a cohort of dry cleaners. Ann Epidemiol 13: 50-56. http://dx.doi.org/10.1016/S1047-2797(02)00250-8

Blando, JD; Schill, DP; De La Cruz, MP; Zhang, L; Zhang, J. (2010). Preliminary study of propyl bromide exposure among New Jersey dry cleaners as a result of a pending ban on perchloroethylene. J Air Waste Manag Assoc 60: 1049-1056. http://dx.doi.org/10.3155/1047-3289.60.9.1049

Boice, JD, Jr.; Marano, D; Fryzek, J; Sadler, C; McLaughlin, JK. (1999). Mortality among aircraft manufacturing workers. Occup Environ Med 56: 581-597. http://dx.doi.org/10.1136/oem.56.9.581

Bois, FY; Gelman, A; Jiang, J; Maszle, DR; Zeise, L; Alexeef, G. (1996). Population toxicokinetics of tetrachloroethylene. Arch Toxicol 70: 347-355. http://dx.doi.org/10.1007/s002040050284

Bond, G; McLaren, E; Sabel, F; Bodner, K; Lipps, T; Cook, R. (1990). Liver and biliary tract cancer among chemical workers. Am J Ind Med 18: 19-24.

Bouwer, EJ; McCarty, PL. (1982). Removal of trace chlorinated organic compounds by activated carbon and fixed-film bacteria. Environ Sci Technol 16: 836–843. http://dx.doi.org/10.1021/es00106a003

Bouwer, EJ; Rittmann, BE; McCarty, PL. (1981). Anaerobic degradation of halogenated 1- and 2-carbon organic compounds. Environ Sci Technol 15: 596-599. http://dx.doi.org/10.1021/es00087a012

Bove, FJ; Fulcomer, MC; Klotz, JB; Esmart, J; Dufficy, EM; Savrin, JE. (1995). Public drinking water contamination and birth outcomes. Am J Epidemiol 141: 850-862. http://dx.doi.org/10.1093/oxfordjournals.aje.a117521

Bove, FJ; Ruckart, PZ; Maslia, M; Larson, TC. (2014a). Electronic supplementary material: Evaluation of mortality among marines and navy personnel exposed to contaminated drinking water at USMC base Camp Lejeune: A retrospective cohort study. Environ Health 13.

Bove, FJ; Ruckart, PZ; Maslia, M; Larson, TC. (2014b). Evaluation of mortality among marines and navy personnel exposed to contaminated drinking water at USMC base Camp Lejeune: A retrospective cohort study. Environ Health 13: 10. http://dx.doi.org/10.1186/1476-069X-13-10

Boverhof, DR; Krieger, SM; Hotchkiss, J; Stebbins, KE; Thomas, J; Woolhiser, MR. (2013). Assessment of the immunotoxic potential of trichloroethylene and perchloroethylene in rats following inhalation exposure. J Immunotoxicol 10: 311-320. http://dx.doi.org/10.3109/1547691X.2012.735275

Boyes, WK; Bercegeay, M; Oshiro, WM; Krantz, QT; Kenyon, EM; Bushnell, PJ; Benignus, VA. (2009). Acute perchloroethylene exposure alters rat visual-evoked potentials in relation to brain concentrations. Toxicol Sci 108: 159-172. http://dx.doi.org/10.1093/toxsci/kfn265

Brack, W; Rottler, H. (1994). Toxicity testing of highly volatile chemicals with green algae: A new assay. Environ Sci Pollut Res Int 1: 223-228.

Briving, C; Jacobson, I; Hamberger, A; Kjellstrand, P; Haglid, KG; Rosengren, LE. (1986). Chronic effects of perchloroethylene and trichloroethylene on the gerbil brain amino acids and glutathione. Neurotoxicology 7: 101-108.

Brodkin, CA; Daniell, W; Checkoway, H; Echeverria, D; Johnson, J; Wang, K; Sohaey, R; Green, D; Redlich, C; Gretch, D. (1995). Hepatic ultrasonic changes in workers exposed to perchloroethylene. Occup Environ Med 52: 679-685.

Bronzetti, G; Bauer, C; Corsi, C; Del Carratore, R; Galli, A; Nieri, R; Paolini, M. (1983). Genetic and biochemical studies on perchloroethylene 'in vitro' and 'in vivo'. Mutat Res Genet Toxicol Environ Mutagen 116: 323-331. http://dx.doi.org/10.1016/0165-1218(83)90070-8

Brown, RP; Delp, MD; Lindstedt, SL; Rhomberg, LR; Beliles, RP. (1997). Physiological parameter values for physiologically based pharmacokinetic models. Toxicol Ind Health 13: 407-484. http://dx.doi.org/10.1177/074823379701300401

Brownson, RC; Alavanja, MC; Chang, JC. (1993). Occupational risk factors for lung cancer among nonsmoking women: A case-control study in Missouri (United States). Cancer Causes Control 4: 449-454. http://dx.doi.org/10.1007/bf00050864

Buben, JA; O'Flaherty, EJ. (1985). Delineation of the role of metabolism in the hepatotoxicity of trichloroethylene and perchloroethylene: A dose-effect study. Toxicol Appl Pharmacol 78: 105-122.

Bulka, C; Nastoupil, LJ; Koff, JL; Bernal-Mizrachi, L; Ward, KC; Williams, JN; Bayakly, AR; Switchenko, JM; Waller, LA; Flowers, CR. (2016). Relations between residential proximity to EPA-designated toxic release sites and diffuse large B-cell lymphoma incidence. South Med J 109: 606-614. http://dx.doi.org/10.14423/SMJ.0000000000000545

Burotn, NC. (1994). Health hazard evaluation report no. HETA 93-0351-2413, Goodwill Industires of America, Inc. Bethesda, Maryland. (HETA 93-0351-2413). Cincinnati, OH: National Institute for Occupational Safety and Health.

Burroughs, GE. (1999a). Evaluation of Eight Dry Cleaning Shops with State-of-the-Art Control Equipment. Report on Task 1. Perchloroethylene in Dry Cleaning Shops. NIOSH. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB99168890.xhtml

Burroughs, GE. (1999b). In-depth survey report evaluation of control technology for perchlorethylene in dry cleaning shops. (ECTB 240-15). Cincinnati, OH: NIOSH. https://www.cdc.gov/niosh/surveyreports/pdfs/240-15.pdf

Burroughs, GE. (2000). In-depth survey report evaluation of control technology for perchlorethylene in dry cleaning shops. (ECTB 240-12). Cincinnati, OH: NIOSH. https://www.cdc.gov/niosh/surveyreports/pdfs/240-12.pdf

Burton, NC; Monestersky, J. (1996). Health hazard evaluation report No. HETA 96-0135-2612, Eagle Knitting Mills, Inc., Shawano, Wisconsin. Cincinnati, OH: U.S. National Institute for Occupational Safety and Health.
Byczkowski, JZ; Fisher, JW. (1994). Lactational transfer of tetrachloroethylene in rats. Risk Anal 14: 339-349. http://dx.doi.org/10.1111/j.1539-6924.1994.tb00250.x
Cabirol, N; Perrier, J; Jacob, F; Fouillet, B; Chambon, P. (1996). Role of methanogenic and sulfate-reducing bacteria in the reductive dechlorination of tetrachloroethylene in mixed culture. Bull Environ Contam Toxicol 56: 817-824. http://dx.doi.org/10.1007/s001289900119
Cai, SX; Huang, MY; Chen, Z; Liu, YT; Jin, C; Watanabe, T; Nakatsuka, H; Seiji, K; Inoue, O; Ikeda, M. (1991). Subjective symptom increase among dry-cleaning workers exposed to tetrachloroethylene vapor. Ind Health 29: 111-121. http://dx.doi.org/10.2486/indhealth.29.111
California Air Resources, B. (2006). California Dry Cleaning Industry Technical Assessment Report. Stationary Source Division, Emissions Assessment Branch. https://www.arb.ca.gov/toxics/dryclean/finaldrycleantechreport.pdf
Call, DJ; Brooke, LT; Ahmad, N. (1979). Toxicity, bioconcentration and metabolism of selected chemicals in aquatic organisms: Third quarterly progress report to EPA (1 October - 31 December 1979). (EPA Cooperative Agreement No.CR 806864020). Superior, WI: University of Wisconsin.
Call, DJ; Brooke, LT; Ahmad, N. (1980). Toxicity, bioconcentration, and metabolism of selected chemicals in aquatic organisms: Fourth quarterly progress report to EPA (1 January - 31 March 1980). (U.S. EPA Cooperative Agreement No. CR 806864020). Superior, WI: University of Wisconsin.
Call, DJ; Brooke, LT; Ahmad, N; Richter, JE. (1983). Toxicity and metabolism studies with EPA (Environmental Protection Agency) priority pollutants and related chemicals in freshwater organisms (pp. 120 p.). (EPA/600/3-83/095 (NTIS PB83263665)). Duluth, MN: U.S. Environmental Protection Agency.
Callen, DF; Wolf, CR; Philpot, RM. (1980). Cytochrome P-450 mediated genetic activity and cytotoxicity of seven halogenated aliphatic hydrocarbons in Saccharomyces cerevisiae. Mutat Res 77: 55-63. http://dx.doi.org/10.1016/0165-1218(80)90120-2
Calvert, GM; Ruder, AM; Petersen, MR. (2011). Mortality and end-stage renal disease incidence among dry cleaning workers. Occup Environ Med 68: 709-716. http://dx.doi.org/10.1136/oem.2010.060665
Canada, C. (2017). Profiles & estimates: Tetrachloroethylene. http://www.carexcanada.ca/en/tetrachloroethylene/
Cano, MI; Pollán, M. (2001). Non-Hodgkin's lymphomas and occupation in Sweden. Int Arch Occup Environ Health 74: 443-449. http://dx.doi.org/10.1007/s004200100248
CARB. (2000). Initial statement of reasons for the proposed airborne toxic control measure for emissions of chlorinated toxic air contaminants from automotive maintenance and repair activities.
Carney, EW; Thorsrud, BA; Dugard, PH; Zablotny, CL. (2006). Developmental toxicity studies in Crl:CD (SD) rats following inhalation exposure to trichloroethylene and perchloroethylene. Birth Defects Res B Dev Reprod Toxicol 77: 405-412. http://dx.doi.org/10.1002/bdrb.20091
Carpenter, CP. (1937). The chronic toxicity of tetrachlorethylene. J Ind Hyg Toxicol 19: 323-336.
Carton, M; Barul, C; Menvielle, G; Cyr, D; Sanchez, M; Pilorget, C; Trétarre, B; Stücker, I; Luce, D. (2017). Occupational exposure to solvents and risk of head and neck cancer in women: A population-based case-control study in France. BMJ Open 7: e012833. http://dx.doi.org/10.1136/bmjopen-2016-012833

Cavalleri, A; Gobba, F; Paltrinieri, M; Fantuzzi, G; Righi, E; Aggazzotti, G. (1994). Perchloroethylene exposure can induce colour vision loss. Neurosci Lett 179: 162-166. http://dx.doi.org/10.1016/0304-3940(94)90959-8
CDC. (2017). National report on human exposure to environmental chemicals. https://www.cdc.gov/exposurereport/
Cederberg, H; Henriksson, J; Binderup, ML. (2010). DNA damage detected by the alkaline comet assay in the liver of mice after oral administration of tetrachloroethylene. Mutagenesis 25: 133-138. http://dx.doi.org/10.1093/mutage/gep051
Chaigne, B; Lasfargues, G; Marie, I; Hüttenberger, B; Lavigne, C; Marchand-Adam, S; Maillot, F; Diot, E. (2015). Primary Sjögren's syndrome and occupational risk factors: A case-control study. J Autoimmun 60: 80-85. http://dx.doi.org/10.1016/j.jaut.2015.04.004
Chan, CC; Vainer, L; Martin, JW; Williams, DT. (1990). Determination of organic contaminants in residential indoor air using an adsorption-thermal desorption technique. J Air Waste Manag Assoc 40: 62-67.
Chan, WR; Cohn, S; Sidheswaran, M; Sullivan, DP; Fisk, WJ. (2014). Contaminant levels, source strengths, and ventilation rates in California retail stores. Indoor Air 25: 381-392. http://dx.doi.org/10.1111/ina.12152
Chang, JC; Guo, Z; Sparks, LE. (1998). Exposure and emission evaluations of methyl ethyl ketoxime (MEKO) in alkyd paints. Indoor Air 8: 295-300. http://dx.doi.org/10.1111/j.1600-0668.1998.00010.x
Chang, YM; Tai, CF; Yang, SC; Lin, RS; Sung, FC; Shih, TS; Liou, SH. (2005). Cancer incidence among workers potentially exposed to chlorinated solvents in an electronics factory. J Occup Health 47: 171-180. http://dx.doi.org/10.1539/joh.47.171
Chao, CYH; Tung, TCW; Niu, JL; Pang, SW; Lee, RYM. (1999). Indoor perchloroethylene accumulation from dry cleaned clothing on residential premises. Build Environ 34: 319-328.
ChemView. (2019). 1-Naphthol. https://chemview.epa.gov/chemview/?tf=0&ch=90-15-3&su=2-5-6-7-37574985&as=3-10-9-8&ac=1-15-16-6378999&ma=4-11-1981377&tds=0&tdl=10&tas1=1&tas2=asc&tas3=undefined&tss=&modal=detail&modalId=121497&modalSrc=5-6-7-3-4
Chen, HH; Chan, MH; Fu, SH. (2002a). Behavioural effects of tetrachloroethylene exposure in rats: Acute and subchronic studies. Toxicology 170: 201-209. http://dx.doi.org/10.1016/S0300-483X(01)00544-3
Chen, SJ; Wang, JL; Chen, JH; Huang, RN. (2002b). Possible involvement of glutathione and p53 in trichloroethylene- and perchloroethylene-induced lipid peroxidation and apoptosis in human lung cancer cells. Free Radic Biol Med 33: 464-472. http://dx.doi.org/10.1016/S0891-5849(02)00817-1
Cherrie, JW; Semple, S; Brouwer, D. (2004). Gloves and Dermal Exposure to Chemicals: Proposals for Evaluating Workplace Effectiveness. Ann Occup Hyg 48: 607-615. http://dx.doi.org/10.1093/annhyg/meh060
Chin, JY; Godwin, C; Parker, E; Robins, T; Lewis, T; Harbin, P; Batterman, S. (2014). Levels and sources of volatile organic compounds in homes of children with asthma. Indoor Air 24: 403-415. http://dx.doi.org/10.1111/ina.12086
Chiu, WA; Ginsberg, GL. (2011a). Development and evaluation of a harmonized physiologically based pharmacokinetic (PBPK) model for perchloroethylene toxicokinetics in mice, rats, and humans. Toxicol Appl Pharmacol 253: 203-234. http://dx.doi.org/10.1016/j.taap.2011.03.020
Chiu, WA; Okino, MS; Evans, MV. (2009). Characterizing uncertainty and population variability in the toxicokinetics of trichloroethylene and metabolites in mice, rats, and humans using an updated

database, physiologically based pharmacokinetic (PBPK) model, and Bayesian approach. Toxicol Appl Pharmacol 241: 36-60. http://dx.doi.org/10.1016/j.taap.2009.07.032

Christensen, KY; Vizcaya, D; Richardson, H; Lavoué, J; Aronson, K; Siemiatycki, J. (2013). Risk of selected cancers due to occupational exposure to chlorinated solvents in a case-control study in Montreal. J Occup Environ Med 55: 198-208. http://dx.doi.org/10.1097/JOM.0b013e3182728eab

Chrostek, WJ; Levine, MS. (1981). Health Hazard Evaluation Report 80-154-1027: Bechtel Power Corporation. (HHE 80-154-1027). NIOSH. https://www.cdc.gov/niosh/hhe/reports/pdfs/80-154-1027.pdf?id=10.26616/NIOSHHHE801541027

Cichocki, JA; Furuya, S; Venkatratnam, A; McDonald, TJ; Knap, AH; Wade, T; Sweet, S; Chiu, WA; Threadgill, DW; Rusyn, I. (2017). Characterization of Variability in Toxicokinetics and Toxicodynamics of Tetrachloroethylene Using the Collaborative Cross Mouse Population. Environ Health Perspect 125: 057006. http://dx.doi.org/10.1289/EHP788

Cichocki, JA; Guyton, KZ; Guha, N; Chiu, WA; Rusyn, I; Lash, LH. (2016). Target organ metabolism, toxicity, and mechanisms of trichloroethylene and perchloroethylene: key similarities, differences, and data gaps [Review]. J Pharmacol Exp Ther 359: 110-123. http://dx.doi.org/10.1124/jpet.116.232629

Clayton, CA; Pellizzari, ED; Whitmore, RW; Perritt, RL; Quackenboss, JJ. (1999). National Human Exposure Assessment Survey (NHEXAS): Distributions and associations of lead, arsenic, and volatile organic compounds in EPA Region 5. J Expo Anal Environ Epidemiol 9: 381-392. http://dx.doi.org/10.1038/sj.jea.7500055

Clewell, HJ; Gentry, PR; Kester, JE; Andersen, ME. (2005). Evaluation of physiologically based pharmacokinetic models in risk assessment: An example with perchloroethylene [Review]. Crit Rev Toxicol 35: 413-433. http://dx.doi.org/10.1080/10408440590931994

Connor, TH; Theiss, JC; Hanna, HA; Monteith, DK; Matney, TS. (1985). Genotoxicity of organic chemicals frequently found in the air of mobile homes. Toxicol Lett 25: 33-40. http://dx.doi.org/10.1016/0378-4274(85)90097-9

Cooper, J. (2017). Comment submitted by James Cooper, Senior Petrochemical Advisor, American Fuel & Petrochemical Manufacturers (AFPM) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0741-0019

Cosgrove, H; Hygiene, I. (1994). Perchloroethylene Survey, Radiator Specialty Company. (EPA-HQ-OPPT-2016-0732-0027). Charlotte, NC: Cosgrove Health & Hygiene Inc. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0027

Costa, AK; Ivanetich, KM. (1984). Chlorinated ethylenes: their metabolism and effect on DNA repair in rat hepatocytes. Carcinogenesis 5: 1629-1636. http://dx.doi.org/10.1093/carcin/5.12.1629

D'Souza, JC; Jia, C; Mukherjee, B; Batterman, S. (2009). Ethnicity, housing and personal factors as determinants of VOC exposures. Atmos Environ 43: 2884-2892. http://dx.doi.org/10.1016/j.atmosenv.2009.03.017

Dallas, CE; Chen, XM; Muralidhara, S; Varkonyi, P; Tackett, RL; Bruckner, JV. (1994a). Use of tissue disposition data from rats and dogs to determine species differences in input parameters for a physiological model for perchloroethylene. Environ Res 67: 54-67. http://dx.doi.org/10.1006/enrs.1994.1064

Dallas, CE; Chen, XM; Muralidhara, S; Varkonyi, P; Tackett, RL; Bruckner, JV. (1995). Physiologically based pharmacokinetic model useful in prediction of the influence of species, dose, and exposure route on perchloroethylene pharmacokinetics. J Toxicol Environ Health 44: 301-317. http://dx.doi.org/10.1006/taap.1994.1179

Dallas, CE; Muralidhara, S; Chen, XM; Ramanathan, R; Varkonyi, P; Gallo, JM; Bruckner, JV. (1994b). Use of a physiologically based model to predict systemic uptake and respiratory elimination of

perchloroethylene. Toxicol Appl Pharmacol 128: 60-68. http://dx.doi.org/10.1006/taap.1994.1180
Davis, A; Gift, JS; Woodall, GM; Narotsky, MG; Fourman, GL. (2009). The role of developmental toxicity studies in acute exposure assessments: analysis of single-day vs. multiple-day exposure regimens. Regul Toxicol Pharmacol 54: 134-142. http://dx.doi.org/10.1016/j.yrtph.2009.03.006
Davis, R. (2017). Comment submitted by Raleigh Davis, Assistant Director, Environmental Health and Safety, American Coatings Association (ACA) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0742-0025
de Blas, M; Navazo, M; Alonso, L; Durana, N; Gomez, MC; Iza, J. (2012). Simultaneous indoor and outdoor on-line hourly monitoring of atmospheric volatile organic compounds in an urban building. The role of inside and outside sources. Sci Total Environ 426: 327-335. http://dx.doi.org/10.1016/j.scitotenv.2012.04.003
de Bruin, WP; Kotterman, MJ; Posthumus, MA; Schraa, G; Zehnder, AJ. (1992). Complete biological reductive transformation of tetrachloroethene to ethane. Appl Environ Microbiol 58: 1996-2000.
De Ceaurriz, J; Desiles, JP; Bonnet, P; Marignac, B; Muller, J; Guenier, JP. (1983). Concentration-dependent behavioral changes in mice following short-term inhalation exposure to various industrial solvents. Toxicol Appl Pharmacol 67: 383-389. http://dx.doi.org/10.1016/0041-008X(83)90322-8
Deferme, L; Wolters, J; Claessen, S; Briedé, J; Kleinjans, J. (2015). Oxidative Stress Mechanisms Do Not Discriminate between Genotoxic and Nongenotoxic Liver Carcinogens. Chem Res Toxicol 28: 1636-1646. http://dx.doi.org/10.1021/acs.chemrestox.5b00222
Dekant, W; Vamvakas, S; Berthold, K; Schmidt, S; Wild, D; Henschler, D. (1986). Bacterial beta-lyase mediated cleavage and mutagenicity of cysteine conjugates derived from the nephrocarcinogenic alkenes trichloroethylene, tetrachloroethylene and hexachlorobutadiene. Chem Biol Interact 60: 31-45. http://dx.doi.org/10.1016/0009-2797(86)90015-3
Delfino, RJ; Gone, H; Linn, WS; Pellizzari, ED; Hu, Y. (2003a). Asthma symptoms in Hispanic children and daily ambient exposures to toxic and criteria air pollutants. Environ Health Perspect 111: 647-656. http://dx.doi.org/10.1289/ehp.5992
Delfino, RJ; Gong, H; Linn, WS; Hu, Y; Pellizzari, ED. (2003b). Respiratory symptoms and peak expiratory flow in children with asthma in relation to volatile organic compounds in exhaled breath and ambient air. J Expo Anal Environ Epidemiol 13: 348-363. http://dx.doi.org/10.1038/sj.jea.7500287
Demarini, DM; Perry, E; Shelton, ML. (1994). Dichloroacetic acid and related compounds: Induction of prophage in E. coli and mutagenicity and mutation spectra in Salmonella TA100. Mutagenesis 9: 429-437. http://dx.doi.org/10.1093/mutage/9.5.429
Di Toro, DM. (1984). Probability model of stream quality due to runoff. J Environ Eng 110: 607-628. http://dx.doi.org/10.1061/(ASCE)0733-9372(1984)110:3(607)
DLI/NCA. (2017). Public comment on tetrachloroethylene. TSCA review and scoping. (EPA-HQ-OPPT-2016-0732). https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0007
Dmitrieva, NV. (1967). Contribution to the metabolism of tetrachloroethylene. Med Tr Prom Ekol 11: 54-56.
Dodson, RE; Levy, JI; Spengler, JD; Shine, JP; Bennett, DH. (2008). Influence of basements, garages, and common hallways on indoor residential volatile organic compound concentrations. Atmos Environ 42: 1569-1581. http://dx.doi.org/10.1016/j.atmosenv.2007.10.088
Doherty, AT; Ellard, S; Parry, EM; Parry, JM. (1996). An investigation into the activation and deactivation of chlorinated hydrocarbons to genotoxins in metabolically competent human cells. Mutagenesis 11: 247-274. http://dx.doi.org/10.1093/mutage/11.3.247

Dosemeci, M; Cocco, P; Chow, WH. (1999). Gender differences in risk of renal cell carcinoma and occupational exposures to chlorinated aliphatic hydrocarbons. Am J Ind Med 36: 54-59. http://dx.doi.org/10.1002/(SICI)1097-0274(199907)36:1<54::AID-AJIM8>3.0.CO;2-0

Dow Chem, C. (1973). Uptake, clearance and bioconcentration of dow-per (perchloroethylene) in rainbow trout, Salmo gairdneri richardson. (8EHQ Num: NA; DCN: 86-870002077; TSCATS RefID: 309906; CIS: NA).

Dow Chem, C. (1979). Evaluation of work exposures in ag production and distribution department (apd2) operations, pittsburg, for 1978 with cover letter. (OTS: OTS0206690; 8EHQ Num: NA; DCN: 878214806; TSCATS RefID: 25878; CIS: NA). Dow Chem Co.

Dow Chem, C. (1982). Chlor-Pyridines - 1981 Industrial Hygiene Survey (Sanitized). (OTS: OTS0515873; 8EHQ Num: NA; DCN: 86-870002349; TSCATS RefID: 309318; CIS: NA).

Dow Chem, C. (1983a). 1982 Industrial Hygiene Monitoring - Chloropyridines (Sanitized). (OTS: OTS0515889; 8EHQ Num: NA; DCN: 86-870002365; TSCATS RefID: 309350; CIS: NA).

Dow Chem, C. (1983b). Chemical exposure evaluation - Trichloroethylene production plant (sanitized). (EPA/OTS; Doc #86-870002355). Dow Chem Co.

Dow Chem, C. (1983c). Initial submission: Perchloroethylene solvent formulation: acute toxicological properties & industrial handling hazards, with cover letter dated 102591 (sanitized). (OTS: OTS0574294; 8EHQ Num: 8EHQ-1091-1410S; DCN: 88-920000056S; TSCATS RefID: 454602; CIS: NA). Dow Chem Co.

Dow Chem, C. (1984a). Industrial Hygiene Surveys During 1983 At The Eastern Division Marine Terminal at Holliet, Illinois (Sanitized). (OTS: OTS0515882; 8EHQ Num: NA; DCN: 86-870002358; TSCATS RefID: 309336; CIS: NA).

Dow Chem, C. (1984b). PERCHLOROETHYLENE (99.97%) FORMULATION: ACUTE TOXICOLOGICAL PROPERTIES. (OTS: OTS0515966; 8EHQ Num: NA; DCN: 86-870002176; TSCATS RefID: 309506; CIS: NA).

Dow Chem, C. (2008). Product safety assessment: Perchloroethylene. http://N/A

Dow Chemical Co (Dow Chemical Company). (2008). Product safety assessment: Perchloroethylene.

Dowell, R. (2017). Comment submitted by Robert Dowell, President, Plasma Technology Inc. (PTI) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0014

Doyle, P; Roman, E; Beral, V; Brookes, M. (1997). Spontaneous abortion in dry cleaning workers potentially exposed to perchloroethylene. Occup Environ Med 54: 848-853. http://dx.doi.org/10.1136/oem.54.12.848

Dreessen, B; Westphal, G; Bünger, J; Hallier, E; Müller, M. (2003). Mutagenicity of the glutathione and cysteine S-conjugates of the haloalkenes 1,1,2-trichloro-3,3,3-trifluoro-1-propene and trichlorofluoroethene in the Ames test in comparison with the tetrachloroethene-analogues. Mutat Res Genet Toxicol Environ Mutagen 539: 157-166. http://dx.doi.org/10.1016/S1383-5718(03)00160-8

Ducommun, I. (2017). HSIA Support Ducommun. (EPA-HQ-OPPT-2016-0732-0027). Washington, D.C.: Ducommun Inc. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0027

Durkee, J. (2014). Cleaning with solvents: Methods and machinery. Oxford, UK: Elsevier Inc. https://www.sciencedirect.com/book/9780323225205/cleaning-with-solvents-methods-and-machinery

Ebrahim, AS; Babakrishnan, K; Sakthisekaran, D. (1996). Perchloroethylene-induced alterations in glucose metabolism and their prevention by 2-deoxy-D-glucose and vitamin E in mice. J Appl Toxicol 16: 339-348. http://dx.doi.org/10.1002/(SICI)1099-1263(199607)16:4<339::AID-JAT352>3.0.CO;2-3

Ebrahim, AS; Babu, E; Thirunavukkarasu, C; Sakthisekaran, D. (2001). Protective role of vitamin E, 2-deoxy-D-glucose, and taurine on perchloroethylene induced alterations in ATPases. Drug Chem Toxicol 24: 429-437. http://dx.doi.org/10.1081/DCT-100106267

ECB. (2005). European Union risk assessment report: Tetrachloroethylene. Part 1 - Environment. (EINECS No: 204-825-9). United Kingdom: European Commission – Joint Research Centre Institute for Health and Consumer Protection European Chemicals Bureau.

Echeverria, D; Heyer, N; Checkoway, H; Brodkin, CA; Bittner, A, Jr.; Toutonghi, G; Ronhovde, N. (1994). A behavioral investigation of occupational exposures to solvents: Perchloroethylene among dry cleaners, and styrene among reinforced fiberglass laminators. (BSRC-100/94/040). Seattle, WA: Battelle Centers for Public Health Research and Evaluation.

Echeverria, D; White, RF; Sampaio, C. (1995). A behavioral evaluation of PCE exposure in patients and dry cleaners: A possible relationship between clinical and preclinical effects. J Occup Environ Med 37: 667-680.

Eisenberg, J; Ramsey, J. (2010). Health hazard evaluation report no. HETA 2008-0175-3111, Evaluation of 1-Bromopropane use in four New Jersey commercial dry cleaning facilities. (HETA 2008-0175-3111). Cincinnati, OH: National Institute for Occupational Safety and Health.

Elfarra, AA; Krause, RJ. (2007). S-(1,2,2-trichlorovinyl)-L-cysteine sulfoxide, a reactive metabolite of S-(1,2,2-Trichlorovinyl)-L-cysteine formed in rat liver and kidney microsomes, is a potent nephrotoxicant. J Pharmacol Exp Ther 321: 1095-1101. http://dx.doi.org/10.1124/jpet.107.120444

Emara, AM; Abo El-Noor, MM; Hassan, NA; Wagih, AA. (2010). Immunotoxicity and hematotoxicity induced by tetrachloroethylene in egyptian dry cleaning workers. Inhal Toxicol 22: 117-124. http://dx.doi.org/10.3109/08958370902934894

Emmert, B; Bünger, J; Keuch, K; Müller, M; Emmert, S; Hallier, E; Westphal, GA. (2006). Mutagenicity of cytochrome P450 2E1 substrates in the Ames test with the metabolic competent S. typhimurium strain YG7108pin3ERb5. Toxicology 228: 66-76. http://dx.doi.org/10.1016/j.tox.2006.08.013

ERG. (2005). [Letter from Eric Goehl and Jennifer O'Neil, Eastern Research group, Inc, to Dry Cleaning Docket, Subject: Background information document] [Personal Communication]. http://www3.epa.gov/airtoxics/dryperc/11-14-05background.pdf

Eskenazi, B; Fenster, L; Hudes, M; Wyrobek, AJ; Katz, DF; Gerson, J; Rempel, DM. (1991a). A study of the effect of perchloroethylene exposure on the reproductive outcomes of wives of dry-cleaning workers. Am J Ind Med 20: 593-600. http://dx.doi.org/10.1002/ajim.4700200503

Eskenazi, B; Wyrobek, AJ; Fenster, L; Katz, DF; Sadler, M; Lee, J; Hudes, M; Rempel, DM. (1991b). A study of the effect of perchloroethylene exposure on semen quality in dry cleaning workers. Am J Ind Med 20: 575-591. http://dx.doi.org/10.1002/ajim.4700200502

Eu. (2001). Draft risk assessment report: Tetrachloroethylene. United Kingdom.

European Solvents Industry, G. (2012). SPERC fact sheet: Manufacture of substance - industrial (solvent-borne). Brussels, Belgium: European Solvents Industry Group (ESIG). https://www.esig.org/reach-ges/environment/

European Solvents Industry, G. (2019). Industrial - solvent-borne (formulation and (re)packaging of substances and mixtures). https://www.esig.org/reach-ges/environment/

Everatt, R; Slapšytė, G; Mierauskienė, J; Dedonytė, V; Bakienė, L. (2013). Biomonitoring study of dry cleaning workers using cytogenetic tests and the comet assay. J Occup Environ Hyg 10: 609-621. http://dx.doi.org/10.1080/15459624.2013.818238

Fay, K. (2017). Comment submitted by Kevin Fay, Executive Director, Alliance for Responsible Atmospheric Policy (Alliance) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0733-0016

Fender, H. (1993). Chromosomenanalytische undersuchungen bei textilreinigern. In D Arndt; G Obe (Eds.), (pp. 71-76). München, Germany: MMV Verlag.
Ferroni, C; Selis, L; Mutti, A; Folli, D; Bergamaschi, E; Franchini, I. (1992). Neurobehavioral and neuroendocrine effects of occupational exposure to perchloroethylene. Neurotoxicology 13: 243-247.
Fishbein, L. (1992). Exposure from occupational versus other sources [Review]. Scand J Work Environ Health 18: 5-16.
Fisher, J; Mahle, D; Bankston, L; Greene, R; Gearhart, J. (1997). Lactational transfer of volatile chemicals in breast milk. Am Ind Hyg Assoc J 58: 425-431. http://dx.doi.org/10.1080/15428119791012667
Fisher, JW; Mahle, D; Abbas, R. (1998). A human physiologically based pharmacokinetic model for trichloroethylene and its metabolites, trichloroacetic acid and free trichloroethanol. Toxicol Appl Pharmacol 152: 339-359. http://dx.doi.org/10.1006/taap.1998.8486
Ford Motor, C. (1981). Industrial hygiene survey - spray booths, oil house, roll weld, bonderite deck, trimline. (OTS: OTS0206239; 8EHQ Num: NA; DCN: 878210810; TSCATS RefID: 17580; CIS: NA).
Franchini, I; Cavatorta, A; Falzoi, M; Lucertini, S; Mutti, A. (1983). Early indicators of renal damage in workers exposed to organic solvents. Int Arch Occup Environ Health 52: 1-9. http://dx.doi.org/10.1007/BF00380601
Frantz, SW; Watanabe, PG. (1983). Tetrachloroethylene: Balance and tissue distribution in male Sprague-Dawley rats by drinking-water administration. Toxicol Appl Pharmacol 69: 66-72. http://dx.doi.org/10.1016/0041-008X(83)90120-5
Frasch, HF; Bunge, AL. (2015). The transient dermal exposure II: post-exposure absorption and evaporation of volatile compounds. J Pharm Sci 104: 1499-1507. http://dx.doi.org/10.1002/jps.24334
Fredriksson, A; Danielsson, BRG; Eriksson, P. (1993). Altered behaviour in adult mice orally exposed to tri- and tetrachloroethylene as neonates. Toxicol Lett 66: 13-19. http://dx.doi.org/10.1016/0378-4274(93)90074-8
Gallagher, LG; Vieira, VM; Ozonoff, D; Webster, TF; Aschengrau, A. (2011). Risk of breast cancer following exposure to tetrachloroethylene-contaminated drinking water in Cape Cod, Massachusetts: Reanalysis of a case-control study using a modified exposure assessment. Environ Health 10: 47. http://dx.doi.org/10.1186/1476-069X-10-47
Galloway, SM; Armstrong, MJ; Reuben, C; Colman, S; Brown, B; Cannon, C; Bloom, AD; Nakamura, F; Ahmed, M; Duk, S; Rimpo, J; Margolin, BH; Resnick, MA; Anderson, B; Zeiger, E. (1987). Chromosome aberrations and sister chromatid exchanges in Chinese hamster ovary cells evaluations of 108 chemicals [Review]. Environ Mol Mutagen 10: 1-175. http://dx.doi.org/10.1002/em.2850100502
Garabrant, DH; Lacey, JV, Jr.; Laing, TJ; Gillespie, BW; Mayes, MD; Cooper, BC; Schottenfeld, D. (2003). Scleroderma and solvent exposure among women. Am J Epidemiol 157: 493-500. http://dx.doi.org/10.1093/aje/kwf223
Gargas, ML; Burgess, RJ; Voisard, DE; Cason, GH; Andersen, ME. (1989). Partition coefficients of low-molecular weight volatile chemicals in various tissues and liquids. Toxicol Appl Pharmacol 98: 87-89. http://dx.doi.org/10.1016/0041-008X(89)90137-3
Ge, R; Yang, S; Kramer, PM; Tao, L; Pereira, MA. (2001). The effect of dichloroacetic acid and trichloroacetic acid on DNA methylation and cell proliferation in B6C3F1 mice. J Biochem Mol Toxicol 15: 100-106. http://dx.doi.org/10.1002/jbt.5
Gearhart, JM; Mahle, DA; Greene, RJ; Seckel, CS; Flemming, CD; Fisher, JW; Clewell, HJ, III. (1993). Variability of physiologically based pharmacokinetic (PBPK) model parameters and their effects

on PBPK model predictions in a risk assessment for perchloroethylene (PCE). Toxicol Lett 68: 131-144. http://dx.doi.org/10.1016/0378-4274(93)90126-I
Gennari, P; Naldi, M; Motta, R; Nucci, MC; Giacomini, C; Violante, FS; Raffi, GB. (1992). gamma-Glutamyltransferase isoenzyme pattern in workers exposed to tetrachloroethylene. Am J Ind Med 21: 661-671. http://dx.doi.org/10.1002/ajim.4700210506
Getz, KD; Janulewicz, PA; Rowe, S; Weinberg, JM; Winter, MR; Martin, BR; Vieira, VM; White, RF; Aschengrau, A. (2012). Prenatal and early childhood exposure to tetrachloroethylene and adult vision. Environ Health Perspect 120: 1327-1332. http://dx.doi.org/10.1289/ehp.1103996
Gobba, F; Righi, E; Fantuzzi, G; Predieri, G; Cavazzuti, L; Aggazzotti, G. (1998). Two-year evolution of perchloroethylene-induced color-vision loss. Arch Environ Health 53: 196-198. http://dx.doi.org/10.1080/00039899809605695
Goldberg, ME; Johnson, HE; Pozzani, UC; Smyth, HF, Jr. (1964). Effect of repeated inhalation of vapors of industrial solvents on animal behavior: I. Evaluation of nine solvent vapors on pole-climb performance in rats. Am Ind Hyg Assoc J 25: 369-375. http://dx.doi.org/10.1080/00028896409342606
Gold, LS; De Roos, AJ; Waters, M; Stewart, P. (2008). Systematic literature review of uses and levels of occupational exposure to tetrachloroethylene [Review]. J Occup Environ Hyg 5: 807-839. http://dx.doi.org/10.1080/15459620802510866
Gold, LS; Stewart, PA; Milliken, K; Purdue, M; Severson, R; Seixas, N; Blair, A; Hartge, P; Davis, S; De Roos, AJ. (2010). The relationship between multiple myeloma and occupational exposure to six chlorinated solvents. Occup Environ Med 68: 391-399. http://dx.doi.org/10.1136/oem.2009.054809
Goldman, JA. (1996). Connective tissue disease in people exposed to organic chemical solvents: Systemic sclerosis (scleroderma) in dry cleaning plant and aircraft industry workers. J Clin Rheumatol 2: 185-190.
Goldman, SM; Quinlan, PJ; Ross, GW; Marras, C; Meng, C; Bhudhikanok, GS; Comyns, K; Korell, M; Chade, AR; Kasten, M; Priestley, B; Chou, KL; Fernandez, HH; Cambi, F; Langston, JW; Tanner, CM. (2012). Solvent exposures and Parkinson disease risk in twins. Ann Neurol 71: 776-784. http://dx.doi.org/10.1002/ana.22629
Goldsworthy, TL; Lyght, O; Burnett, VL; Popp, JA. (1988). Potential role of [alpha]-2[mu]-globulin, protein droplet accumulation, and cell replication in the renal carcinogenicity of rats exposed to trichloroethylene, perchloroethylene, and pentachloroethane. Toxicol Appl Pharmacol 96: 367-379. http://dx.doi.org/10.1016/0041-008X(88)90095-6
Goldsworthy, TL; Popp, JA. (1987). Chlorinated hydrocarbon-induced peroxisomal enzyme activity in relation to species and organ carcinogenicity. Toxicol Appl Pharmacol 88: 225-233. http://dx.doi.org/10.1016/0041-008X(87)90008-1
Gorman, R; Rinsky, R; Stein, G; Anderson, K. (1984). Health hazard evaluation report no. HETA 82-075-1545, Pratt & Whitney Aircraft, West Palm Beach, Florida. (HETA 82-075-1545). Cincinnati, OH: National Institute for Occupational Safety and Health.
Gossett, JM. (1987). Measurement of Henry's law constants for C1 and C2 chlorinated hydrocarbons. Environ Sci Technol 21: 202-208. http://dx.doi.org/10.1021/es00156a012
Graul, F. (2017). Comment submitted by Faye Graul, Executive Director, Halogenated Solvents Industry Alliance, Inc. (HSIA) regarding Docket No. EPA-HO-OPPT-20 I 6-0732.
Green, T; Odum, J; Nash, JA; Foster, JR. (1990). Perchloroethylene-induced rat kidney tumors: An investigation of the mechanisms involved and their relevance to humans. Toxicol Appl Pharmacol 103: 77-89. http://dx.doi.org/10.1016/0041-008X(90)90264-U

Greim, H; Bonse, G; Radwan, Z; Reichert, D; Henschler, D. (1975). Mutagenicity in vitro and potential carcinogenicity of chlorinated ethylenes as a function of metabolic oxirane formation. Biochem Pharmacol 24: 2013-2017. http://dx.doi.org/10.1016/0006-2952(75)90396-2

Gromiec, JP; Wesolowski, W; Brzeznicki, S; Wroblewska-Jakubowska, K; Kucharska, M. (2002). Occupational exposure to rubber vulcanization products during repair of rubber conveyor belts in a brown coal mine. J Environ Monit 4: 1054-1059. http://dx.doi.org/10.1039/b209207g

Gulyas, H; Hemmerling, L. (1990). Tetrachloroethene air pollution originating from coin-operated dry cleaning establishments. Environ Res 53: 90-99.

Gunter, BJ; Lybarger, JA. (1979). Health Hazard Evaluation Determination Report No. HHE-78-95-596, Jonas Brothers Taxidermy Co., Denver, Colorado (pp. 78-95). (NIOSH/00091563). Gunter, BJ; Lybarger, JA.

Gunter, BJ; Thoburn, TW; London, M. (1984). Health Hazard Evaluation Report HETA 83-425-1500: Westview Press. (HETA 83-425-1500). NIOSH. https://www.cdc.gov/niosh/hhe/reports/pdfs/1983-0425-1500.pdf

Guyton, KZ; Hogan, KA; Scott, CS; Cooper, GS; Bale, AS; Kopylev, L; Barone, S; Makris, SL; Glenn, B; Subramaniam, RP; Gwinn, MR; Dzubow, RC; Chiu, WA. (2014). Human health effects of tetrachloroethylene: key findings and scientific issues. Environ Health Perspect 122: 325-334. http://dx.doi.org/10.1289/ehp.1307359

Hadkhale, K; Martinsen, JI; Weiderpass, E; Kjaerheim, K; Sparen, P; Tryggvadottir, L; Lynge, E; Pukkala, E. (2017). Occupational exposure to solvents and bladder cancer: A population-based case control study in Nordic countries. Int J Cancer 140: 1736-1746. http://dx.doi.org/10.1002/ijc.30593

Haerer, AF; Udelman, HD. (1964). Acute brain syndrome secondary to tetrachloroethylene ingestion. Am J Psychiatry 12: 78-79. http://dx.doi.org/10.1176/ajp.121.1.78

Hake, CL; Stewart, RD. (1977). Human exposure to tetrachloroethylene: Inhalation and skin contact. Environ Health Perspect 21: 231-238.

Hanioka, N; Jinno, H; Toyo'oka, T; Nishimura, T; Ando, M. (1995). Induction of rat liver drug-metabolizing enzymes by tetrachloroethylene. Arch Environ Contam Toxicol 28: 273-280. http://dx.doi.org/10.1007/BF00213102

Hanley, KW. (1993). Health hazard evaluation report no. HETA 91-004-2316, Daubert Coated Products, Inc., Dixon, Illinois. (HETA 91-004-2316). Cincinnati, OH: National Institute for Occupational Safety and Health.

Hansch, C; Leo, A; Hoekman, D. (1995). Exploring QSAR: Hydrophobic, electronic, and steric constants. In C Hansch; A Leo; DH Hoekman (Eds.), ACS Professional Reference Book. Washington, DC: American Chemical Society.

Hartmann, A; Speit, G. (1995). Genotoxic effects of chemicals in the single cell gel (SCG) test with human blood cells in relation to the induction of sister-chromatid exchanges (SCE). Mutat Res Lett 346: 49-56. http://dx.doi.org/10.1016/0165-7992(95)90068-3

Haworth, S; Lawlor, T; Mortelmans, K; Speck, W; Zeiger, E. (1983). Salmonella mutagenicity test results for 250 chemicals. Environ Mutagen 5: 3-142. http://dx.doi.org/10.1002/em.2860050703

Hayes, JR; Condie, LW, Jr.; Borzelleca, JF. (1986). The subchronic toxicity of tetrachloroethylene (perchloroethylene) administered in the drinking water of rats. Fundam Appl Toxicol 7: 119-125.

Heavner, DL; Morgan, WT; Ogden, MW. (1995). Determination of volatile organic compounds and ETS apportionment in 49 homes. Environ Int 21: 3-21. http://dx.doi.org/10.1016/0160-4120(94)00018-3

Heck, JE; Park, AS; Qiu, J; Cockburn, M; Ritz, B. (2013). An exploratory study of ambient air toxics exposure in pregnancy and the risk of neuroblastoma in offspring. Environ Res 127: 1-6. http://dx.doi.org/10.1016/j.envres.2013.09.002

Heineman, EF; Cocco, P; Gomez, MR; Dosemeci, M; Stewart, PA; Hayes, RB; Zahm, SH; Thomas, TL; Blair, A. (1994). Occupational exposure to chlorinated aliphatic hydrocarbons and risk of astrocytic brain cancer. Am J Ind Med 26: 155-169. http://dx.doi.org/10.1002/ajim.4700260203

Hejtmancik, MR; Trela, BA; Kurtz, PJ; Persing, RL; Ryan, MJ; Yarrington, JT; Chhabra, RS. (2002). Comparative gavage subchronic toxicity studies of o-chloroaniline and m-chloroaniline in F344 rats and B6C3F1 mice. Toxicol Sci 69: 234-243.

Hervin, RL; Stroman, R; Belanger, P; Ruhe, R; Collins, C; Dyches, T. (1977). Health Hazard Evaluation Determination, Report No. HHE-77-63-449, McDonnell Aircraft Company, St. Louis, Missouri (pp. 77-63). (NIOSH/00076128). Hervin, RL; Stroman, R; Belanger, P; Ruhe, R; Collins, C; Dyches, T.

Hickman, JC. (2000). Kirk-Othmer Encyclopedia of Chemical Technology

Tetrachloroethylene. New York, NY: John Wiley & Sons. http://dx.doi.org/10.1002/0471238961.2005201808090311.a01

Hill, AB. (1965). The environment and disease: Association or causation? Proc R Soc Med 58: 295-300.

Hollister, TA; Parker, AH, Jr.; Parrish, PR. (1968). Acute and chronic toxicity of five chemicals to mysid shrimp (Mysidopsis bahia) (pp. 15). (Published in Part as 4809, 5184, 5590, 9607, 10366, 83162, 83925). Pensacola, FL: EG&G Bionomics, Marine Research Lab.

Holmes, L. (2017). Comment submitted by Laurie Holmes, Senior Director, Environmental Policy, Motor & Equipment Manufacturers Association (MEMA). https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0723-0017

Horne, JD; Swirsky, MA; Hollister, TA; Oblad, BR; Kennedy, JH. (1983). Aquatic toxicity studies of five priority pollutants (pp. 196). (Final Report, EPA Contract No.68-01-6201, Task 3). Houston, TX: NUS Corporation.

Horvath, AL. (1982). Halogenated hydrocarbons: Solubility-miscibility with water. New York, NY: Marcel Dekker, Inc.

Howie, SJ. (1981). Ambient perchloroethylene levels inside coin-operated laundries with drycleaning machines on the premises. (EPA 600/4-82-032). Research Triangle Park, NC: U.S. Environmental Protection Agency; Environmental Monitoring Systems Laboratory. https://ntrl.ntis.gov/NTRL/dashboard/searchResults.xhtml?searchQuery=PB82230947

HSIA. (2008). Perchloroethylene - White Paper. Arlington, VA. http://www.nttworldwide.com/docs/percwp2008.pdf

HSIA. (2018a). Comment letter of Halogenated Solvents Industry Alliance, Inc. (HSIA) regarding Docket ID: EPA-HQ-OPPT-2016-0732-0097 [Personal Communication]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0097

HSIA. (2018b). Comment submitted by Faye Graul, Executive Director, Halogenated Solvents Industry Alliance, Inc. (HSIA). (EPA-HQ-OPPT-2016-0733-0084). Washington, D.C. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0733-0084

IARC. (1995). Tetrachloroethylene. In IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, vol 63 (pp. 159-221). Lyon, France. http://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Evaluation-Of-Carcinogenic-Risks-To-Humans/Dry-Cleaning-Some-Chlorinated-Solvents-And-Other-Industrial-Chemicals-1995

IARC. (2014). IARC Monographs on the evaluation of carcinogenic risks to humans: Trichloroethylene, tetrachloroethylene, and some other chlorinated agents. Geneva, Switzerland: World Health Organization, International Agency for Research on Cancer. http://monographs.iarc.fr/ENG/Monographs/PDFs/index.php

Icis. (2011). US chemical profile: Perchloroethylene. http://www.icis.com/resources/news/2011/04/25/9454665/us-chemical-profile-perchloroethylene/

ICRP. (2002). Basic anatomical and physiological data for use in radiological protection: Reference values. In Annals of the ICRP, vol 32, no 3-4. (ICRP Publication 89). New York, NY: Pergamon Press. http://dx.doi.org/10.1016/S0146-6453(03)00002-2
Ikeda, M; Koizumi, A; Watanabe, T; Endo, A; Sato, K. (1980). Cytogenetic and cytokinetic investigations on lymphocytes from workers occupationally exposed to tetrachloroethylene. Toxicol Lett 5: 251-256. http://dx.doi.org/10.1016/0378-4274(80)90068-5
Irta. (2007). Spotting chemicals: Alternatives to perchloroethylene and trichloroethylene in the textile cleaning industry. Prepared for: Cal/EPA's Department of Toxic Substances Control and U.S. Environmental Protection Agency Region IX. http://www.irta.us/reports/DTSC%20Spotting%20Chemical%20for%20Web.pdf
Irving, R; Elfarra, AA. (2013). Mutagenicity of the cysteine S-conjugate sulfoxides of trichloroethylene and tetrachloroethylene in the Ames test. Toxicology 306: 157-161. http://dx.doi.org/10.1016/j.tox.2013.02.003
Ji, J; Granström, C; Hemminki, K. (2005a). Occupation and bladder cancer: A cohort study in Sweden. Br J Cancer 92: 1276-1278. http://dx.doi.org/10.1038/sj.bjc.6602473
Ji, J; Granström, C; Hemminki, K. (2005b). Occupational risk factors for kidney cancer: A cohort study in Sweden. World Journal of Urology 23: 271-278. http://dx.doi.org/10.1007/s00345-005-0007-5
Ji, J; Hemminki, K. (2005). Variation in the risk for liver and gallbladder cancers in socioeconomic and occupational groups in Sweden with etiological implications. Int Arch Occup Environ Health 78: 641-649. http://dx.doi.org/10.1007/s00420-005-0015-1
Ji, J; Hemminki, K. (2006). Socioeconomic/occupational risk factors for lymphoproliferative diseases in Sweden. Ann Epidemiol 16: 370-376. http://dx.doi.org/10.1016/j.annepidem.2005.09.002
Jia, C; Batterman, S; Godwin, C. (2008a). VOCs in industrial, urban and suburban neighborhoods, Part 1: Indoor and outdoor concentrations, variation, and risk drivers. Atmos Environ 42: 2083-2100. http://dx.doi.org/10.1016/j.atmosenv.2007.11.055
Jia, CR; D'Souza, J; Batterman, S. (2008b). Distributions of personal VOC exposures: A population-based analysis. Environ Int 34: 922-931. http://dx.doi.org/10.1016/j.envint.2008.02.002
Jisa. (1993). Carcinogenicity study of tetrachloroethylene by inhalation in rats and mice. Hadano, Japan. https://www.epa.gov/iris/supporting-documents-tetrachloroethylene-perchloroethylene
Jonker, D; Woutersen, RA; Feron, VJ. (1996). Toxicity of mixtures of nephrotoxicants with similar or dissimilar mode of action. Food Chem Toxicol 34: 1075-1082. http://dx.doi.org/10.1016/S0278-6915(97)00077-X
Kalkbrenner, AE; Daniels, JL; Chen, JC; Poole, C; Emch, M; Morrissey, J. (2010). Perinatal exposure to hazardous air pollutants and autism spectrum disorders at age 8. Epidemiology 21: 631-641. http://dx.doi.org/10.1097/EDE.0b013e3181e65d76
Kanegsberg, B; Kanegsberg, E. (2011). Handbook for critical cleaning, cleaning agents and systems (2nd ed.). Boca Raton, FL: CRC Press.
Kaplan, BLF; Sulentic, CEW; Haggerty, HG; Holsapple, MP; Kaminski, NE. (2018). Chapter 12: Toxic responses of the immune system. In CD Klaassen (Ed.), (9th ed., pp. 633-717). New York, NY: McGraw Hill.
Karlsson, JE; Rosengren, LE; Kjellstrand, P; Haglid, KG. (1987). Effects of low-dose inhalation of three chlorinated aliphatic organic solvents on deoxyribonucleic acid in gerbil brain [Comment]. Scand J Work Environ Health 13: 453-458. http://dx.doi.org/10.5271/sjweh.2015
Kasting, BG; Miller, MA. (2006). Kinetics of finite dose absorption through skin 2: Volatile compounds. J Pharm Sci 95: 268-280. http://dx.doi.org/10.1002/jps.20497
Kawasaki, M. (1980). Experiences with the test scheme under the chemical control law of Japan: An approach to structure-activity correlations. Ecotoxicol Environ Saf 4: 444-454. http://dx.doi.org/10.1016/0147-6513(80)90046-9

Kawauchi, T; Nishiyama, K. (1989). Residual tetrachloroethylene in dry-cleaned clothes. Environ Res 48: 296-301.
Kendrick, TF. (1929). The treatment of hookworm disease with tetrachloroethylene. Am J Trop Med Hyg 9: 483-488.
Kezic, S; Monster, AC; van de Gevel, I; Krüse, J; Opdam, JG; Verberk, MM. (2001). Dermal absorption of neat liquid solvents on brief exposures in volunteers. Am Ind Hyg Assoc J 62: 12-18. http://dx.doi.org/10.1080/15298660108984604
Kido, T; Sugaya, C; Ikeuchi, R; Kudo, Y; Tsunoda, M; Aizawa, Y. (2013). The Increases in mRNA Expressions of Inflammatory Cytokines by Adding Cleaning Solvent or Tetrachloroethylene in the Murine Macrophage Cell Line J774.1 Evaluated by Real-time PCR. Ind Health 51: 319-325.
Kiurski, JS; Oros, IB; Kecic, VS; Kovacevic, IM; Aksentijevic, SM. (2016). The temporal variation of indoor pollutants in photocopying shop. Stoch Environ Res Risk Assess 30: 1289-1300. http://dx.doi.org/10.1007/s00477-015-1107-4
Kjellstrand, P; Holmquist, B; Kanje, M; Alm, P; Romare, S; Jonsson, I; Mansson, L; Bjerkemo, M. (1984). Perchloroethylene: Effects on body and organ weights and plasma butyrylcholinesterase activity in mice. Acta Pharmacol Toxicol 54: 414-424. http://dx.doi.org/10.1111/j.1600-0773.1984.tb01951.x
Klaunig, JE; Babich, MA; Baetcke, KP; Cook, JC; Corton, JC; David, RM; Deluca, JG; Lai, DY; McKee, RH; Peters, JM; Roberts, RA; Fenner-Crisp, PA. (2003). PPARalpha agonist-induced rodent tumors: modes of action and human relevance [Review]. Crit Rev Toxicol 33: 655-780. http://dx.doi.org/10.1080/713608372
Kleymenova, E; Everitt, JI; Pluta, L; Portis, M; Gnarra, JR; Walker, CL. (2004). Susceptibility to vascular neoplasms but no increased susceptibility to renal carcinogenesis in Vhl knockout mice. Carcinogenesis 25: 309-315. http://dx.doi.org/10.1093/carcin/bgh017
Kline, SA; McCoy, EC; Rosenkranz, HS; Van Duuren, BL. (1982). Mutagenicity of chloroalkene epoxides in bacterial systems. Mutat Res 101: 115-125. http://dx.doi.org/10.1016/0165-1218(82)90002-7
Koch, R; Schlegelmilch, R; Wolf, HU. (1988). Genetic effects of chlorinated ethylenes in the yeast Saccharomyces cerevisiae. Mutat Res 206: 209-216. http://dx.doi.org/10.1016/0165-1218(88)90162-0
Koizumi, A. (1989). Potential of physiologically based pharmacokinetics to amalgamate kinetic data of trichloroethylene and tetrachloroethylene obtained in rats and man. Br J Ind Med 46: 239-249.
Koppel, C; Arndt, I; Arendt, U; Koeppe, P. (1985). Acute tetrachloroethylene poisoning - Blood elimination kinetics during hyperventilation therapy. Clin Toxicol 23: 103-115. http://dx.doi.org/10.3109/15563658508990621
Kowalska, J; Gierczak, T. (2013). Qualitative and quantitative analyses of the halogenated volatile organic compounds emitted from the office equipment items. Indoor Built Environ 22: 920-931. http://dx.doi.org/10.1177/1420326X12458299
Kringstad, KP; Ljungquist, PO; de Sousa, F; Stromberg, LM. (1981). Identification and mutagenic properties of some chlorinated aliphatic compounds in the spent liquor from kraft pulp chlorination. Environ Sci Technol 15: 562-566. http://dx.doi.org/10.1021/es00087a006
Krock, R. (2017a). Comment submitted by Richard Krock, Vice President, Regulatory and Technical Affairs, The Vinyl Institute (VI) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0736-0063
Krock, R. (2017b). Comment submitted by Richard Krock, Vice President, Regulatory and Technical Affairs, The Vinyl Institute (VI), Part 2 [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0733-0027

Küçük, M; Korkmaz, Y. (2012). The effect of physical parameters on sound absorption properties of natural fiber mixed nonwoven composites. Text Res J 82: 2043-2053. http://dx.doi.org/10.1177/0040517512441987
Kyrklund, T; Alling, C; Kjellstrand, P; Haglid, KG. (1984). Chronic effects of perchloroethylene on the composition of lipid and acyl groups in cerebral cortex and hippocampus of the gerbil. Toxicol Lett 22: 343-349. http://dx.doi.org/10.1016/0378-4274(84)90112-7
Kyrklund, T; Kjellstrand, P; Haglid, KG. (1987). Lipid composition and fatty acid pattern of the gerbil brain after exposure to perchloroethylene. Arch Toxicol 60: 397-400. http://dx.doi.org/10.1007/BF00295762
Kyrklund, T; Kjellstrand, P; Haglid, KG. (1990). Long-term exposure of rats to perchloroethylene, with and without a post-exposure solvent-free recovery period: Effects on brain lipids. Toxicol Lett 52: 279-285. http://dx.doi.org/10.1016/0378-4274(90)90037-M
Kyyronen, P; Taskinen, H; Lindbohm, ML; Hemminki, K; Heinonen, OP. (1989). Spontaneous abortions and congenital malformations among women exposed to tetrachloroethylene in dry cleaning. J Epidemiol Community Health 43: 346-351. http://dx.doi.org/10.1136/jech.43.4.346
Labra, M; Mattia, F; Bernasconi, M; Bertacchi, D; Grassi, F; Bruni, I; Citterio, S. (2010). The Combined Toxic and Genotoxic Effects of Chromium and Volatile Organic Contaminants to Pseudokirchneriella subcapitata. Water Air Soil Pollut 213: 57-70. http://dx.doi.org/10.1007/s11270-010-0367-3
Lacey, JV, Jr.; Garabrant, DH; Laing, TJ; Gillespie, BW; Mayes, MD; Cooper, BC; Schottenfeld, D. (1999). Petroleum distillate solvents as risk factors for undifferentiated connective tissue disease (UCTD). Am J Epidemiol 149: 761-770.
Lange, NA; Dean, JA. (1985). Lange's handbook of chemistry (13th ed.). New York, NY: McGraw-Hill.
Lash, LH; Parker, JC. (2001). Hepatic and renal toxicities associated with perchloroethylene [Review]. Pharmacol Rev 53: 177-208.
Lash, LH; Qian, W; Putt, DA; Hueni, SE; Elfarra, AA; Sicuri, AR; Parker, JC. (2002). Renal toxicity of perchloroethylene and S-(1,2,2-trichlorovinyl)glutathione in rats and mice: sex- and species-dependent differences. Toxicol Appl Pharmacol 179: 163-171. http://dx.doi.org/10.1006/taap.2001.9358
Lauwerys, R; Herbrand, J; Buchet, JP; Bernard, A; Gaussin, J. (1983). Health surveillance of workers exposed to tetrachloroethylene in dry-cleaning shops. Int Arch Occup Environ Health 52: 69-77. http://dx.doi.org/10.1007/BF00380609
Lee, LJH; Chung, CW; Ma, YC; Wang, GS; Chen, PC; Hwang, YH; Wang, JD. (2003). Increased mortality odds ratio of male liver cancer in a community contaminated by chlorinated hydrocarbons in groundwater. Occup Environ Med 60: 364-369. http://dx.doi.org/10.1136/oem.60.5.364
Lehmann, I; Rehwagen, M; Diez, U; Seiffart, A; Rolle-Kampczyk, U; Richter, M; Wetzig, H; Borte, M; Herbarth, O. (2001). Enhanced in vivo IgE production and T cell polarization toward the type 2 phenotype in association with indoor exposure to VOC: Results of the LARS study. Int J Hyg Environ Health 204: 211-221. http://dx.doi.org/10.1078/1438-4639-00100
Lehmann, I; Thoelke, A; Rehwagen, M; Rolle-Kampczyk, U; Schlink, U; Schulz, R; Borte, M; Diez, U; Herbarth, O. (2002). The influence of maternal exposure to volatile organic compounds on the cytokine secretion profile of neonatal T cells. Environ Toxicol 17: 203-210. http://dx.doi.org/10.1002/tox.10055
Lewis, RJ, Sr. (2007). Hawley's condensed chemical dictionary (15th ed.). Hoboken, NJ: John Wiley & Sons. http://dx.doi.org/10.1002/9780470114735
Lewis, RJ, Sr. (1992). Sax's dangerous properties of industrial materials: v III (8th ed.). New York, NY: Van Nostrand Reinhold.

Li, X; Sundquist, J; Sundquist, K. (2008). Socioeconomic and occupational risk factors for rheumatoid arthritis: A nationwide study based on hospitalizations in Sweden. J Rheumatol 35: 986-991.
Lide, DR. (2007). CRC handbook of chemistry and physics: A ready-reference book of chemical and physical data. In DR Lide (Ed.), (88th ed.). Boca Raton, FL: CRC Press.
Lin, JH. (1995). Species similarities and differences in pharmacokinetics [Review]. Drug Metab Dispos 23: 1008-1021.
Lindbohm, ML; Sallmén, M; Kyyrönen, P; Kauppinen, T; Pukkala, E. (2009). Risk of liver cancer and exposure to organic solvents and gasoline vapors among Finnish workers. Int J Cancer 124: 2954-2959. http://dx.doi.org/10.1002/ijc.24309
Lindbohm, ML; Taskinen, H; Sallmen, M; Hemminki, K. (1990). Spontaneous abortions among women exposed to organic solvents. Am J Ind Med 17: 449-463. http://dx.doi.org/10.1002/ajim.4700170404
Lindstrom, AB; Proffitt, D; Fortune, CR. (1995). Effects of modified residential construction on indoor air quality. Indoor Air 5: 258-269. http://dx.doi.org/10.1111/j.1600-0668.1995.00005.x
Lipworth, L; Sonderman, JS; Mumma, MT; Tarone, RE; Marano, DE; Boice, JD; McLaughlin, JK. (2011). Cancer mortality among aircraft manufacturing workers: An extended follow-up. J Occup Environ Med 53: 992-1007. http://dx.doi.org/10.1097/JOM.0b013e31822e0940
Long, JL; Stensel, HD; Ferguson, JF; Strand, SE; Ongerth, JE. (1993). Anaerobic and aerobic treatment of chlorinated aliphatic compounds. J Environ Eng 119: 300-320. http://dx.doi.org/10.1061/(ASCE)0733-9372(1993)119:2(300)
Love, JR. (1982). Health hazard evaluation report no. HETA 81-310-1039, King-Smith Printing Company, Detroit, Michigan. (HETA 81-310-1039). Cincinnati, OH: National Institute for Occupational Safety and Health.
Lucas, D; Hervé, A; Lucas, R; Cabioch, C; Capellmann, P; Nicolas, A; Bodenes, A; Jegaden, D. (2015). Assessment of exposure to perchloroethylene and its clinical repercussions for 50 dry-cleaning employees. J Occup Environ Hyg 12: 767-773. http://dx.doi.org/10.1080/15459624.2015.1048346
Lumpkin, MH; Bruckner, JV; Campbell, JL; Dallas, CE; White, CA; Fisher, JW. (2003). Plasma binding of trichloroacetic acid in mice, rats, and humans under cancer bioassay and environmental exposure conditions. Drug Metab Dispos 31: 1203-1207. http://dx.doi.org/10.1124/dmd.31.10.1203
Lundberg, I; Alfredsson, L; Plato, N; Sverdrup, B; Klareskog, L; Kleinau, S. (1994). Occupation, occupational exposure to chemicals and rheumatological disease: A register based cohort study. Scand J Rheumatol 23: 305-310. http://dx.doi.org/10.3109/03009749409099278
Luo, Y; Cichocki, JA; Hsieh, N; Lewis, L; Wright, FA; Threadgill, DW; Chiu, WA; Rusyn, I. (2019). Using collaborative cross mouse population to fill data gaps in risk assessment: a case study of population-based analysis of toxicokinetics and kidney toxicodynamics of tetrachloroethylene. Environ Health Perspect 127: 067011. http://dx.doi.org/10.1289/EHP5105
Luo, Y; Hsieh, N; Soldatow, VY; Chiu, WA; Rusyn, I. (2018a). Comparative analysis of metabolism of trichloroethylene and tetrachloroethylene among mouse tissues and strains. Toxicology 409: 33-43. http://dx.doi.org/10.1016/j.tox.2018.07.012
Luo, YS; Cichocki, JA; McDonald, TJ; Rusyn, I. (2017). Simultaneous detection of the tetrachloroethylene metabolites S-(1,2,2-trichlorovinyl) glutathione, S-(1,2,2-trichlorovinyl)-L-cysteine, and N-acetyl-S-(1,2,2-trichlorovinyl)-L-cysteine in multiple mouse tissues via ultra-high performance liquid chromatography electrospray ionization tandem mass spectrometry. J Toxicol Environ Health A 80: 513-524. http://dx.doi.org/10.1080/15287394.2017.1330585
Luo, YS; Furuya, S; Soldatov, VY; Kosyk, O; Yoo, HS; Fukushima, H; Lewis, L; Iwata, Y; Rusyn, I. (2018b). Metabolism and Toxicity of Trichloroethylene and Tetrachloroethylene in Cytochrome

P450 2E1 Knockout and Humanized Transgenic Mice. Toxicol Sci 164: 489-500. http://dx.doi.org/10.1093/toxsci/kfy099
Luo, Yu; Hsieh, N; Soldatow, VY; Chiu, WA; Rusyn, I. (2018c). Comparative analysis of metabolism of trichloroethylene and tetrachloroethylene among mouse tissues and strains. Toxicology 409: 33-43. http://dx.doi.org/10.1016/j.tox.2018.07.012
Lynge, E; Andersen, A; Rylander, L; Tinnerberg, H; Lindbohm, ML; Pukkala, E; Romundstad, P; Jensen, P; Clausen, LB; Johansen, K. (2006). Cancer in persons working in dry cleaning in the Nordic countries. Environ Health Perspect 114: 213-219. http://dx.doi.org/10.1289/ehp.8425
Lynge, E; Carstensen, B; Andersen, O. (1995). Primary liver cancer and renal cell carcinoma in laundry and dry-cleaning workers in Denmark. Scand J Work Environ Health 21: 293-295.
Lynge, E; Thygesen, L. (1990). Primary liver cancer among women in laundry and dry-cleaning work in Denmark. Scand J Work Environ Health 16: 108-112.
M.S.C. Industrial Supply Inc. (2019). AlumTap: 1 Pt Can Cutting & Tapping Fluid. https://www.mscdirect.com/product/details/00265025?rItem=00265025
Mahle, DA; Gearhart, JM; Grigsby, CC; Mattie, DR; Barton, HA; Lipscomb, JC; Cook, RS. (2007). Age-dependent partition coefficients for a mixture of volatile organic solvents in Sprague-Dawley rats and humans. J Toxicol Environ Health A 70: 1745-1751. http://dx.doi.org/10.1080/15287390701458991
Maloney, EK; Waxman, DJ. (1999). trans-Activation of PPARalpha and PPARgamma by structurally diverse environmental chemicals. Toxicol Appl Pharmacol 161: 209-218. http://dx.doi.org/10.1006/taap.1999.8809
Mandel, JS; McLaughlin, JK; Schlehofer, B; Mellemgaard, A; Helmert, U; Lindblad, P; McCredie, M; Adami, HO. (1995). International renal-cell cancer study. IV. Occupation. Int J Cancer 61: 601-605. http://dx.doi.org/10.1002/ijc.2910610503
Marano, DE; Boice, JD, Jr.; Fryzek, JP; Morrison, JA; Sadler, CJ; McLaughlin, JK. (2000). Exposure assessment for a large epidemiological study of aircraft manufacturing workers. Appl Occup Environ Hyg 15: 644-656. http://dx.doi.org/10.1080/10473220050075653
Marquart, H; Franken, R; Goede, H; Fransman, W; Schinkel, J. (2017). Validation of the dermal exposure model in ECETOC TRA. Ann Work Expo Health 61: 854-871. http://dx.doi.org/10.1093/annweh/wxx059
Marth, E. (1987). Metabolic changes following oral exposure to tetrachloroethylene in subtoxic concentrations. Arch Toxicol 60: 293-299.
Marth, E; Stuenzner, D; Binder, H; Moese, JR. (1985a). Tetrachlorethylen: eine Studie uber die Wirkung niedriger Konzentrationen von 1,1,2,2,-Tetrachlorethylen (Perchlorethylen) am Organismus der Maus II Ruckstandsuntersuchungen von Tetrachlorethylen in verschiedenen Organen und Nachweis von histologischen Veranderungen der untersuchten organe. Zentralbl Bakteriol Mikrobiol Hyg B 181: 541-547.
Marth, E; Stunzner, D; Binder, H; Mose, JR. (1985b). [Tetrachloroethylene: effect of low concentrations of 1,1,2,2-tetrachloroethylene (perchloroethylene) on organisms in the mouse. I. Laboratory chemical research]. Zentralbl Bakteriol Mikrobiol Hyg B 181: 525-540.
Marth, E; Stünzner, D; Köck, M; Möse, JR. (1989). Toxicokinetics of chlorinated hydrocarbons. J Hyg Epidemiol Microbiol Immunol 33: 514-520.
Matsushima, T; Hayashi, M; Matsuoka, A; Ishidate, M; Miura, KF; Shimizu, H; Suzuki, Y; Morimoto, K; Ogura, H; Mure, K; Koshi, K; Sofuni, T. (1999). Validation study of the in vitro micronucleus test in a Chinese hamster lung cell line (CHL/IU). Mutagenesis 14: 569-580. http://dx.doi.org/10.1093/mutage/14.6.569
Mattei, F; Guida, F; Matrat, M; Cenée, S; Cyr, D; Sanchez, M; Radoi, L; Menvielle, G; Jellouli, F; Carton, M; Bara, S; Marrer, E; Luce, D; Stücker, I. (2014). Exposure to chlorinated solvents and

lung cancer: Results of the ICARE study. Occup Environ Med 71: 681-689. http://dx.doi.org/10.1136/oemed-2014-102182

Mattsson, J; Albee, RR; Yano, BL; Bradley, GJ; Spencer, PJ. (1998). Neurotoxicologic examination of rats exposed to 1,1,2,2-tetrachloroethylene (perchloroethylene) vapor for 13 weeks. Neurotoxicol Teratol 20: 83-98.

Mazzullo, M; Grilli, S; Lattanzi, G; Prodi, G; Turina, MP; Colacci, A. (1987). Evidence of DNA binding activity of perchloroethylene. Res Commun Chem Pathol Pharmacol 58: 215-235.

McCormick, L. (2017). Comment submitted by Lindsay McCormick, Chemicals and Health Project Manager on behalf of Environmental Defense Fund (EDF) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0723-0021

McGoldrick, T; Lock, E; Rodilla, V; Hawksworth, G. (2003). Renal cysteine conjugate C-S lyase mediated toxicity of halogenated alkenes in primary cultures of human and rat proximal tubular cells. Arch Toxicol 77: 365-370. http://dx.doi.org/10.1007/s00204-003-0459-6

Mersch-Sundermann, V; Schneider, U; Klopman, G; Rosenkranz, HS. (1994). SOS induction in Escherichia coli and Salmonella mutagenicity: A comparison using 330 compounds [Review]. Mutagenesis 9: 205-224. http://dx.doi.org/10.1093/mutage/9.3.205

Miligi, L; Costantini, AS; Benvenuti, A; Kriebel, D; Bolejack, V; Tumino, R; Ramazzotti, V; Rodella, S; Stagnaro, E; Crosignani, P; Amadori, D; Mirabelli, D; Sommani, L; Belletti, I; Troschel, L; Romeo, L; Miceli, G; Tozzi, GA; Mendico, I; Vineis, P. (2006). Occupational exposure to solvents and the risk of lymphomas. Epidemiology 17: 552-561. http://dx.doi.org/10.1097/01.ede.0000231279.30988.4d

Milman, HA; Story, DL; Riccio, ES; Sivak, A; Tu, AS; Williams, GM; Tong, C; Tyson, CA. (1988). Rat liver foci and in vitro assays to detect initiating and promoting effects of chlorinated ethanes and ethylenes. Ann N Y Acad Sci 534: 521-530. http://dx.doi.org/10.1111/j.1749-6632.1988.tb30143.x

Monster, AC; Boersma, G; Steenweg, H. (1979). Kinetics of tetrachloroethylene in volunteers; influence of exposure concentration and work load. Int Arch Occup Environ Health 42: 303-309.

Moody, PL; Kramkowski, R; Keyserling, M. (1983). Health Hazard Evaulation Report HETA 81-409-1290: The Donaldson Company, Inc. (HETA 81-409-1290). NIOSH. https://www.cdc.gov/niosh/hhe/reports/pdfs/81-409-1290.pdf?id=10.26616/NIOSHHETA814091290

Morales-Suárez-Varela, MM; Olsen, J; Villeneuve, S; Johansen, P; Kaerlev, L; Llopis-González, A; Wingren, G; Hardell, L; Ahrens, W; Stang, A; Merletti, F; Gorini, G; Aurrekoetxea, JJ; Févotte, J; Cyr, D; Guénel, P. (2013). Occupational exposure to chlorinated and petroleum solvents and mycosis fungoides. J Occup Environ Med 55: 924-931. http://dx.doi.org/10.1097/JOM.0b013e3182941a1c

Morrison, RD; Murphy, BL. (2013). Chlorinated solvents: A forensic evaluation. Cambridge, UK: The Royal Society of Chemistry.

Morton, LM; Hartge, P; Holford, TR; Holly, EA; Chiu, BC; Vineis, P; Stagnaro, E; Willett, EV; Franceschi, S; La Vecchia, C; Hughes, AM; Cozen, W; Davis, S; Severson, RK; Bernstein, L; Mayne, ST; Dee, FR; Cerhan, JR; Zheng, T. (2005). Cigarette smoking and risk of non-Hodgkin lymphoma: A pooled analysis from the International Lymphoma Epidemiology Consortium (InterLymph) [Review]. Cancer Epidemiol Biomarkers Prev 14: 925-933. http://dx.doi.org/10.1158/1055-9965.EPI-04-0693

Moseley, CL. (1980). Health hazard evaluation report no. HHE 79-42-685, Motion Picture Screen Cartoonists, Local 841, New York, New York. (HHE 79-42-685). Cincinnati, OH: National Institute for Occupational Safety and Health.

Moseley, CL; McConnell, R. (1985). Health Hazard Evaluation Report HETA-85-108-1593, Carey Plastics Division, Toledo Molding and Die Corp. (HETA-85-108-1593). NTIS. https://search.proquest.com/docview/14475370?accountid=171501
Moser, VC; Cheek, BM; Macphail, RC. (1995). A multidisciplinary approach to toxicological screening: III. Neurobehavioral toxicity. J Toxicol Environ Health 45: 173-210. [Journal of toxicology and environmental health].
Murakami, K; Horikawa, K. (1995). The induction of micronuclei in mice hepatocytes and reticulocytes by tetrachloroethylene. Chemosphere 31: 3733-3739. http://dx.doi.org/10.1016/0045-6535(95)00222-T
Mutti, A; Alinovi, R; Bergamaschi, E; Biagini, C; Cavazzini, S; Franchini, I; Lauwerys, RR; Bernard, AM; Roels, H; Gelpi, E; Rosello, J; Ramis, I; Price, RG; Taylor, SA; de Broe, M; Nuyts, GD; Stolte, H; Fels, LM; Herbort, C. (1992). Nephropathies and exposure to perchloroethylene in dry-cleaners. Lancet 330: 189-193. http://dx.doi.org/10.1016/0140-6736(92)90463-D
NAC/AEGL. (2009). Tetrachloroethylene (CAS reg. no. 127-18-4): Interim acute exposure guideline levels (AEGLs). (Interim 1 modified without modeling results) [AEGL]. Washington, DC: National Advisory Committee for Acute Exposure Guideline Levels. https://www.epa.gov/sites/production/files/2014-08/documents/tetrachloroethylene_interim_ornl_dec2009c.pdf
Nakatsuka, H; Watanabe, T; Takeuchi, Y; Hisanaga, N; Shibata, E; Suzuki, H; Huang, MY; Chen, Z; Qu, QS; Ikeda, M. (1992). Absence of blue-yellow color vision loss among workers exposed to toluene or tetrachloroethylene, mostly at levels below occupational exposure limits. Int Arch Occup Environ Health 64: 113-117. http://dx.doi.org/10.1007/BF00381478
Namkung, E; Rittmann, BE. (1987). Estimating Volatile Organic Compound Emissions from Publicly Owned Treatment Works (pp. 670-678). (NIOSH/00172323). Namkung, E; Rittmann, BE.
Nci. (1977). Bioassay of tetrachloroethylene for possible carcinogenicity. (NCI-CGTR-13; DHEW Publication No. (NIH) 77-813). Bethesda, Md: National Institutes of Health. http://ntp.niehs.nih.gov/ntp/htdocs/LT_rpts/tr013.pdf
Nelson, BK; Taylor, BJ; Setzer, JV; Hornung, RW. (1979). Behavioral teratology of perchloroethylene in rats. J Environ Pathol Toxicol Oncol 3: 233-250.
Neta, G; Stewart, PA; Rajaraman, P; Hein, MJ; Waters, MA; Purdue, MP; Samanic, C; Coble, JB; Linet, MS; Inskip, PD. (2012). Occupational exposure to chlorinated solvents and risks of glioma and meningioma in adults. Occup Environ Med 69: 793-801. http://dx.doi.org/10.1136/oemed-2012-100742
Newmoa. (2001). Pollution prevention technology profile - Closed loop vapor degreasing. Boston, MA. http://www.newmoa.org/prevention/p2tech/ProfileVaporDegreasing.pdf
Nfpa. (2010). Fire protection guide to hazardous materials (14th ed.). Quincy, MA.
NICNAS. (2001). Tetrachloroethylene – Priority existing chemical. Assessment Report No. 15. http://www.nicnas.gov.au/publications/car/pec/pecindex.htm
Niederlehner, B; Cairns, J; Smith, E. (1998). Modeling acute and chronic toxicity of nonpolar narcotic chemicals and mixtures to Ceriodaphnia dubia. Ecotoxicol Environ Saf 39: 136-146. http://dx.doi.org/10.1006/eesa.1997.1621
NIOSH. (1976). Criteria for a recommended standard occupational exposure to tetrachloroethylene (perchloroethylene). (NIOSH-HSM-99-73-20; PB90-180092). Cincinnati, OH.
NIOSH. (1980). Health Hazard Evaluation report no. HHE 80-18-691, Looart Press Incorporate, Colorado Springs,Colorado. (HHE 80-18-691). Washington, DC: U.S. Department of Health and Human Services.

NIOSH. (1995). In-depth survey report: control of perchloroethylene exposures in commercial dry cleaners at Brown's Cleaners, Sant Monica, California. (ECTB 201-16a). The National Institute for Occupational Safety and Health.
NIOSH. (1997a). Control of health and safety hazards in commercial drycleaners: chemical exposures, fire hazards, and ergonomic risk factors. (DHHS (NIOSH) Publication Number 97-150). Atlanta, GA. http://www.cdc.gov/niosh/docs/97-150/
NIOSH. (1997b). Hazard control: Control of exposure to perchloroethylene in commercial drycleaning (machine design) (HC 18). (97-156). https://www.cdc.gov/niosh/docs/hazardcontrol/pdfs/hc18.pdf?id=10.26616/NIOSHPUB97156
NIOSH. (2000). In-depth survey report: Comparision of perchloroethylene exposures before and after the installation of local exhaust ventilation at a commercial dry cleaners at drycleaning plus. (ECTB 240-13). CDC. http://www.cdc.gov/niosh/nioshtic-2/20000629.html
NIOSH. (2001a). Evaluation of Solvent Exposures from the Degreaser. Trilthic Inc., IN. (HETA 2000-0233-2845). NIOSH Publishing Office: National Institute of Occupational Safety and Health. http://www.cdc.gov/niosh/hhe/reports/pdfs/2000-0233-2845.pdf
NIOSH. (2001b). Respirator Usage in Private Sector Firms. Washington D.C.: United States Department of Labor, Bureau of Labor Statistics and National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/docs/respsurv/
NIOSH. (2002a). In-depth survey report: control of perchloroethylene (PCE) in vapor degreasing operations, site #1. (EPHB 256-19b). Cincinnati, Ohio: National Institute for Occupational Safety and Health (NIOSH).
NIOSH. (2002b). In-depth survey report: Control of perchloroethylene (PCE) in vapor degreasing operations, site #2. (EPHB 256-16b). CDC. https://www.cdc.gov/niosh/surveyreports/pdfs/256-16b.pdf
NIOSH. (2002c). In-depth survey report: control of perchloroethylene (PCE) in vapor degreasing operations, site #4. (EPHB 256-18b). Cincinnati, Ohio: National Institute for Occupational Safety and Health (NIOSH).
NIOSH. (2002d). In-depth survey report: Control of perchloroethylene exposure (PCE) in vapor degreasing operations, site #3. (EPHB 256-17b). CDC. https://www.cdc.gov/niosh/surveyreports/pdfs/ECTB-256-17b.pdf
NIOSH. (2005). NIOSH pocket guide to chemical hazards & other databases CD-ROM. (DHHS-2005-151). Cincinnati, OH.
NRC. (2001). Standing Operating Procedures for Developing Acute Exposure Guideline Levels for Hazardous Chemicals. http://www.nap.edu/catalog.php?record_id=10122
NRC. (2010). Review of the Environmental Protection Agency's draft IRIS assessment of tetrachloroethylene. Washington, DC: National Academies Press.
NTP. (1986a). Toxicology and carcinogenesis studies of tetrachloroethylene (perchloroethylene) (CAS No. 127-18-4) in F344 rats and B6C3F1 mice (inhalation studies). (NTP TR 311). Research Triangle Park, NC: U.S. Department of Health and Human Services. http://ntp.niehs.nih.gov/ntp/htdocs/LT_rpts/tr311.pdf
NTP. (1986b). Toxicology and carcinogenesis studies of tetrachloroethylene (perchloroethylene) (CAS no. 127-18-4) in F344/N rats and B6C3F1 mice (inhalation studies). (NTP TR 311). Research Triangle Park, NC: U.S. Department of Health and Human Services, National Toxicology Program. http://ntp.niehs.nih.gov/ntp/htdocs/LT_rpts/tr311.pdf
NTP. (2014). 13th Report on carcinogens [NTP]. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service.
Nwqmc. (2017). Water quality portal. https://www.waterqualitydata.us/

Odum, J; Green, T; Foster, JR; Hext, PM. (1988). The role of trichloroacetic acid and peroxisome proliferation in the differences in carcinogenicity of perchloroethylene in the mouse and rat. Toxicol Appl Pharmacol 92: 103-112. http://dx.doi.org/10.1016/0041-008X(88)90232-3
OECD. (2011). Emission scenario document on the use of metalworking fluids. (JT03304938). Organization for Economic Cooperation and Development.
OECD. (2015). Emission scenario document on use of adhesives. In Series on Emission Scenario Documents No 34. (Number 34). Paris, France. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2015)4&doclanguage=en
OECD. (2017a). Draft ESD on Vapor Degreasing - Internal EPA document. Organization for Economic Co-operation and Development (OECD).
OECD. (2017b). Emission Scenario Document (ESD) on the use of textile dyes. http://www.oecd.org/chemicalsafety/risk-assessment/emissionscenariodocuments.htm
OEHHA. (2001). Public health goal for tetrachloroethylene in drinking water. Sacramento, CA. https://oehha.ca.gov/media/downloads/water/chemicals/phg/pceaug2001_0.pdf
OEHHA. (2016). Air Toxics Hot Spots Program: Perchloroethylene Inhalation Cancer Unit Risk Factor. https://oehha.ca.gov/media/downloads/crnr/pceurf090816.pdf
Olsen, J; Hemminki, K; Ahlborg, G; Bjerkedal, T; Kyyronen, P; Taskinen, H; Lindbohm, ML; Heinonen, OP; Brandt, L; Kolstad, H; Halvorsen, BA; Egenaes, J. (1990). Low birthweight, congenital malformations, and spontaneous abortions among dry-cleaning workers in Scandinavia. Scand J Work Environ Health 16: 163-168.
Opdam, JJ; Smolders, JF. (1986). Alveolar sampling and fast kinetics of tetrachloroethene in man. I. Alveolar sampling. Br J Ind Med 43: 814-824. http://dx.doi.org/10.1136/oem.43.12.814
Orris, P; Daniels, W. (1981). Health Hazard Evaluation Report 80-201-816: Peterson/Puritan Company. (HE 80-201-816). NIOSH. https://www.cdc.gov/niosh/hhe/reports/pdfs/80-201-816.pdf?id=10.26616/NIOSHHHE80201816
OSHA. (2005). Reducing worker exposure to perchloroethylene (PERC) in dry cleaning. (OSHA 3253-05N). Washington, DC: U.S. Department of Labor, Occupational Safety & Health Administration. https://www.osha.gov/dsg/guidance/perc.html
OSHA. (2017). Chemical Exposure Health Data (CEHD) provided by OSHA to EPA. U.S. Occupational Safety and Health Administration.
OSHA. (2020). Chemical Exposure Health Data (CEHD). Washington, DC. https://www.osha.gov/opengov/healthsamples.html
Oshiro, WM; Krantz, QT; Bushnell, PJ. (2008). Characterization of the effects of inhaled perchloroethylene on sustained attention in rats performing a visual signal detection task. Neurotoxicol Teratol 30: 167-174. http://dx.doi.org/10.1016/j.ntt.2008.01.002
Park, JH; Spengler, JD; Yoon, DW; Dumyahn, T; Lee, K; Ozkaynak, H. (1998). Measurement of air exchange rate of stationary vehicles and estimation of in-vehicle exposure. J Expo Anal Environ Epidemiol 8: 65-78.
Paulu, C; Aschengrau, A; Ozonoff, D. (1999). Tetrachloroethylene-contaminated drinking water in Massachusetts and the risk of colon-rectum, lung, and other cancers. Environ Health Perspect 107: 265-271.
Pegg, DG; Zempel, JA; Braun, WH; Watanabe, PG. (1979). Disposition of tetrachloro(14C)ethylene following oral and inhalation exposure in rats. Toxicol Appl Pharmacol 51: 465-474.
Pellizzari, ED; Hartwell, TD; Harris, BS, III; Waddell, RD; Whitaker, DA; Erickson, MD. (1982). Purgeable organic compounds in mother's milk. Bull Environ Contam Toxicol 28: 322-328. http://dx.doi.org/10.1007/BF01608515

Peplonska, B; Stewart, P; Szeszenia-Dabrowska, N; Rusiecki, J; Garcia-Closas, M; Lissowska, J; Bardin-Mikolajczak, A; Zatonski, W; Gromiec, J; Brzeznicki, S; Brinton, L; Blair, A. (2007). Occupation and breast cancer risk in Polish women: A population-based case-control study. Am J Ind Med 50: 97-111. http://dx.doi.org/10.1002/ajim.20420

Perocco, P; Bolognesi, S; Alberghini, W. (1983). Toxic activity of seventeen industrial solvents and halogenated compounds on human lymphocytes cultured in vitro. Toxicol Lett 16: 69-75. http://dx.doi.org/10.1016/0378-4274(83)90012-7

Pesch, B; Haerting, J; Ranft, U; Klimpel, A; Oelschlägel, B; Schill, W. (2000). Occupational risk factors for urothelial carcinoma: Agent-specific results from a case-control study in Germany. Int J Epidemiol 29: 238-247. http://dx.doi.org/10.1093/ije/29.2.238

Philip, BK; Mumtaz, MM; Latendresse, JR; Mehendale, HM. (2007). Impact of repeated exposure on toxicity of perchloroethylene in Swiss Webster mice. Toxicology 232: 1-14. http://dx.doi.org/10.1016/j.tox.2006.12.018

Pohlabeln, H; Boffetta, P; Ahrens, W; Merletti, F; Agudo, A; Benhamou, E; Benhamou, S; Bruske-Hohlfeld, I; Ferro, G; Fortes, C; Kreuzer, M; Mendes, A; Nyberg, F; Pershagen, G; Saracci, R; Schmid, G; Siemiatycki, J; Simonato, L; Whitley, E; Wichmann, HE; Winck, C; Zambon, P; Jockel, KH. (2000). Occupational risks for lung cancer among nonsmokers. Epidemiology 11: 532-538.

Potter, CL; Chang, LW; Deangelo, AB; Daniel, FB. (1996). Effects of four trihalomethanes on DNA strand breaks, renal hyaline droplet formation and serum testosterone in male F-344 rats. Cancer Lett 106: 235-242.

Preidis, GA; Kim, KH; Moore, DD. (2017). Nutrient-sensing nuclear receptors PPARa and FXR control liver energy balance [Review]. J Clin Invest 127: 1193-1201. http://dx.doi.org/10.1172/JCI88893

Price, PJ; Hassett, CM; Mansfield, JI. (1978). Transforming activities of trichloroethylene and proposed industrial alternatives. In Vitro 14: 290-293. http://dx.doi.org/10.1007/bf02616038

Products, AC. (2017). Maskants and their use in aerospace: Regulatory compliance of the industry. (EPA-HQ-OPPT-2016-0732-0077). Washington, D.C.: AC Products. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0077

Pukkala, E; Martinsen, J; Lynge, E; Gunnarsdottir, H; Sparén, P; Tryggvadottir, L; Weiderpass, E; Kjaerheim, K. (2009). Occupation and cancer - follow-up of 15 million people in five Nordic countries. Acta Oncol 48: 646-790. http://dx.doi.org/10.1080/02841860902913546

Purdue, MP; Stewart, PA; Friesen, MC; Colt, JS; Locke, SJ; Hein, MJ; Waters, MA; Graubard, BI; Davis, F; Ruterbusch, J; Schwartz, K; Chow, WH; Rothman, N; Hofmann, JN. (2017). Occupational exposure to chlorinated solvents and kidney cancer: A case-control study. Occup Environ Med 74: 268-274. http://dx.doi.org/10.1136/oemed-2016-103849

Rachootin, P; Olsen, J. (1983). The risk of infertility and delayed conception associated with exposures in the Danish workplace. J Occup Med 25: 394-402.

Radican, L; Blair, A; Stewart, P; Wartenberg, D. (2008). Mortality of aircraft maintenance workers exposed to trichloroethylene and other hydrocarbons and chemicals: Extended follow-up. J Occup Environ Med 50: 1306-1319. http://dx.doi.org/10.1097/JOM.0b013e3181845f7f

Ramdhan, DH; Kamijima, M; Wang, D; Ito, Y; Naito, H; Yanagiba, Y; Hayashi, Y; Tanaka, N; Aoyama, T; Gonzalez, FJ; Nakajima, T. (2010). Differential response to trichloroethylene-induced hepatosteatosis in wild-type and PPARalpha-humanized mice. Environ Health Perspect 118: 1557-1563. http://dx.doi.org/10.1289/ehp.1001928

Reichert, D; Neudecker, T; Spengler, U; Henschler, D. (1983). Mutagenicity of dichloroacetylene and its degradation products trichloroacetyl chloride, trichloroacryloyl chloride and hexachlorobutadiene. Mutat Res Genet Toxicol Environ Mutagen 117: 21-29. http://dx.doi.org/10.1016/0165-1218(83)90149-0

Reinhardt, CF; Mullin, LS; Maxfield, ME. (1973). Epinephrine-induced cardiac arrhythmia potential of some common industrial solvents. J Occup Environ Med 15: 953-955.
Reitz, RH; Gargas, ML; Mendrala, AL; Schumann, AM. (1996). In vivo and in vitro studies of perchloroethylene metabolism for physiologically based pharmacokinetic modeling in rats, mice, and humans. Toxicol Appl Pharmacol 136: 289-306. http://dx.doi.org/10.1006/taap.1996.0036
Richter, JE; Peterson, SF; Kleiner, CF. (1983). Acute and chronic toxicity of some chlorinated benzenes, chlorinated ethanes, and tetrachloroethylene to Daphnia magna. Arch Environ Contam Toxicol 12: 679-684. http://dx.doi.org/10.1007/BF01060751
Riddick, JA; Bunger, WB; Sakano, TK. (1985). Techniques of chemistry. Fourth edition. Organic solvents. New York, NY: John Wiley and Sons.
Riegle, L. (2017). Comment submitted by Leslie Riegle, Director, Environmental Policy, Aerospace Industries Association (AIA) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0733-0011
Roberts, AL; Lyall, K; Hart, JE; Laden, F; Just, AC; Bobb, JF; Koenen, KC; Ascherio, A; Weisskopf, MG. (2013). Perinatal air pollutant exposures and autism spectrum disorder in the children of Nurses' Health Study II participants. Environ Health Perspect 121: 978-984. http://dx.doi.org/10.1289/ehp.1206187
Roda, C; Kousignian, I; Ramond, A; Momas, I. (2013). Indoor tetrachloroethylene levels and determinants in Paris dwellings. Environ Res 120: 1-6. http://dx.doi.org/10.1016/j.envres.2012.09.005
Roldán-Arjona, T; García-Pedrajas, MD; Luque-Romero, FL; Hera, C; Pueyo, C. (1991). An association between mutagenicity of the ara test of salmonella typhimurium and carcinogenicity in rodents for 16 halogenated aliphatic hydrocarbons. Mutagenesis 6: 199-205. http://dx.doi.org/10.1093/mutage/6.3.199
Rosengren, LE; Kjellstrand, P; Haglid, KG. (1986). Tetrachloroethylene: Levels of DNA and S-100 in the gerbil CNS after chronic exposure. Neurobehav Toxicol Teratol 8: 201-206.
Rowe, VK; McCollister, DD; Spencer, HC; Adams, EM; Irish, DD. (1952). Vapor toxicity of tetrachloroethylene for laboratory animals and human subjects. Arch Environ Occup Health 5: 566-579.
Ruckart, PZ; Bove, FJ; Maslia, M. (2013). Evaluation of exposure to contaminated drinking water and specific birth defects and childhood cancers at Marine Corps Base Camp Lejeune, North Carolina: A case-control study. Environ Health 12: 104. http://dx.doi.org/10.1186/1476-069X-12-104
Ruckart, PZ; Bove, FJ; Maslia, M. (2014). Evaluation of contaminated drinking water and preterm birth, small for gestational age, and birth weight at Marine Corps Base Camp Lejeune, North Carolina: A cross-sectional study. Environ Health 13: 99. http://dx.doi.org/10.1186/1476-069X-13-99
Ruckart, PZ; Bove, FJ; Shanley, E, III; Maslia, M. (2015). Evaluation of contaminated drinking water and male breast cancer at Marine Corps Base Camp Lejeune, North Carolina: A case-control study. Environ Health 14: 74. http://dx.doi.org/10.1186/s12940-015-0061-4
Ruder, AM; Yiin, JH; Waters, MA; Carreon, T; Hein, MJ; Butler, MA; Calvert, GM; Davis-King, KE; Schulte, PA; Mandel, JS; Morton, RF; Reding, DJ; Rosenman, KD; Stewart, PA; Brain Cancer Collaborative Study, G. (2013). The Upper Midwest Health Study: Gliomas and occupational exposure to chlorinated solvents. Occup Environ Med 70: 73-80. http://dx.doi.org/10.1136/oemed-2011-100588
Rudnick, M. (2017a). Comment submitted by Michelle Rudnick, Senior Manager Regulatory Affairs, CRC Industries, Inc [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0741-0018

Rudnick, M. (2017b). Comment submitted by Michelle Rudnick, Senior Manager Regulatory Affairs, CRC Industries, Inc., Part 2 [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0743-0025
Ruhe, RL. (1982). Health hazard evaluation report no. HETA 82-040-119, Synthes Ltd. (USA), Monument, Colorado. (HETA 82-040-119). Cincinnati, OH: National Institute for Occupational Safety and Health.
Ruhe, RL. (1983). Health Hazard Evaluation Report No. HETA-83-266-1391, McCourt Label Company, Bradford, Pennsylvania (pp. 83-266). (NIOSH/00137711). Ruhe, RL.
Ryan, TJ; Hart, EM; Kappler, LL. (2002). VOC exposures in a mixed-use university art building. AIHA J 63: 703-708. http://dx.doi.org/10.1202/0002-8894(2002)063<0703:VEIAMU>2.0.CO;2
Sallmen, M; Lindbohm, ML; Kyyronen, P; Nykyri, E; Anttila, A; Taskinen, H; Hemminki, K. (1995). Reduced fertility among women exposed to organic solvents. Am J Ind Med 27: 699-713. http://dx.doi.org/10.1002/ajim.4700270506
Sanchez-Fortun, S; Sanz, F; Santa-Maria, A; Ros, JM; De Vicente, ML; Encinas, MT; Vinagre, E; Barahona, MV. (1997). Acute sensitivity of three age classes of Artemia salina larvae to seven chlorinated solvents. Bull Environ Contam Toxicol 59: 445-451. http://dx.doi.org/10.1007/s001289900498
Sandground, JH. (1941). Coma following medication with tetrachloroethylene. JAMA 117: 440-441.
Sarangapani, R; Gentry, PR; Covington, TR; Teeguarden, JG; Clewell, HJ, III. (2003). Evaluation of the potential impact of age- and gender-specific lung morphology and ventilation rate on the dosimetry of vapors. Inhal Toxicol 15: 987-1016. http://dx.doi.org/10.1080/08958370390226350
Sass, J. (2017). Comment submitted by Jennifer Sass, Ph.D., Senior Scientist, Natural Resources Defense Council (NRDC) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0737-0020
Sato, A; Nakajima, T. (1979). Partition coefficients of some aromatic hydrocarbons and ketones in water, blood and oil. Br J Ind Med 36: 231-234. http://dx.doi.org/10.1136/oem.36.3.231
Sax, SN; Bennett, DH; Chillrud, SN; Kinney, PL; Spengler, JD. (2004). Differences in source emission rates of volatile organic compounds in inner-city residences of New York City and Los Angeles. J Expo Anal Environ Epidemiol 14: S95-109. http://dx.doi.org/10.1038/sj.jea.7500364
Scher. (2008). Scientific opinion on the risk assessment report on tetrachloroethylene (CAS no. 127-18-4; EINECS no. 204-825-9). Human health part. European Union. https://ec.europa.eu/health/archive/ph_risk/committees/04_scher/docs/scher_o_088.pdf
Schlehofer, B; Heuer, C; Blettner, M; Niehoff, D; Wahrendorf, J. (1995). Occupation, smoking and demographic factors, and renal cell carcinoma in Germany. Int J Epidemiol 24: 51-57. http://dx.doi.org/10.1093/ije/24.1.51
Schlichting, LM; Wright, PF; Stacey, NH. (1992). Effects of tetrachloroethylene on hepatic and splenic lymphocytotoxic activities in rodents. Toxicol Ind Health 8: 255-266.
Schreiber, JS. (1993). Predicted infant exposure to tetrachloroethene in human breastmilk [Review]. Risk Anal 13: 515-524. http://dx.doi.org/10.1111/j.1539-6924.1993.tb00010.x
Schreiber, JS; Hudnell, HK; Geller, AM; House, DE; Aldous, KM; Force, MS; Langguth, K; Prohonic, EJ; Parker, JC. (2002). Apartment residents' and day care workers' exposures to tetrachloroethylene and deficits in visual contrast sensitivity. Environ Health Perspect 110: 655-664.
Schultz, IR; Merdink, JL; Gonzalez-Leon, A; Bull, RJ. (1999). Comparative toxicokinetics of chlorinated and brominated haloacetates in F344 rats. Toxicol Appl Pharmacol 158: 103-114. http://dx.doi.org/10.1006/taap.1999.8698

Schumann, AM; Quast, JF; Watanabe, PG. (1980). The pharmacokinetics and macromolecular interactions of perchloroethylene in mice and rats as related to oncogenicity. Toxicol Appl Pharmacol 55: 207-219. http://dx.doi.org/10.1016/0041-008X(80)90082-4
Schwetz, BA; Leong, BKJ; Gehring, PJ. (1975). The effect of maternally inhaled trichloroethylene, perchloroethylene, methyl chloroform, and methylene chloride on embryonal and fetal development in mice and rats. Toxicol Appl Pharmacol 32: 84-96. http://dx.doi.org/10.1016/0041-008X(75)90197-0
Scriven, EFV; Murugan, R. (2005). Pyridine and Pyridine Derivatives. http://dx.doi.org/10.1002/0471238961.1625180919031809.a01.pub2
Seeber, A. (1989). Neurobehavioral toxicity of long-term exposure to tetrachloroethylene. Neurotoxicol Teratol 11: 579-583. http://dx.doi.org/10.1016/0892-0362(89)90041-X
Seidel, HJ; Weber, L; Barthel, E. (1992). Hematological toxicity of tetrachloroethylene in mice. Arch Toxicol 66: 228-230. http://dx.doi.org/10.1007/BF01974021
Seidler, A; Möhner, M; Berger, J; Mester, B; Deeg, E; Elsner, G; Nieters, A; Becker, N. (2007). Solvent exposure and malignant lymphoma: A population-based case-control study in Germany. J Occup Med Toxicol 2: 2. http://dx.doi.org/10.1186/1745-6673-2-2
Seiji, K; Jin, C; Watanabe, T; Nakatsuka, H; Ikeda, M. (1990). Sister chromatid exchanges in peripheral lymphocytes of workers exposed to benzene, trichloroethylene, or tetrachloroethylene, with reference to smoking habits. Int Arch Occup Environ Health 62: 171-176. http://dx.doi.org/10.1007/BF00383594
Seldén, AI; Ahlborg, G. (2011). Cancer morbidity in Swedish dry-cleaners and laundry workers: Historically prospective cohort study. Int Arch Occup Environ Health 84: 435-443. http://dx.doi.org/10.1007/s00420-010-0582-7
Sexton, K; Adgate, JL; Church, TR; Ashley, DL; Needham, LL; Ramachandran, G; Fredrickson, AL; Ryan, AD. (2005). Children's exposure to volatile organic compounds as determined by longitudinal measurements in blood. Environ Health Perspect 113: 342-349. http://dx.doi.org/10.1289/ehp.7412
Sexton, K; Mongin, SJ; Adgate, JL; Pratt, GC; Ramachandran, G; Stock, TH; Morandi, MT. (2007). Estimating volatile organic compound concentrations in selected microenvironments using time-activity and personal exposure data. J Toxicol Environ Health A 70: 465-476. http://dx.doi.org/10.1080/15287390600870858
Sharanjeet-Kaur; Mursyid, A; Kamaruddin, A; Ariffin, A. (2004). Effect of petroleum derivatives and solvents on colour perception. Clin Exp Optom 87: 339-343. http://dx.doi.org/10.1111/j.1444-0938.2004.tb05064.x
Sherlach, KS; Gorka, AP; Dantzler, A; Roepe, PD. (2011). Quantification of perchloroethylene residues in dry-cleaned fabrics. Environ Toxicol Chem 30: 2481-2487. http://dx.doi.org/10.1002/etc.665
Shimada, T; Swanson, AF; Leber, P; Williams, GM. (1985). Activities of chlorinated ethane and ethylene compounds in the Salmonella/rat microsome mutagenesis and rat hepatocyte/DNA repair assays under vapor phase exposure conditions. Cell Biol Toxicol 1: 159-179. http://dx.doi.org/10.1007/BF00120162
Siemiatycki, J. (1991). Risk factors for cancer in the workplace. In J Siemiatycki (Ed.). Boca Raton, FL: CRC Press.
Silver, SR; Pinkerton, LE; Fleming, DA; Jones, JH; Allee, S; Luo, L; Bertke, SJ. (2014). Retrospective cohort study of a microelectronics and business machine facility. Am J Ind Med 57: 412-424. http://dx.doi.org/10.1002/ajim.22288
Singh, HB; Salas, LJ; Stiles, RE. (1983). Selected man-made halogenated chemicals in the air and oceanic environment. J Geophys Res 88: 3675-3683.

Smith, AD; Bharath, A; Mallard, C; Orr, D; Smith, K; Sutton, JA; Vukmanich, J; McCarty, LS; Ozburn, GW. (1991). The acute and chronic toxicity of 10 chlorinated organic-compounds to the american flagfish (jordanella-floridae). Arch Environ Contam Toxicol 20: 94-102.
Snedecor, G; Hickman, JC; Mertens, JA. (2004). Chloroethylenes and chloroethanes.
Sofuni, T; Hayashi, M; Matsuoka, A; Sawada, M; Hatanaka, M; Ishidate, M, Jr. (1985). [Mutagenicity tests on organic chemical contaminants in city water and related compounds. II. Chromosome aberration tests in cultured mammalian cells]. Kokuritsu Iyakuhin Shokuhin Eisei Kenkyūjo Hōkoku 103: 64-75.
Solet, D; Robins, TG. (1991). Renal function in dry cleaning workers exposed to perchloroethylene. Am J Ind Med 20: 601-614.
Spirit AeroSystems, I. (2017). Perchloroethylene usage at Spirit AeroSystems, Inc. (EPA-HQ-OPPT-2016-0732-0077). Washington, D.C.: Spirit AeroSystems Inc. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0077
Spirit AeroSystems, I. (2020). Comments to draft Risk Evaluation for perchloroethylene from Spirit AeroSystems to US EPA (Docket No. EPA-HQ-OPPT-2019-0502).
Stefaniak, AB; Breysse, PN; Murray, MPM; Rooney, BC; Schaefer, J. (2000). An evaluation of employee exposure to volatile organic compounds in three photocopy centers. Environ Res 83: 162-173. http://dx.doi.org/10.1006/enrs.2000.4061
Stemhagen, A; Slade, J; Altman, R; Bill, J. (1983). Occupational risk factors and liver cancer: A retrospective case-control study of primary liver cancer in New Jersey. Am J Epidemiol 117: 443-454.
Stephenson, RL; Albrecht, WN. (1986). Health Hazard Evaluation Report No. HETA-85-482-86-116-1730, Winters Industry Foundry, Canton, Ohio (pp. 85-482). (NIOSH/00166571). Stephenson, RL; Albrecht, WN.
Stewart, RD; Baretta, ED; Dodd, HC; Torkelson, TR. (1970). Experimental human exposure to tetrachloroethylene. Arch Environ Health 20: 224-229.
Stewart, RD; Gay, HH; Erley, DS; Hake, CL; Schaffer, AW. (1961). Human exposure to tetrachloroethylene vapor. Arch Environ Health 2: 516-522.
Stewart, RD; Hake, CL; Wu, A; Kalbfleisch, J; Newton, PE; Marlow, SK; Vucicevic-Salama, M. (1977). Effects of perchloroethylene/drug interaction on behavior and neurological function. Milwaukee, WI: Allen-Bradley Medical Science Laboratory.
Stingone, JA; McVeigh, KH; Claudio, L. (2016). Association between prenatal exposure to ambient diesel particulate matter and perchloroethylene with children's 3rd grade standardized test scores. Environ Res 148: 144-153. http://dx.doi.org/10.1016/j.envres.2016.03.035
Storm, JE; Mazor, KA; Aldous, KM; Blount, BC; Brodie, SE; Serle, JB. (2011). Visual contrast sensitivity in children exposed to tetrachloroethylene. Arch Environ Occup Health 66: 166-177. http://dx.doi.org/10.1080/19338244.2010.539638
Stoye, D. (2000). Ulmann’s Encyclopedia of Industry Chemistry
Solvents. [online]: John Wiley & Sons.
Su, FC; Mukherjee, B; Batterman, S. (2013). Determinants of personal, indoor and outdoor VOC concentrations: An analysis of the RIOPA data. Environ Res 126: 192-203. http://dx.doi.org/10.1016/j.envres.2013.08.005
Suarez, L; Weiss, NS; Martin, J. (1989). Primary liver cancer death and occupation in Texas. Am J Ind Med 15: 167-175.
Sung, TI; Chen, PC; Lee, LJH; Lin, YP; Hsieh, GY; Wang, JD. (2007). Increased standardized incidence ratio of breast cancer in female electronics workers. BMC Public Health 7: 102. http://dx.doi.org/10.1186/1471-2458-7-102

Szakmáry, É; Gungváry, G; Tátrai, E. (1997). The offspring-damaging effect of tetrachloroethylene in rats, mice, and rabbits. Central Eur J Occup Env Med 3: 31-39.
Tabak, HH; Quave, SA; Mashni, CI; Barth, EF. (1981). Biodegradability studies with organic priority pollutant compounds. J Water Pollut Control Fed 53: 1503-1518.
Takakura, K; Oikawa, T; Nakano, M; Saeki, C; Torisu, Y; Kajihara, M; Saruta, M. (2019). Recent insights into the multiple pathways driving non-alcoholic steatohepatitis-derived hepatocellular carcinoma [Review]. Front Oncol 9: 762. http://dx.doi.org/10.3389/fonc.2019.00762
Talbott, EO; Marshall, LP; Rager, JR; Arena, VC; Sharma, RK; Stacy, SL. (2015). Air toxics and the risk of autism spectrum disorder: The results of a population based case-control study in southwestern Pennsylvania. Environ Health 14: 80. http://dx.doi.org/10.1186/s12940-015-0064-1
Talibov, M; Lehtinen-Jacks, S; Martinsen, JI; Kjærheim, K; Lynge, E; Sparén, P; Tryggvadottir, L; Weiderpass, E; Kauppinen, T; Kyyrönen, P; Pukkala, E. (2014). Occupational exposure to solvents and acute myeloid leukemia: A population-based, case-control study in four Nordic countries. Scand J Work Environ Health 40: 511-517. http://dx.doi.org/10.5271/sjweh.3436
Tao, L; Kramer, PM; Ge, R; Pereira, MA. (1998). Effect of dichloroacetic acid and trichloroacetic acid on DNA methylation in liver and tumors of female B6C3F1 mice. Toxicol Sci 43: 139-144. http://dx.doi.org/10.1093/toxsci/43.2.139
Tao, L; Wang, W; Li, L; Kramer, PM; Pereira, MA. (2004). Effect of dibromoacetic acid on DNA methylation, glycogen accumulation, and peroxisome proliferation in mouse and rat liver. Toxicol Sci 82: 62-69. http://dx.doi.org/10.1093/toxsci/kfh266
Tao, L; Yang, S; Xie, M; Kramer, PM; Pereira, MA. (2000). Hypomethylation and overexpression of c-jun and c-myc protooncogenes and increased DNA methyltransferase activity in dichloroacetic and trichloroacetic acid-promoted mouse liver tumors. Cancer Lett 158: 185-193. http://dx.doi.org/10.1016/S0304-3835(00)00518-8
Tatman, S. (2017). Comment submitted by Stacy Tatman, MS, JD, Director, Environmental Affairs, Alliance of Automobile Manufacturers (Alliance) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0723-0010
Tech Met, I. (2017). Tech Met letter to HSIA. (EPA-HQ-OPPT-2016-0732-0027). Washington, D.C.: Tech Met Inc. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0027
Templin, MV; Parker, JC; Bull, RJ. (1993). Relative formation of dichloroacetate and trichloroacetate from trichloroethylene in male B6C3F1 mice. Toxicol Appl Pharmacol 123: 1-8. http://dx.doi.org/10.1006/taap.1993.1214
Templin, MV; Stevens, DK; Stenner, RD; Bonate, PL; Tuman, D; Bull, RJ. (1995). Factors affecting species differences in the kinetics of metabolites of trichloroethylene. J Toxicol Environ Health 44: 435-447. http://dx.doi.org/10.1080/15287399509531972
Thomas, KW; Pellizzari, ED; Perritt, RL; Nelson, WC. (1991). Effect of dry-cleaned clothes on tetrachloroethylene levels in indoor air, personal air, and breath for residents of several New Jersey homes. J Expo Anal Environ Epidemiol 1: 475-490.
Tichenor, BA; Sparks, LE; Jackson, MD; Guo, Z; Mason, MA; Plunket, CM; Rasor, SA. (1990). Emissions of perchloroethylene from dry cleaned fabrics. Atmos Environ 24: 1219-1229. http://dx.doi.org/10.1016/0960-1686(90)90087-4
Tinston, DJ. (1994). Perchloroethylene: A multigeneration inhalation study in the rat. (CTL/P/4097, 86950000190). Cheshire, UK: Zeneca Central Toxicology Laboratory. https://www.epa.gov/iris/supporting-documents-tetrachloroethylene-perchloroethylene
Tirsell, D. (2000). Ulmann's Encyclopedia of Industry Chemistry Dry cleaning. [online]: John Wiley & Sons.

Tong, Z; Board, PG; Anders, MW. (1998a). Glutathione transferase zeta-catalyzed biotransformation of dichloroacetic acid and other alpha-haloacids. Chem Res Toxicol 11: 1332-1338. http://dx.doi.org/10.1021/tx980144f

Tong, Z; Board, PG; Anders, MW. (1998b). Glutathione transferase zeta catalyses the oxygenation of the carcinogen dichloroacetic acid to glyoxylic acid. Biochem J 331: 371-374.

Toraason, M; Butler, MA; Ruder, A; Forrester, C; Taylor, L; Ashley, DL; Mathias, P; Marlow, KL; Cheever, KL; Krieg, E; Wey, H. (2003). Effect of perchloroethylene, smoking, and race on oxidative DNA damage in female dry cleaners. Mutat Res Genet Toxicol Environ Mutagen 539: 9-18. http://dx.doi.org/10.1016/S1383-5718(03)00130-X

Toraason, M; Clark, J; Dankovic, D; Mathias, P; Skaggs, S; Walker, C; Werren, D. (1999). Oxidative stress and DNA damage in Fischer rats following acute exposure to trichloroethylene or perchloroethylene. Toxicology 138: 43-53. http://dx.doi.org/10.1016/S0300-483X(99)00083-9

Travier, N; Gridley, G; De Roos, AJ; Plato, N; Moradi, T; Boffetta, P. (2002). Cancer incidence of dry cleaning, laundry and ironing workers in Sweden. Scand J Work Environ Health 28: 341-348.

Trevisan, A; Macca; Rui, F; Carrieri, M; Bartolucci, GB; Manno, M. (2000). Kidney and liver biomakers in female dry-cleaning workers exposed to perchloroethylene. Biomarkers 5: 399-409.

Tu, AS; Murray, TA; Hatch, KM; Sivak, A; Milman, HA. (1985). In vitro transformation of BALB/c-3T3 cells by chlorinated ethanes and ethylenes. Cancer Lett 28: 85-92. http://dx.doi.org/10.1016/0304-3835(85)90096-5

Tucker, JD; Sorensen, KJ; Ruder, AM; McKernan, LT; Forrester, CL; Butler, MA. (2011). Cytogenetic analysis of an exposed-referent study: perchloroethylene-exposed dry cleaners compared to unexposed laundry workers. Environ Health 10: 16. http://dx.doi.org/10.1186/1476-069X-10-16

U.S. BLS. (2016). May 2016 Occupational Employment and Wage Estimates: National Industry-Specific Estimates [Website]. http://www.bls.gov/oes/tables.htm

U.S. Census Bureau. (2015). Statistics of U.S. Businesses (SUSB). https://www.census.gov/data/tables/2015/econ/susb/2015-susb-annual.html

U.S. Coast Guard. (1984). The chemical hazards response information system (CHRIS) hazardous chemical data. Washington, DC: Department of Transportation.

U.S. DOD. (2017). Comment submitted by OASD (EI&E), ESOH Directorate, CMRM Program, Department of Defense (DOD) Re: Tetrachloroethylene (perchloroethylene); TSCA Review and Risk Evaluation, EPA-HQ-OPPT-2016-0732. (EPA-HQ-OPPT-2016-0732-0062). https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0062

U.S. DOD, O; Environmental Health Readiness System - Industrial, H. (2018). Email between DOD and EPA: RE: [Non-DoD Source] Update: DoD exposure data for EPA risk evaluation - EPA request for additional information [Personal Communication]. Washington, D.C.: U.S. Department of Defense.

U.S. EPA. (1977). Control of volatile organic emissions from solvent metal cleaning [EPA Report]. (EPA-450/2-77-022). Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards.

U.S. EPA. (1980). Ambient water quality criteria for tetrachloroethylene [EPA Report]. (EPA/440/5-80/073). Office of Water. http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000M4GG.txt

U.S. EPA. (1985a). Health assessment document for tetrachloroethylene (perchloroethylene) Final report [EPA Report]. (EPA/600/8-82/005F). Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=38082

U.S. EPA. (1985b). Occupational exposure and environmental release assessment of tetrachloroethylene. Office of Pesticides and Toxic Substances.

U.S. EPA. (1991a). Alpha-2u-globulin: Association with chemically induced renal toxicity and neoplasia in the male rat (pp. 1-136). (EPA/625/3-91/019F). Washington, DC: U.S. Environmental Protection Agency, National Center for Environmental Assessment. https://ntrl.ntis.gov/NTRL/dashboard/searchResults.xhtml?searchQuery=PB92143668

U.S. EPA. (1991b). Dry cleaning facilities - Draft background information for proposed standards. (EPA 450/3-91-020a). Research Triangle Park,NC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. https://nepis.epa.gov/Exe/ZyPDF.cgi/00002H9E.PDF?Dockey=00002H9E.PDF

U.S. EPA. (1991c). Guidelines for developmental toxicity risk assessment (pp. 1-71). (EPA/600/FR-91/001). Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=23162

U.S. EPA. (1994a). Fabric finishing - generic scenario for estimating occupational exposures and environmental releases -final.

U.S. EPA. (1994b). Guidelines for Statistical Analysis of Occupational Exposure Data: Final. United States Environmental Protection Agency :: U.S. EPA.

U.S. EPA. (1994c). Methods for derivation of inhalation reference concentrations and application of inhalation dosimetry [EPA Report]. (EPA/600/8-90/066F). Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Research and Development, Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=71993&CFID=51174829&CFTOKEN=25006317

U.S. EPA. (1995). Protocol for Equipment Leak Emission Estimates. (EPA-453/R-95-017). Research Triangle Park, NC: Office of Air and Radiation, Office of Air Quality and Planning Standards. https://www3.epa.gov/ttn/chief/efdocs/equiplks.pdf

U.S. EPA. (1996). Guidelines for reproductive toxicity risk assessment (pp. 1-143). (EPA/630/R-96/009). Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum. https://www.epa.gov/sites/production/files/2014-11/documents/guidelines_repro_toxicity.pdf

U.S. EPA. (1997). Solvent Cleaning. Volume III, Chapter 6. pp. 6.2.1. Washington, DC. http://www3.epa.gov/ttnchie1/eiip/techreport/volume03/iii06fin.pdf

U.S. EPA. (1998). Guidelines for ecological risk assessment [EPA Report]. (EPA/630/R-95/002F). Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum. https://www.epa.gov/risk/guidelines-ecological-risk-assessment

U.S. EPA. (2000). Tetrachloroethylene (perchloroethylene) 127-18-4 [Fact Sheet]. Office of Air Toxics. https://www.epa.gov/sites/production/files/2016-09/documents/tetrachloroethylene.pdf

U.S. EPA. (2001). Sources, emission and exposure for trichloroethylene (TCE) and related chemicals [EPA Report] (pp. 138). (EPA/600/R-00/099). Washington, DC. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=21006

U.S. EPA. (2002). A review of the reference dose and reference concentration processes (pp. 1-192). (EPA/630/P-02/002F). Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum. http://www.epa.gov/osa/review-reference-dose-and-reference-concentration-processes

U.S. EPA. (2005a). Guidelines for Carcinogen Risk Assessment [EPA Report]. (EPA/630/P-03/001B). Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum. https://www.epa.gov/sites/production/files/2013-09/documents/cancer_guidelines_final_3-25-05.pdf

U.S. EPA. (2005b). Guidelines for carcinogen risk assessment. Risk Assessment Forum, Washington, DC; EPA/630/P-03/001B. U.S. EPA. http://www.epa.gov/iris/backgr-d.htm

U.S. EPA. (2005c). Perchloroethylene dry cleaners refined human health risk characterization. https://www.epa.gov/sites/production/files/2015-06/documents/riskassessment_dry_cleaners.pdf
U.S. EPA. (2006a). Approaches for the application of physiologically based pharmacokinetic (PBPK) models and supporting data in risk assessment (Final Report) [EPA Report] (pp. 1-123). (EPA/600/R-05/043F). Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=157668
U.S. EPA. (2006b). Economic impact analysis of the final perchloroethylene dry cleaning residual risk standard. (EPA-HQ-OAR-2005-0155-0505). Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impact Division. https://www.regulations.gov/document?D=EPA-HQ-OAR-2005-0155-0505
U.S. EPA. (2006c). Economic impact analysis of the perchloroethylene dry cleaning residual risk standard (pp. 1-19). (EPA 452/R-06-005). Research Triangle Park,NC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Health and Environmental Impacts Division. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100QFLJ.PDF?Dockey=P100QFLJ.PDF
U.S. EPA. (2009). INTERIM ACUTE EXPOSURE GUIDELINE LEVELS (AEGLs) - Tetrachloroethylene. U.S. Environmental Protection Agency :: U.S. EPA. https://www.epa.gov/aegl/tetrachloroethylene-results-aegl-program
U.S. EPA. (2011a). Exposure factors handbook: 2011 edition [EPA Report]. (EPA/600/R-090/052F). Washington, DC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=236252
U.S. EPA. (2011b). Toxicological review of Trichloroacetic acid [EPA Report]. (EPA/635/R-09/003F). Washington, DC. http://www.epa.gov/iris/toxreviews/0655tr.pdf
U.S. EPA. (2012a). Estimation Programs Interface Suite™ for Microsoft® Windows, v 4.11. Washington, DC. https://www.epa.gov/tsca-screening-tools/epi-suitetm-estimation-program-interface
U.S. EPA. (2012b). Sustainable futures P2 framework manual [EPA Report]. (EPA-748-B12-001). Washington DC. http://www.epa.gov/sustainable-futures/sustainable-futures-p2-framework-manual
U.S. EPA. (2012c). Toxicological review of tetrachloroethylene (perchloroethylene). (EPA/635/R-08/011F). Washington, DC. https://cfpub.epa.gov/ncea/iris/search/
U.S. EPA. (2012d). Toxicological Review of Tetrachloroethylene (Perchloroethylene) (CAS No. 127-18-4) In Support of Summary Information on the Integrated Risk Information System (IRIS). (NTIS/10860149).
U.S. EPA. (2012e). Toxicological review of tetrachloroethylene (perchloroethylene) (CAS No. 127-18-4) In support of summary information on the Integrated Risk Information System (IRIS) (pp. 1077).
U.S. EPA. (2012f). PhysProp database. Estimation Programs Interface Suite™ for Microsoft® Windows, v 4.11: 106-46-7. Washington, DC.
U.S. EPA. (2013). Interpretive assistance document for assessment of discrete organic chemicals. Sustainable futures summary assessment [EPA Report]. Washington, DC. http://www.epa.gov/sites/production/files/2015-05/documents/05-iad_discretes_june2013.pdf
U.S. EPA. (2014a). Degreasing with TCE in commercial facilities: Protecting workers [EPA Report]. Washington, DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics.
U.S. EPA. (2014b). Exposure and Fate Assessment Screening Tool Version 2014 (E-FAST 2014). Washington, DC: Office of Pollution Prevention and Toxics. https://www.epa.gov/tsca-screening-tools/e-fast-exposure-and-fate-assessment-screening-tool-version-2014

U.S. EPA. (2014c). Framework for human health risk assessment to inform decision making. Final [EPA Report]. (EPA/100/R-14/001). Washington, DC: U.S. Environmental Protection, Risk Assessment Forum. https://www.epa.gov/risk/framework-human-health-risk-assessment-inform-decision-making
U.S. EPA. (2014d). The Superfund Enterprise Management System (SEMS) [Website]. https://www.epa.gov/enviro/sems-overview
U.S. EPA. (2015a). Peer review handbook [EPA Report] (4th ed.). (EPA/100/B-15/001). Washington, DC: U.S. Environmental Protection Agency, Science Policy Council. https://www.epa.gov/osa/peer-review-handbook-4th-edition-2015
U.S. EPA. (2015b). Update of human health ambient water quality criteria: Tetrachloroethylene (Perchloroethylene) 127-18-4. (EPA 820-R-15-063). https://hero.epa.gov/hero/index.cfm?action=search.view&reference_id=5176443U.S. EPA. (2016b). Instructions for Reporting 2016 TSCA Chemical Data Reporting. (EPA/600/R-09/052F). Washington, DC: U.S. Environmental Protection Agency (EPA). https://www.epa.gov/chemical-data-reporting/instructions-reporting-2016-tsca-chemical-data-reporting
U.S. EPA. (2016c). Non-confidential 2016 Chemical Data Reporting (CDR) Database [Website]. http://www.epa.gov/cdr/
U.S. EPA. (2016d). Public database 2016 chemical data reporting (May 2017 release). Washington, DC: US Environmental Protection Agency, Office of Pollution Prevention and Toxics. https://www.epa.gov/chemical-data-reporting
U.S. EPA. (2016e). A Set of Scientific Issues Being Considered by the Environmental Protection Agency Regarding the Draft Risk Assessment for TSCA Work Plan Chemical 1-Bromopropane (CASRN-106-94-5). (Chemical Safety Advisory Committee Minutes No. 2016-02).
U.S. EPA. (2016f). TSCA work plan chemical risk assessment: Peer review draft 1-bromopropane: (n-Propyl bromide) spray adhesives, dry cleaning, and degreasing uses CASRN: 106-94-5 [EPA Report]. (EPA 740-R1-5001). Washington, DC. https://www.epa.gov/sites/production/files/2016-03/documents/1-bp_report_and_appendices_final.pdf
U.S. EPA. (2017a). Consumer Exposure Model (CEM) version 2.0: User guide. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics. https://www.epa.gov/sites/production/files/2017-06/documents/cem_2.0_user_guide.pdf
U.S. EPA. (2017b). EPA Use and Market Profile. (EPA-HQ-OPPT-2016-0732-0058).
U.S. EPA. (2017c). Federal Register: Procedures for chemical risk evaluation under the amended toxic substances control act. Fed Reg 82: 33726-33753.
U.S. EPA. (2017d). Perchloroethylene (CASRN: 127-18-4) bibliography: Supplemental file for the TSCA Scope Document [EPA Report]. https://www.epa.gov/sites/production/files/2017-06/documents/perc_comp_bib.pdf
U.S. EPA. (2017e). Preliminary information on manufacturing, processing, distribution, use, and disposal: tetrachloroethylene (perchloroethylene). (EPA-HQ-OPPT-2016-0732-0003). https://www.epa.gov/sites/production/files/2017-02/documents/perchloroethylene.pdf
U.S. EPA. (2017f). Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: Tetrachloroethylene (Perchloroethylene) [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0732-0003
U.S. EPA. (2017g). Procedures for chemical risk evaluation under the amended Toxic Substances Control Act. Final Rule Federal Registrar 82: 33726-33753. Fed Reg 82.

U.S. EPA. (2017h). Scope of the risk evaluation for perchloroethylene (ethene, 1,1,2,2-tetrachloro). CASRN: 127-18-4 [EPA Report]. (EPA-740-R1-7007). https://www.epa.gov/sites/production/files/2017-06/documents/perc_scope_06-22-17.pdf
U.S. EPA. (2017i). Strategy for conducting literature searches for tetrachloroethylene (perc): Supplemental document to the TSCA Scope Document. CASRN: 127-18-4 [EPA Report]. https://www.epa.gov/sites/production/files/2017-06/documents/perc_lit_search_strategy_053017_0.pdf
U.S. EPA. (2018a). 2014 National Emissions Inventory (NEI) data (2 ed.). Washington, DC. https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data
U.S. EPA. (2018b). Application of systematic review in TSCA risk evaluations. (740-P1-8001). Washington, DC: U.S. Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention. https://www.epa.gov/sites/production/files/2018-06/documents/final_application_of_sr_in_tsca_05-31-18.pdf
U.S. EPA. (2018c). Application of systematic review in TSCA risk evaluations: DRAFT Version 1.0. (740P18001). Washington, D.C.: U.S. Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2018d). Problem Formulation of the risk evaluation for perchloroethylene (ethene, 1,1,2,2-tetrachloro). (EPA-740-R1-7017). Washington, DC: Office of Chemical Safety and Pollution Prevention, United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2018-06/documents/perc_problem_formulation_5-31-2018v3.pdf
U.S. EPA. (2018e). Problem Formulation of the Risk Evaluation for Trichloroethylene. (EPA-740-R1-7014). Washington, DC: Office of Chemical Safety and Pollution Prevention, United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2018-06/documents/tce_problem_formulation_05-31-31.pdf
U.S. EPA. (2018f). Strategy for assessing data quality in TSCA risk evaluations. Washington DC: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics.
U.S. EPA. (2019a). Assessment of Occupational Exposure and Environmental Releases for Perchloroethylene (Ethene, 1,1,2,2-Tetrachloro), CASRN: 127-18-4 [draft] [EPA Report] (pp. 302). Washington D.C.: U. S. Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2019b). Consumer Exposure Model (CEM) 2.1 User Guide. (EPA Contract # EP-W-12-010). Washington, DC.
U.S. EPA. (2019d). Envirofacts Toxics Release Inventory 2017 Updated Dataset (released April 2019).
U.S. EPA. (2019e). Multi-Chamber Concentration and Exposure Model (MCCEM) User Guide. U.S. EPA.
U.S. EPA. (2020a). Final Risk Evaluation for perchloroethylene. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020b). Final Risk Evaluation for perchloroethylene consumer dermal risk calculations. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020c). Final Risk Evaluation for perchloroethylene consumer inhalation risk calculations. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020d). Final Risk Evaluation for perchloroethylene engineering report. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.

U.S. EPA. (2020e). Final Risk Evaluation for perchloroethylene occupational risk calculations. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020f). Final Risk Evaluation for perchloroethylene supplemental information on consumer exposure. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020g). Final Risk Evaluation for perchloroethylene, systematic review supplemental file: Data extraction data for human health hazard studies. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020h). Final Risk Evaluation for perchloroethylene, systematic review supplemental file: Data extraction tables for environmental fate and transport studies. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020i). Final Risk Evaluation for perchloroethylene, systematic review supplemental file: Data quality evaluation of ecological hazard studies. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020j). Final Risk Evaluation for perchloroethylene, systematic review supplemental file: Data quality evaluation of environmental fate and transport studies. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020k). Final Risk Evaluation for perchloroethylene, systematic review supplemental file: Data quality evaluation of epidemiological studies. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020l). Final Risk Evaluation for perchloroethylene, systematic review supplemental file: Data quality evaluation of human health hazard studies-animal and in vitro studies. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020m). TRI-listed chemicals. Washington, DC. https://www.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals
U.S. EPA. (2020n). Memorandum: NIOSH/BLS Respirator Usage in Private Sector Firms [Personal Communication]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2019-0500-0029
U.S. EPA. (2020o). Final Risk Evaluation for perchloroethylene, systematic review supplemental file: Data quality evaluation for physical-chemical properties studies. Washington, D.C.: U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention.
U.S. EPA. (2020a). 2017 National Emissions Inventory (NEI) data (April 2020 version) (April 2020 ed.). Washington, DC: US Environmental Protection Agency. https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data
U.S. EPA. (2020b). 2017 Toxics Release Inventory (TRI) data. Washington, DC: US Environmental Protection Agency. https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools
U.S. EPA. (2020c). EPA Discharge Monitoring Report Data, reporting years 2012-2018. Washington, DC: US Environmental Protection Agency. https://echo.epa.gov/trends/loading-tool/water-pollution-search
U.S. EPA. (2020d). Toxics Release Inventory (TRI), reporting years 2012-2018. Washington, DC: US Environmental Protection Agency. https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools
Union Carbide, C. (1962). COMPARATIVE INHALATION TOXICITIES OF PERCHLOROETHYLENE. (OTS: OTS0515591; 8EHQ Num: NA; DCN: 86-870001429; TSCATS RefID: 308754; CIS: NA).

USGS. (2003). A national survey of methyl tert-butyl ether and other volatile organic compounds in drinking-water sources: Results of the random survey. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. https://pubs.er.usgs.gov/publication/wri024079
USGS. (2006). Water-quality conditions of Chester Creek, Anchorage, Alaska, 1998-2001. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. https://pubs.er.usgs.gov/publication/sir20065229
USGS. (2013). Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD): Techniques and Methods 11–A3 (4th ed., pp. 63). U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service. https://pubs.usgs.gov/tm/11/a3/
Valencia, R; Mason, JM; Woodruff, RC; Zimmering, S. (1985). Chemical mutagenesis testing in Drosophila. III. Results of 48 coded compounds tested for the National Toxicology Program. Environ Mutagen 7: 325-348. http://dx.doi.org/10.1002/em.2860070309
Vamvakas, S; Dekant, W; Berthold, K; Schmidt, S; Wild, D; Henschler, D. (1987). Enzymatic transformation of mercapturic acids derived from halogenated alkenes to reactive and mutagenic intermediates. Biochem Pharmacol 36: 2741-2748. http://dx.doi.org/10.1016/0006-2952(87)90258-9
Vamvakas, S; Dekant, W; Henschler, D. (1989a). Assessment of unscheduled DNA synthesis in a cultured line of renal epithelial cells exposed to cysteine S-conjugates of haloalkenes and haloalkanes. Mutat Res 222: 329-335. http://dx.doi.org/10.1016/0165-1218(89)90108-0
Vamvakas, S; Dekant, W; Henschler, D. (1989b). Genotoxicity of haloalkene and haloalkane glutathione S-conjugates in porcine kidney cells. Toxicol In Vitro 3: 151-156. http://dx.doi.org/10.1016/0887-2333(89)90058-1
Vamvakas, S; Herkenhoff, M; Dekant, W; Henschler, D. (1989c). Mutagenicity of tetrachloroethene in the ames test: Metabolic activation by conjugation with glutathione. J Biochem Toxicol 4: 21-27. http://dx.doi.org/10.1002/jbt.2570040105
Vamvakas, S; Kochling, A; Berthold, K; Dekant, W. (1989d). Cytotoxicity of cysteine S-conjugates: structure-activity relationships. Chem Biol Interact 71: 79-90.
Van Amber, RR; Niven, BE; Wilson, CA. (2010). Effects of laundering and water temperature on the properties of silk and silk-blend knitted fabrics. Text Res J 80: 1557-1568. http://dx.doi.org/10.1177/0040517510366019
van Hook, DE. (2017). Comment submitted by D. Evan van Hook, Corporate Vice President, Health Safety, and Environment, Product Stewardship and Sustainability, Honeywell International Inc [Comment]. https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0736-0043
Van Raaij, MTM; Janssen, PAH; Piersma, AH. (2003). The relevance of developmental toxicity endpoints for acute limits settings (pp. 1-88). (RIVM Report 601900004). Nederlands: Nederlands National Institute for Public Health and the Environment. http://www2.epa.gov/sites/production/files/2014-04/documents/mtg35b.pdf
Van Winkle, MR; Scheff, PA. (2001). Volatile organic compounds, polycyclic aromatic hydrocarbons and elements in the air of ten urban homes. Indoor Air 11: 49-64. http://dx.doi.org/10.1034/j.1600-0668.2001.011001049.x
Vartiainen, T; Pukkala, E; Rienoja, T; Strandman, T; Kaksonen, K. (1993). Population exposure to tri- and tetrachloroethene and cancer risk: Two cases of drinking water pollution. Chemosphere 27: 1171-1181. http://dx.doi.org/10.1016/0045-6535(93)90165-2
Vaughan, TL; Stewart, PA; Davis, S; Thomas, DB. (1997). Work in dry cleaning and the incidence of cancer of the oral cavity, larynx, and oesophagus. Occup Environ Med 54: 692-695.
Verplanke, AJ; Leummens, MH; Herber, RF. (1999). Occupational exposure to tetrachloroethene and its effects on the kidneys. J Occup Environ Med 41: 11-16.

Vizcaya, D; Christensen, KY; Lavoue, J; Siemiatycki, J. (2013). Risk of lung cancer associated with six types of chlorinated solvents: Results from two case-control studies in Montreal, Canada. Occup Environ Med 70: 81-85. http://dx.doi.org/10.1136/oemed-2012-101155

Vlaanderen, J; Straif, K; Pukkala, E; Kauppinen, T; Kyyronen, P; Martinsen, J; Kjaerheim, K; Tryggvadottir, L; Hansen, J; Sparen, P; Weiderpass, E. (2013). Occupational exposure to trichloroethylene and perchloroethylene and the risk of lymphoma, liver, and kidney cancer in four Nordic countries. Occup Environ Med 70: 393-401. http://dx.doi.org/10.1136/oemed-2012-101188

Völkel, W; Friedewald, M; Lederer, E; Pähler, A; Parker, J; Dekant, W. (1998). Biotransformation of perchloroethene: Dose-dependent excretion of trichloroacetic acid, dichloroacetic acid, and N-acetyl-S-(trichlorovinyl)-L-cysteine in rats and humans after inhalation. Toxicol Appl Pharmacol 153: 20-27. http://dx.doi.org/10.1006/taap.1998.8548

von der Hude, W; Behm, C; Gürtler, R; Basler, A. (1988). Evaluation of the SOS chromotest. Mutat Res 203: 81-94. http://dx.doi.org/10.1016/0165-1161(88)90023-4

von Ehrenstein, OS; Aralis, H; Cockburn, M; Ritz, B. (2014). In utero exposure to toxic air pollutants and risk of childhood autism. Epidemiology 25: 851-858. http://dx.doi.org/10.1097/EDE.0000000000000150

Von Grote, J. (2003) Occupational Exposure Assessment in Metal Degreasing and Dry Cleaning - Influences of Technology Innovation and Legislation. A dissertation submitted to the Swiss Federal Institute of Technology Zürich for the degree of Doctor of Natural Sciences. (Swiss Federal Institute of Technology Zürich, Retrieved from https://www.research-collection.ethz.ch/handle/20.500.11850/116460

Vulcan, C. (1992). INDUSTRIAL HYGIENE STUDY OF PERCHLOROETHYLENE/METHYLCHLOROFORM BLENDED AEROSOL BRAKE CLEANERS (FINAL REPORT) WITH COVER LETTER DATED 031292. (OTS: OTS0535416; 8EHQ Num: NA; DCN: 86-920000858; TSCATS RefID: 422422; CIS: NA).

Vulcan, C. (1993). INDUSTRIAL HYGIENE STUDY OF METHYLENE CHLORIDE/PERCHLOROETHYLENE/METHYLCHLOROFORM BLENDED AEROSOL BRAKE CLEANERS. (OTS: OTS0556634; 8EHQ Num: NA; DCN: 86940000038; TSCATS RefID: NA; CIS: 86940000038).

Vulcan, C. (1994). Task Report- Cold Cleaning Field Tests of Perchloroethylene / Alcohol Blends Vickers Electromechanical, Wichita, KS. (OTS: OTS0556807; 8EHQ Num: NA; DCN: 86-940000212; TSCATS RefID: NA; CIS: 86940000212).

Vyskocil, A; Emminger, S; Tejral, J; Fiala, Z; Ettlerova, E; Cermanova, A. (1990). Study on kidney function in female workers exposed to perchlorethylene. Hum Exp Toxicol 9: 377-380.

Wakeham, SG; Davis, AC; Karas, JA. (1983). Mesocosm experiments to determine the fate and persistence of volatile organic compounds in coastal seawater. Environ Sci Technol 17: 611-617. http://dx.doi.org/10.1021/es00116a009

Wallace, LA. (1987). The total exposure assessment methodology (TEAM) study: Summary and analysis: Volume I [EPA Report]. (EPA/600/6-87/002a). Washington, DC: U.S. Environmental Protection Agency; Office of Acid Deposition, Environmental Monitoring, and Quality Assurance.

Walles, SAS. (1986). Induction of single-strand breaks in dna of mice by trichloroethylene and tetrachloroethylene. Toxicol Lett 31: 31-35. http://dx.doi.org/10.1016/0378-4274(86)90191-8

Wang, G; Wang, J; Ansari, GAS; Khan, MF. (2017). Autoimmune potential of perchloroethylene: Role of lipid-derived aldehydes. Toxicol Appl Pharmacol 333: 76-83. http://dx.doi.org/10.1016/j.taap.2017.08.009

Wang, JL; Chen, WL; Tsai, SY; Sung, PY; Huang, RN. (2001). An in vitro model for evaluation of vaporous toxicity of trichloroethylene and tetrachloroethylene to CHO-K1 cells. Chem Biol Interact 137: 139-154. http://dx.doi.org/10.1016/S0009-2797(01)00226-5

Wang, X; Harada, S; Watanabe, M; Koshikawa, H; Sato, K; Kimura, T. (1996). Determination of bioconcentration potential of tetrachloroethylene in marine algae by 13C. Chemosphere 33: 865-877. http://dx.doi.org/10.1016/0045-6535(96)00230-5

Warren, DA; Reigle, TG; Muralidhara, S; Dallas, CE. (1996). Schedule-controlled operant behavior of rats following oral administration of perchloroethylene: Time course and relationship to blood and brain solvent levels. J Toxicol Environ Health 47: 345-362. http://dx.doi.org/10.1080/009841096161690

Watanabe, K; Satamoto, K; Sasaki, T. (1998). Comparisons on chemically-induced mutation among four bacterial strains, Salmonella typhimurium TA102 and TA2638, and Escherichia coli WP2/pKM101 and WP2 uvrA/pKM101: Collaborative study II. Mutat Res 412: 17-31. http://dx.doi.org/10.1016/S1383-5718(97)00155-1

Westat. (1987). Household solvent products: A national usage survey [EPA Report]. (EPA-OTS 560/5-87-005). Washington, DC: Office of Toxic Substances, Office of Pesticides and Toxic Substances. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100754Q.txt

White, IN; Razvi, N; Gibbs, AH; Davies, AM; Manno, M; Zaccaro, C; De Matteis, F; Pahler, A; Dekant, W. (2001). Neoantigen formation and clastogenic action of HCFC-123 and perchloroethylene in human MCL-5 cells. Toxicol Lett 124: 129-138. http://dx.doi.org/10.1016/S0378-4274(00)00281-2

Whittaker, SG; Johanson, CA. (2011). A profile of the dry cleaning industry in King County, Washington: Final report. (LHWMP 0048). Seattle, WA: Local Hazardous Waste Management Program in King County. http://www.hazwastehelp.org/publications/publications_detail.aspx?DocID=Oh73%2fQilg9Q%3d

WHO. (2006a). Concise international chemical assessment document 68: Tetrachloroethene. Geneva, Switzerland: World Health Organization, International Programme on Chemical Safety. http://www.inchem.org/documents/cicads/cicads/cicad68.htm

WHO. (2006b). Reproductive health indicators: guidelines for their generation, interpretation and analysis for global monitoring.

WHO/IPCS. (2007). Harmonization project document no. 4: Part 1: IPCS framework for analysing the relevance of a cancer mode of action for humans and case-studies: Part 2: IPCS framework for analysing the relevance of a non-cancer mode of action for humans. Geneva, Switzerland: World Health Organization. http://www.who.int/ipcs/methods/harmonization/areas/cancer_mode.pdf?ua=1

Wilson, R; Donahue, M; Gridley, G; Adami, J; El Ghormli, L; Dosemeci, M. (2008). Shared occupational risks for transitional cell cancer of the bladder and renal pelvis among men and women in Sweden. Am J Ind Med 51: 83-99. http://dx.doi.org/10.1002/ajim.20522

Windham, GC; Shusterman, D; Swan, SH; Fenster, L; Eskenazi, B. (1991). Exposure to organic solvents and adverse pregnancy outcome. Am J Ind Med 20: 241-259. http://dx.doi.org/10.1002/ajim.4700200210

Winfield Brooks, C. (2014). Safety Data Sheet: Original Formula Alumtap. http://www1.mscdirect.com/MSDS/MSDS00002/00265025-20160420.PDF

Wright, WH; Bozicevick, J; Gordon, LS. (1937). Studies on oxyuriasis. V. Therapy with-single doses of tetrachloroethylene. JAMA 109: 570-573. http://dx.doi.org/10.1001/jama.1937.02780340026009

Yoo, HS; Cichocki, JA; Kim, S; Venkatratnam, A; Iwata, Y; Kosyk, O; Bodnar, W; Sweet, S; Knap, A; Wade, T; Campbell, J; Clewell, HJ; Melnyk, SB; Chiu, WA; Rusyn, I. (2015). The Contribution

of Peroxisome Proliferator-Activated Receptor Alpha to the Relationship Between Toxicokinetics and Toxicodynamics of Trichloroethylene. Toxicol Sci 147: 339-349. http://dx.doi.org/10.1093/toxsci/kfv134

Yoshioka, T; Krauser, JA; Guengerich, FP. (2002). Tetrachloroethylene oxide: hydrolytic products and reactions with phosphate and lysine. Chem Res Toxicol 15: 1096-1105. http://dx.doi.org/10.1021/tx020028j

Yu, KO; Barton, HA; Mahle, DA; Frazier, JM. (2000). In vivo kinetics of trichloroacetate in male Fischer 344 rats. Toxicol Sci 54: 302-311.

Zhao, JH; Duan, Y; Wang, YJ; Huang, XL; Yang, GJ; Wang, J. (2016). The influence of different solvents on systemic sclerosis: An updated meta-analysis of 14 case-control studies. 22: 253-259. http://dx.doi.org/10.1097/RHU.0000000000000354

Zhou, YH; Cichocki, JA; Soldatow, VY; Scholl, EH; Gallins, PJ; Jima, D; Yoo, HS; Chiu, WA; Wright, FA; Rusyn, I. (2017). Editor's Highlight: Comparative Dose-Response Analysis of Liver and Kidney Transcriptomic Effects of Trichloroethylene and Tetrachloroethylene in B6C3F1 Mouse. Toxicol Sci 160: 95-110. http://dx.doi.org/10.1093/toxsci/kfx165

Zielhuis, GA; Gijsen, R; van der Gulden, JWJ. (1989). Menstrual disorders among dry-cleaning workers [Letter]. Scand J Work Environ Health 15: 238.

APPENDICES

Appendix A REGULATORY HISTORY

A.1 Federal Laws and Regulations

Table_Apx A-1. Federal Laws and Regulations

Statutes/Regulations	Description of Authority/Regulation	Description of Regulation
EPA Regulations		
Toxics Substances Control Act (TSCA) – Section 6(b)	EPA is directed to identify and begin risk evaluations on 10 chemical substances drawn from the 2014 update of the TSCA Work Plan for Chemical Assessments.	PCE is on the initial list of chemicals to be evaluated for unreasonable risk under TSCA (81 FR 91927, December 19, 2016).
Toxics Substances Control Act (TSCA) – Section 8(a)	The TSCA Section 8(a) Chemical Data Reporting (CDR) Rule requires manufacturers (including importers) to give EPA basic exposure-related information on the types, quantities and uses of chemical substances produced domestically and imported into the United States.	PCE manufacturing (including importing), processing, and use information is reported under the Chemical Data Reporting (CDR) rule (40 CFR Part 711).
Toxics Substances Control Act (TSCA) – Section 8(b)	EPA must compile, keep current, and publish a list (the TSCA Inventory) of each chemical substance manufactured, processed or imported in the United States.	PCE was on the initial TSCA Inventory and therefore was not subject to EPA's new chemicals review process (60 FR 16309, March 29, 1995).
Toxics Substances Control Act (TSCA) – Section 8(e)	Manufacturers (including imports), processors, and distributors must immediately notify EPA if they obtain information that supports the conclusion that a chemical substance or mixture presents a substantial risk of injury to health or the environment.	Eleven risk reports received for PCE (1978-2010) (US EPA, ChemView. Accessed April 13, 2017).

Toxics Substances Control Act (TSCA) – Section 4	Provides EPA with authority to issue rules and orders requiring manufacturers (including importers) and processors to test chemical substances and mixtures.	Nine chemical data submissions from test rules received for PCE (1978-1980) (US EPA, ChemView. Accessed April 13, 2017).
Emergency Planning and Community Right-to-Know Act (EPCRA) – Section 313	Requires annual reporting from facilities in specific industry sectors that employ 10 or more full time equivalent employees and that manufacture, process or otherwise use a TRI-listed chemical in quantities above threshold levels.	PCE is a listed substance subject to reporting requirements under 40 CFR 372.65 effective as of January 1, 1987.
Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) - Sections 3 and 6	FIFRA governs the sale, distribution and use of pesticides. Section 3 of FIFRA generally requires that pesticide products be registered by EPA prior to distribution or sale. Pesticides may only be registered if, among other things, they do not cause "unreasonable adverse effects on the environment." Section 6 of FIFRA provides EPA with the authority to cancel pesticide registrations if either (1) the pesticide, labeling or other material does not comply with FIFRA; or (2) when used in accordance with widespread and commonly recognized practice, the pesticide generally causes unreasonable adverse effects on the environment.	EPA removed PCE and other chemical substances from its list of pesticide product inert ingredients used in pesticide products (63 FR 34384, June 24, 1998).
Clean Air Act (CAA) – Section 112(b)	Defines the original list of 189 hazardous air pollutants (HAP). Under 112(c) of the CAA, EPA must identify and list source categories that emit HAP and then set emission standards for those listed source categories under CAA	Lists PCE as a Hazardous Air Pollutant (42 U.S. Code § 7412), and is considered an "urban air toxic" (CAA Section 112(k)).

	section 112(d). CAA section 112(b)(3)(A) specifies that any person may petition the Administrator to modify the list of HAP by adding or deleting a substance. Since 1990 EPA has removed two pollutants from the original list leaving 187 at present.	
Clean Air Act (CAA) – Section 112(d)	Section 112(d) states that the EPA must establish national emission standards for HAP (NESHAP) for each category or subcategory of major sources and area sources of HAPs [listed pursuant to Section 112(c)]. The standards must require the maximum degree of emission reduction that the EPA determines to be achievable by each particular source category. Different criteria for maximum achievable control technology (MACT) apply for new and existing sources. Less stringent standards, known as generally available control technology (GACT) standards, are allowed at the Administrator's discretion for area sources.	There are a number of source-specific CAA, Section 112, NESHAPs for PCE, including: Dry cleaners (73 FR 39871, July 11, 2008) Organic liquids distribution (non-gasoline) (69 FR 5038, February 3, 2004) Off-site waste and recovery operations (64 FR 38950, July 20, 1999) Rubber Tire Manufacturing (67 FR 45588, July 9, 2002) Wood furniture manufacturing (60 FR 62930, December 7, 1995) Synthetic organic chemical manufacturing (59 FR 19402, April 22,1994) Chemical Manufacturing Area Source Categories (74 FR 56008, October 29, 2009) Publicly Owned Treatment Works (64 FR 57572, October 26, 1999) Site Remediation includes PCE (68 FR 58172, October 8, 2003)
Clean Air Act (CAA) – Section 112(d) and 112(f)	Risk and technology review (RTR) of section 112(d) MACT standards. Section 112(f)(2) requires EPA to conduct risk assessments for each source category subject to section 112(d) MACT standards, and to determine if additional standards are needed to reduce remaining risks. Section 112(d)(6) requires EPA to review and revise the MACT standards, as necessary, taking into account developments in	EPA has promulgated a number of RTR NESHAP (*e.g.*, the RTR NESHAP for PCE Dry Cleaning (71 FR 42724; July 27, 2006) and the RTR NESHAP for Halogenated Solvent Cleaning (72 FR 25138; May 3, 2007) and will do so, as required, for the remaining source categories with NESHAP

	practices, processes and control technologies."	
Clean Air Act (CAA) – Section 183(e)	Section 183(e) requires EPA to list the categories of consumer and commercial products that account for at least 80 percent of all VOC emissions in areas that violate the National Ambient Air Quality Standards (NAAQS) for ozone and to issue standards for these categories that require "best available controls." In lieu of regulations, EPA may issue control techniques guidelines if the guidelines are determined to be substantially as effective as regulations.	PCE is listed under the National Volatile Organic Compound Emission Standards for Aerosol Coatings (40 CFR part 59, subpart E). PCE has a reactivity factor of 0.04g O3/g VOC.
Clean Air Act (CAA) – Section 612	Under Section 612 of the Clean Air Act (CAA), EPA's Significant New Alternatives Policy (SNAP) program reviews substitutes for ozone depleting substances within a comparative risk framework. EPA publishes lists of acceptable and unacceptable alternatives. A determination that an alternative is unacceptable or acceptable only with conditions, is made through rulemaking.	Under the SNAP program, EPA listed PCE as an acceptable substitute in cleaning solvent for metal cleaning, electronics cleaning and precision cleaning (59 FR 13044, March 18, 1994). PCE is cited as an alternative to methyl chloroform and CFC-113 for metals, electronics and precision cleaning. PCE was also noted to have no ozone depletion potential and cited as a VOC-exempt solvent and acceptable ozone-depleting substance substitute (72 FR 30142, May 30, 2007).
Clean Water Act (CWA) – Section 301(b), 304(b), 306, and 307(b)	Requires establishment of Effluent Limitations Guidelines and Standards for conventional, toxic, and non-conventional pollutants. For toxic and non-conventional pollutants, EPA identifies the best available technology that is economically achievable for that industry after considering statutorily prescribed factors and sets regulatory requirements based on the	PCE is designated as a toxic pollutant under section 307(a)(1) of CWA and as such is subject to effluent limitations. Also under section 304, PCE is included in the list of total toxic organics (TTO) (40 CFR 413.02(i)). In 2015, EPA published updated ambient water quality criteria for PCE, including recommendations for "water + organism" and "organism only" human health criteria for states and authorized tribes to consider when adopting criteria into their water quality standards. See 80 FR 36986 (June 29, 2015);

	performance of that technology.	https://www.regulations.gov/document?D=EPA-HQ-OW-2014-0135-0189.
Clean Water Act (CWA) 304(a)	Section 304(a)(1) of the Clean Water Act (CWA) requires EPA to develop and publish, and from time to time revise, recommended criteria for the protection of water quality that accurately reflect the latest scientific knowledge. Water quality criteria developed under section 304(a) are based solely on data and scientific judgments on the relationship between pollutant concentrations and human health and environmental effects.	
Clean Water Act (CWA) – Section 307(a)	Establishes a list of toxic pollutants or combination of pollutants under the CWA. The statute specifies a list of families of toxic pollutants also listed in the Code of Federal Regulations at 40 CFR 401.15. The "priority pollutants" specified by those families are listed in 40 CFR part 423, Appendix A. These are pollutants for which best available technology effluent limitations must be established on either a national basis through rules (Sections 301(b), 304(b), 307(b), 306), or on a case-by-case best professional judgment basis in NPDES permits (Section 402(a)(1)(B)).	
Safe Drinking Water Act (SDWA) – Section 1412	Requires EPA to publish a non-enforceable maximum contaminant level goals (MCLGs) for contaminants which 1. may have an adverse effect on the health of persons; 2. are known to	PCE is subject to National Primary Drinking Water Regulations (NPDWR) under SDWA with a MCLG of zero and an enforceable maximum contaminant level (MCL) of 0.005 mg/L (40 CFR 141.50; 40 CFR 141.61).

	occur or there is a substantial likelihood that the contaminant will occur in public water systems with a frequency and at levels of public health concern; and 3. in the sole judgment of the Administrator, regulation of the contaminant presents a meaningful opportunity for health risk reductions for persons served by public water systems. When EPA publishes an MCLG, EPA must also promulgate a National Primary Drinking Water Regulation (NPDWR) which includes either an enforceable maximum contaminant level (MCL) or a required treatment technique. Public water systems are required to comply with NPDWRs	
Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) – Section 102(a) and 103	Authorizes EPA to promulgate regulations designating as hazardous substances those substances which, when released into the environment, may present substantial danger to the public health or welfare or the environment. EPA must also promulgate regulations establishing the quantity of any hazardous substance the release of which must be reported under Section 103. Section 103 requires persons in charge of vessels or facilities to report to the National Response Center if they have knowledge of a release of a hazardous substance above the reportable quantity threshold.	PCE is a hazardous substance under CERCLA. Releases of PCE in excess of 100 pounds must be reported (40 CFR 302.4).

Resource Conservation and Recovery Act (RCRA) – Section 3001	Directs EPA to develop and promulgate criteria for governing hazardous waste identification, classification, generation, management and disposal.	PCE is identified as a characteristic and listed hazardous waste pursuant to RCRA Section 3001. RCRA Hazardous Waste Codes: D039 (Toxicity); F001, F002; U210 (40 CFR 261.24(b), 261.31(a), 261.33(f)). In 2013, EPA modified its hazardous waste management regulations to conditionally exclude solvent-contaminated wipes that have been cleaned and reused from the definition of solid waste under RCRA (78 FR 46447, July 31, 2013).
Superfund Amendments and Reauthorization Act (SARA) –	Requires the Agency to revise the hazardous ranking system and update the National Priorities List of hazardous waste sites, increases state and citizen involvement in the superfund program and provides new enforcement authorities and settlement tools.	PCE is listed on SARA, an amendment to CERCLA and the CERCLA Priority List of Hazardous Substances. This list includes substances most commonly found at facilities on the CERCLA National Priorities List (NPL) that have been deemed to pose the greatest threat to public health.
Other Federal Regulations		
Federal Hazardous Substance Act (FHSA)	Allows the Consumer Product Safety Commission (CPSC) to (1) require precautionary labeling on the immediate container of hazardous household products or (2) to ban certain products that are so dangerous or the nature of the hazard is such that required labeling is not adequate to protect consumers.	Under the Federal Hazardous Substance Act, section 1500.83(a)(31), visual novelty devices containing PCE are regulated by CPSC.
Federal Food, Drug, and Cosmetic Act (FFDCA)	Provides the U.S. FDA (Food and Drug Administration) with authority to oversee the safety of food, drugs and cosmetics.	The FDA regulates PCE in bottled water. The maximum permissible level of PCE in bottled water is 0.005 mg/L (21 CFR 165.110).
Occupational Safety and Health Act (OSH Act)	Requires employers to provide their workers with a place of employment free from recognized hazards to safety and health, such as	The OSHA PEL for PCE is 100 ppm, as an 8-hour TWA with an acceptable ceiling concentration of 200 ppm and an acceptable maximum peak above the acceptable ceiling

	exposure to toxic chemicals, excessive noise levels, mechanical dangers, heat or cold stress or unsanitary conditions. Under the Act, the Occupational Safety and Health Administration can issue occupational safety and health standards including such provisions as Permissible Exposure Limits (PELs), exposure monitoring, engineering and administrative control measures and respiratory protection.	concentration for an 8 hour shift of 300 ppm, maximum duration of 5 minutes in any 3 hours. While OSHA has established a PEL for PCE, OSHA has recognized that many of its PELs are outdated and inadequate for ensuring protection of worker health. Most of OSHA's PELs were issued shortly after adoption of the Occupational Safety and Health (OSH) Act in 1970, and have not been updated since that time. Section 6(a) of the OSH Act granted the Agency the authority to adopt Federal standards or national consensus standards as enforceable OSHA standards. "OSHA recommends that employers consider using the alternative occupational exposure limits because the Agency believes that exposures above some of these alternative occupational exposure levels are in compliance with the relevant PELs." For PCE, the alternative occupational exposure limits are the California OSHA PEL of 25 ppm and the ACGIH TLV of 25 ppm. (https://www.osha.gov/annotated-pels)
Atomic Energy Act Department of Energy (DOE)	The Atomic Energy Act authorizes DOE to regulate the health and safety of its contractor employees	10 CFR 851.23, Worker Safety and Health Program, requires the use of the 2005 ACGIH® TLV®s if they are more protective than the OSHA PEL. The 2005 TLV® for PCE is 25 ppm (8hr Time Weighted Average) and 100 ppm Short Term Exposure Limit(STEL).
Federal Hazardous Material Transportation Act	Section 5103 of the Act directs the Secretary of Transportation to: Designate material (including an explosive, radioactive material, infectious substance, flammable or combustible liquid, solid or gas, toxic, oxidizing or corrosive material and compressed gas) as hazardous when the Secretary determines that transporting the material in commerce may pose an	The Department of Transportation (DOT) has designated PCE as a hazardous material, and there are special requirements for marking, labeling and transporting it (49 CFR Part 171, 49 CFR 172, 40 CFR § 173.202 and 40 CFR § 173.242).

	unreasonable risk to health and safety or property. Issue regulations for the safe transportation, including security, of hazardous material in intrastate, interstate and foreign commerce.	

A.2 State Laws and Regulations

Table_Apx A-2. State Laws and Regulations

State Actions	Description of Action
State actions	
State Permissible Exposure Limits	California has a workplace PEL of 25 ppm (California, OEHHA, 1988)
State Right-to-Know Acts	Massachusetts (454 CMR 21.00), New Jersey (42 N.J.R 1709(a)), Pennsylvania (Chapter 323, Hazardous Substance List), Rhode Island (RI Gen. Laws Sec. 28-21-1et seq).
Volatile Organic Compound (VOC) Regulations for Consumer Products	Many states regulate PCE as a VOC. These regulations may set VOC limits for consumer products and/or ban the sale of certain consumer products as an ingredient and/or impurity. Regulated products vary from state to state, and could include contact and aerosol adhesives, aerosols, electronic cleaners, footwear or leather care products, and general degreasers, among other products. California (Title 17, California Code of Regulations, Division 3, Chapter 1, Subchapter 8.5, Articles 1, 2, 3 and 4), Connecticut (R.C.S.A Sections 22a-174-40, 22a-174-41, and 22a-174-44), Delaware (Adm. Code Title 7, 1141), District of Columbia (Rules 20-720, 20-721, 20-735, 20-736, 20737), Illinois (35 Adm Code 223), Indiana (326 IAC 8-15), Maine (Chapter 152 of the Maine Department of Environmental Protection Regulations), Maryland (COMAR 26.11.32.00 to 26.11.32.26), Michigan (R 336.1660 and R 336. 1661), New Hampshire (Env--A 4100) New Jersey (Title 7, Chapter 27, Subchapter 24), New York (6 CRR-NY III A 235), Rhode Island (Air Pollution Control Regulation No. 31), and Virginia (9VAC5 CHAPTER 45) all have VOC regulations or limits for consumer products. Some of these states also require emissions reporting.
Other	There are several state level NESHAPs for dry cleaning and restrictions or phase outs of PCE (*e.g.*, California, Maine, Massachusetts). Numerous states list PCE on a list of chemical substances of high concern to children (*e.g.*, Oregon, Vermont, Washington). Under the California Proposition 65 list (California OEHHA), PCE is known to the state of California to cause cancer.

A.3 International Laws and Regulations

Table_Apx A-3. Regulatory Actions by Other Governments and Tribes

Country/Organization	Requirements and Restrictions
Canada	PCE is on the Canadian List of Toxic Substances (CEPA 1999 Schedule 1). The use and sale of PCE in the dry cleaning industry is regulated under *Use in Dry Cleaning and Reporting Requirements Regulations (Canada Gazette*, Part II on March 12, 2003. PCE is also regulated for use and sale for solvent degreasing under Solvent Degreasing Regulations (SOR/2003-283) (Canada Gazette, Part II on August 13, 2003). The purpose of the regulation is to reduce releases of PCE into the environment from solvent degreasing facilities using more than 1,000 kilograms of PCE per year. The regulation includes a market intervention by establishing tradable allowances for the use of PCE in solvent degreasing operations that exceed the 1,000 kilograms threshold per year.
European Union	PCE was evaluated under the 2013 Community Rolling Action Plan (CoRAP). The conclusion was no additional regulatory action was required (European Chemicals Agency (ECHA) database. Accessed April, 18 2017).
Australia	In 2011, a preliminary assessment of PCE was conducted (National Industrial Chemicals Notification and Assessment Scheme, NICNAS, 2016, Tetrachloroethylene. Accessed April, 18 2017).
Japan	PCE is regulated in Japan under the following legislation: • Act on the Evaluation of Chemical Substances and Regulation of Their Manufacture, etc. (Chemical Substances Control Law; CSCL) • Act on Confirmation, etc. of Release Amounts of Specific Chemical Substances in the Environment and Promotion of Improvements to the Management Thereof • Industrial Safety and Health Act (ISHA) • Air Pollution Control Law • Water Pollution Control Law • Soil Contamination Countermeasures Act • Law for the Control of Household Products Containing Harmful Substances (National Institute of Technology and Evaluation (NITE) Chemical Risk Information Platform (CHIRP). Accessed April 18, 2017)
Australia, Austria, Belgium, Canada, Denmark, European Union, Finland, France, Germany, Hungary, Ireland, Israel, Japan, Latvia, New Zealand, People's Republic of China, Poland, Singapore, South Korea, Spain, Sweden,	Occupational exposure limits for PCE (GESTIS International limit values for chemical agents (Occupational exposure limits, OELs) database. Accessed April 18, 2017).

Switzerland, United Kingdom	
Basel Convention	Halogenated organic solvents (Y41) are listed as a category of waste under the Basel Convention – Annex I. Although the United States is not currently a party to the Basel Convention, this treaty still affects U.S. importers and exporters.
OECD Control of Transboundary Movements of Wastes Destined for Recovery Operations	Halogenated organic solvents (A3150) are listed as a category of waste subject to The Amber Control Procedure under Council Decision C (2001) 107/Final.

Appendix B LIST OF SUPPLEMENTAL DOCUMENTS

1. Risk Evaluation for Perchloroethylene

2. Summary of External Peer Review and Public Comments and Disposition for Perchloroethylene (PCE): Response to Support Risk Evaluation for Perchloroethylene (PCE)

3. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Extraction Tables of Environmental Fate and Transport Studies

4. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation of Environmental Fate and Transport Studies

5. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation of Physical-Chemical Properties Studies

6. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation of Environmental Releases and Occupational Exposure Data Common Sources

7. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation of Environmental Releases and Occupational Exposure

8. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation for Data Sources on Consumer and Environmental Exposure

9. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Consumer and General Population Exposure Monitoring Data Extraction Tables

10. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation of Ecological Hazard Studies

11. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Extraction Tables for Environmental Hazard Studies

12. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Updates to the Data Quality Criteria for Epidemiological Studies

13. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation of Human Health Hazard Studies – Epidemiological Studies

14. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Extraction for Human Health Hazard Studies

15. Final Risk Evaluation for Perchloroethylene, Systematic Review Supplemental File: Data Quality Evaluation of Human Health Hazard Studies – Animal and in Vitro Studies

16. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: Environmental Releases and Occupational Exposure Assessment

17. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: Risk Calculator for Occupational Exposures

18. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: Consumer Inhalation Exposure Risk Calculations

19. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: Consumer Dermal Exposure Risk Calculator

20. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: Perchloroethylene Exposures from Consumer Products and Articles

21. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: E-Fast Surface Water Modeling Outputs

22. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: Consumer Exposure Assessment Model Input Parameter Spreadsheets

23. Final Risk Evaluation for Perchloroethylene, Supplemental Information File: Companion Consumer Exposure Assessment Model Output Spreadsheets

Appendix C MASS BALANCE

EPA attempted to develop a mass balance to account for the amount of PCE entering and leaving all facilities in the United States. EPA attempted to quantify the amount of carbon tetrachloride associated with each of its life cycle stages from introduction into commerce in the U.S. (from both domestic manufacture and import), processing, use, release, and disposal using 2016 CDR, 2017 TRI, 2017 NEI and readily available market data. Due to limitations in the available data (*e.g.*, reporting thresholds, CBI claims, data from different years), the mass balance may not account for all of the PCE in commerce in the U.S. or could potentially allocate portions of the production volume inaccurately. In the mass balance, EPA attempted to use data from the same year wherever possible; however, due to different requirements in reporting frequencies for CDR, TRI, and NEI and the availability of market data this was not always possible. Where data from the same year was not available, EPA gave preference to the most recent data. In the mass balance, EPA used the 2017 TRI data to align with the 2017 NEI (the latest NEI available) data. However, CDR production volume data for 2017 will not be available until reporting for the 2020 CDR is complete; therefore, EPA used 2015 production volume data, which is the latest available in the 2016 CDR. The following subsections described EPA's approach to developing the mass balance and the result of the mass balance.

C.1 Approach for Developing the Mass Balance

EPA used the reported aggregated production volume of 324,240,744 lbs from the 2016 CDR data as the amount of PCE manufactured and imported to the U.S. (U.S. EPA, 2016d). Starting with this volume, EPA attempted to estimate the portion of the volume used domestically versus or exported. The export volume was estimated to be 54,835,047 lbs in 2015; however, this does not account for export volumes claimed as CBI in the 2016 CDR (U.S. EPA, 2016d). The domestic use volume was assumed to be anything not reported as exported in the 2016 CDR plus any volume reported as transferred for off-site recycling in the 2017 TRI. EPA only considered the off-site recycling volume as EPA assumes any volume reported for on-site recycling is reused at the site with consumption, disposal, and treatment of the recycled volume accounted for in the facility's other reported TRI values and thus already accounted for in the mass balance. EPA assumed the volume reported for off-site recycling is reintroduced into commerce similar to virgin (*i.e.,* unused directly from manufacturer or importer) PCE. This resulted in a total of 274,911,543 lbs, or 85% of the total PV, being used domestically.

Use volumes were determined based on an HSIA market report which estimated 70% of the domestic use volume is used as a reactant, 10% is used as a dry cleaning solvent, 10% is used as an aerosol degreaser, 7% is used as a vapor degreasing solvent, and 3% is for miscellaneous uses (HSIA, 2008). Accounting for exports and the off-site recycled volume, this resulted in 192,438,080 lbs for intermediate uses, 27,491,154 lbs each for dry cleaning solvent and aerosol degreasing uses, 19,243,808 lbs for vapor degreasing, and 8,247,346 lbs for miscellaneous uses.

During manufacture, processing, and use, a portion of volume of PCE at a given site may be released to the environment on-site or end up in waste streams that are ultimately treated, disposed of, used for energy recovery, or recycled on- or off-site. EPA used data from the 2017 TRI and 2017 NEI to quantify volumes associated with each end-of-life activities (U.S. EPA, 2020a; U.S. EPA, 2020b). 2017 TRI data was grouped into the following categories of end-of-life activities: wastewater discharges, air emissions, land disposal, off-site recycling, energy recovery, and waste treatment. During manufacture, processing, and use, a portion of volume of PCE at a given site may be released to the environment or end up in waste streams that are ultimately sent for on- or off-site treatment, disposal, energy recovery, or recycling. EPA used data from the 2017 TRI and 2017 NEI to quantify volumes associated with each

end-of-life activities (U.S. EPA, 2020a; U.S. EPA, 2020b). 2017 TRI data was grouped into the following categories of end-of-life activities: wastewater discharges, air emissions, land disposal, off-site recycling, energy recovery, and waste treatment.

In addition to surface water discharges, the volume estimated for wastewater discharges includes the total volume reported by facilities as transferred to off-site wastewater treatment (non-POTW) and off-site POTW treatment. It does not account for subsequent removal from wastewater streams into air or sludge that may occur at such treatment sites. The amount calculated for land disposal includes the releases from all on-site and off-site underground injection, surface impoundment, land application, landfills, and any other land disposal reported in the 2017 TRI.

For recycling, TRI includes volumes for both on- and off-site recycling. As stated above, EPA assumed that any volume reported as recycled on-site is reused at the site with consumption, disposal, and treatment of the recycled volume accounted for in the facility's other reported TRI values and not further considered for the mass balance. EPA assumed the volume reported for off-site recycling is reintroduced into commerce similar to virgin (*i.e.*, unused directly from manufacturer or importer) PCE.

The calculated amount of PCE released as air emissions include data from both 2017 TRI and 2017 NEI (U.S. EPA, 2020a; U.S. EPA, 2020b). The air emissions include the total reported fugitive air emissions and stack air emissions from 2017 TRI reporters as well as all nonpoint source emission totals from NEI. NEI also collects data from point sources which may include sites that also report to TRI. To avoid double counting any volume reported in both TRI and NEI, EPA excluded a point emission source if the facility also reported PCE to TRI. Such sites were identified by cross-walking TRIFIDs reported in TRI to those in NEI. EPA also excluded emissions from any point source in NEI reported as being from landfills, POTW, or wastewater treatment facilities. EPA assumed that emissions from these sources are already accounted for in the "wastewater treatment" and "land disposal" volumes from TRI. Finally, EPA excluded air emissions from any point source reported as being from remediation activities. These volumes are assumed to be from historical uses of PCE such that any volume associated with those activities are not assumed to be related to the current year's production volume.

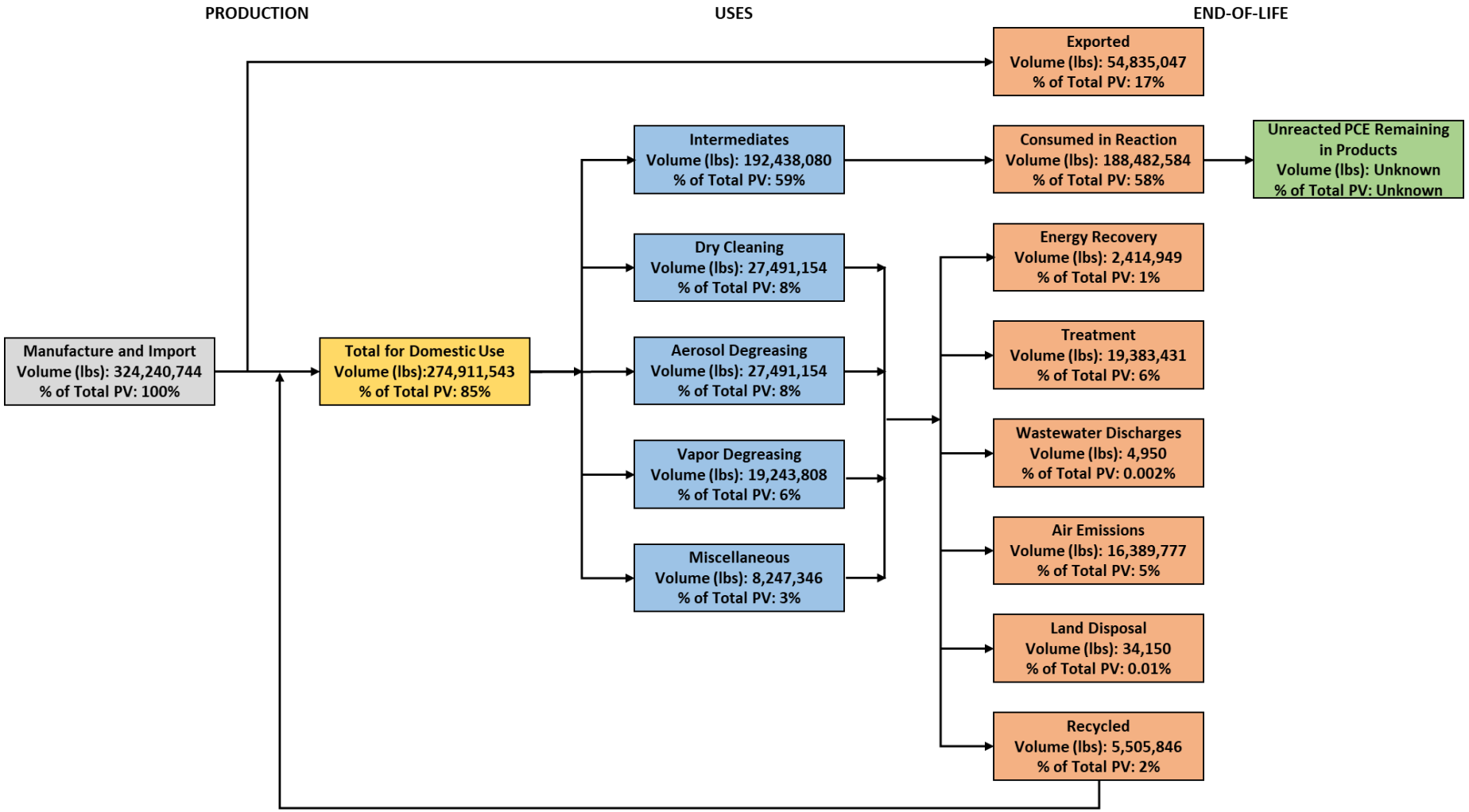
Any unused, spent, or waste PCE not accounted for above is expected to be sent for further waste management. These methods can be reported to TRI specifically as energy recovery or generally as waste treatment. However, volumes reported as sent off-site for energy recovery or treatment can be double counted if the site receiving the waste PCE is also required to report to TRI for PCE. This double counting is not addressed in the mass balance. For purposes of the mass balance, EPA assumed 100% destruction/removal efficiencies for volumes of PCE sent for waste treatment and energy recovery which is likely unrealistic. Therefore, some portion of these values may also be counted in releases.

The end-of-life stage also accounts for PCE that is consumed in a reaction from intermediate uses. To estimate the amount that is consumed in reaction, EPA identified in the sites in TRI that report PCE uses as a reactant and subtracted out the volume reported as released, disposed of, or otherwise managed as waste at each site from the intermediate use volume and assumed the remainder was consumed. EPA acknowledges that some portion of the intermediate use volume may remain as unintended impurities in products from the reaction; however, this volume cannot be quantified.

C.2 Results and Uncertainties in the Mass Balance

Figure_Apx C-1 shows the result of the mass balance. The overall percentage of PCE accounted for at the end-of-life is 89% of the 2016 CDR production volume. The 11% of the volume that is unaccounted

for is potentially due to limitations in reporting requirements (*e.g.*, reporting thresholds) for TRI and NEI resulting in certain sites not being required to report. Other sources of uncertainty include comparison of data from different years, CBI claims on exported volumes, double counting of treatment and energy recovery volumes, and unknown volumes of unreacted PCE remaining in products.

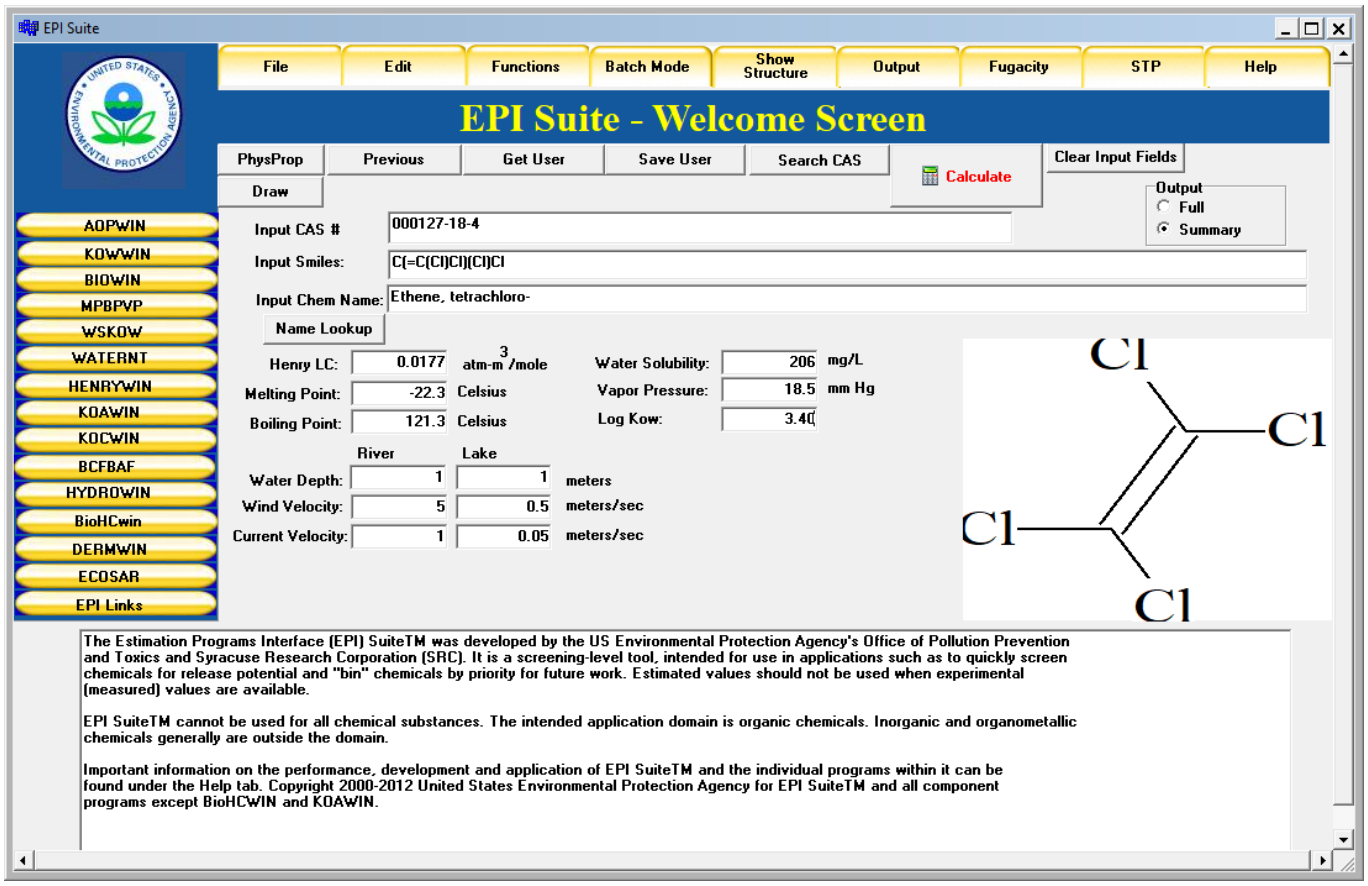


Figure_Apx C-1. Mass Balance for Perchloroethylene

Appendix D FATE AND TRANSPORT

EPI Suite™ Model Inputs

To set up EPI Suite™ for estimating fate properties of PCE, PCE was identified using the "Name Lookup" function. The physical-chemical properties were input based on the values in Table 1-1. EPI Suite™ was run using default settings (*i.e.*, no other parameters were changed or input).



Figure_Apx D-1. Screen capture of EPISuite™ parameters used to calculate fate and physical chemical properties for PCE.

Appendix E ENVIRONMENTAL EXPOSURES

EPA presents the industrial sectors for each condition of use category below. In cases where the NPDES is unknown, no close analog could be identified, or the exact location of a chemical loading is unknown, surface water concentrations were modeled using the "SIC Code Option" within E-FAST 2014 (U.S. EPA, 2014b) to estimate potential occurrence of PCE shown in Table_Apx E-1.

EPA also conducted a geospatial analysis at the watershed level (HUC-8 and HUC-12) to compare the measured and predicted surface water concentrations and investigate if the facility releases may be associated with the observed concentrations in surface water. Below in Table_Apx E-2, Table_Apx E-3 and Table_Apx E-4 EPA has broken out the occurrence of PCE by facility, monitoring sites and location by State.

Table_Apx E-1 provides the industrial sectors for each condition of use.

Table_Apx E-1. Industry Sector Modeled for Facilities without Site-Specific Flow Data in E-FAST 2014

Condition of Use	Industry Sector (SIC Code Option)
OES: Manufacturing	Organic Chemicals Manufacture
OES: Import/Repackaging	POTW (Industrial)
OES: Processing as a Reactant	Organic Chemicals Manufacture
OES: Incorporation into Formulation	POTW (Industrial)
OES: OTVD (Includes releases for Closed-Loop Degreasing, Conveyorized Degreasing, Web Degreasing, Cold Cleaning, and Metalworking Fluids)	Primary Metal Forming Manufacture
OES: OTVDs (not in TRI/DMR)	POTW (Industrial)
OES: Closed-Loop Vapor Degreasers (not in TRI/DMR)	POTW (Industrial)
OES: Conveyorized Degreasers (not in TRI/DMR)	POTW (Industrial)
OES: Web Degreasers (not in TRI/DMR)	POTW (Industrial)
OES: Aerosol Degreasing/Lubricants	n/a
OES: Dry Cleaning (commercial only)	Laundry/Dry Cleaner
OES: Dry Cleaning (industrial only)	Laundry/Dry Cleaner
OES: Adhesives, Paints, and Coatings	Adhesives and Sealants Manufacturer
OES: Chemical Maskant	Metal Finishing
OES: Industrial Processing Aid	Organic Chemicals Mfg

OES: Wipe Cleaning	n/a
OES: Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)	n/a
OES: Other Industrial Uses	POTW (Industrial)
OES: Other Commercial Uses	POTW (Industrial)
OES: Waste Handling, Disposal, Treatment, and Recycling	POTW (Industrial)

n/a = Not applicable because a NPDES or surrogate NPDES was available in E-FAST 2014 (U.S. EPA, 2014b) to obtain a site-specific stream flow for all facilities within the OES.

Table_Apx E-2 and Table_Apx E-3 show the occurrence of PCE release via facilities and monitoring sites for HUC 8 and HUC 12 respectively.

Table_Apx E-2. Occurrence of PCE Releases (Facilities) and Monitoring Sites By HUC-8.

HUC8	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
Co-located PERC Releases (Facilities) and Monitoring Sites (n = 4 HUCs)							
04040001	Little Calumet-Galien	440799.0	1783.8	IL,IN,MI	1	2	5
04050006	Lower Grand	1293837.6	5236.0	MI	1	1	4
07040001	Rush-Vermillion	711813.5	2880.6	MN,WI	1	1	1
11030012	Little Arkansas	910452.3	3684.5	KS	1	5	14
PERC Releases (Facilities) Only (n = 64 HUCs)							
10190003	Middle South Platte-Cherry Creek	1838438.0	7439.9	CO	5	0	0
02030105	Raritan	707463.2	2863.0	NJ	4	0	0
08080206	Lower Calcasieu	812177.5	3286.8	LA	4	0	0
12040104	Buffalo-San Jacinto	756769.3	3062.5	TX	4	0	0
02060003	Gunpowder-Patapsco	907202.4	3671.3	MD,PA	3	0	0
07120004	Des Plaines	931517.4	3769.7	IL,WI	3	0	0
08070204	Lake Maurepas	456253.8	1846.4	LA	3	0	0
02040201	Crosswicks-Neshaminy	347995.5	1408.3	NJ,PA	2	0	0
04120104	Niagara	871679.6	3527.6	CN,NY	2	0	0
05030201	Little Muskingum-Middle Island	1161545.0	4700.6	OH,WV	2	0	0
07090002	Middle Rock	1172085.4	4743.3	IL,WI	2	0	0
07120005	Upper Illinois	644077.9	2606.5	IL	2	0	0
08090301	East Central Louisiana Coastal	1728228.3	6993.9	LA	2	0	0
12020003	Lower Neches	709968.8	2873.1	TX	2	0	0
12030105	Upper Trinity	876612.0	3547.5	TX	2	0	0
12040204	West Galveston Bay	776232.4	3141.3	TX	2	0	0
15010015	Las Vegas Wash	1202287.8	4865.5	NV	2	0	0
18070106	San Gabriel	579966.3	2347.0	CA	2	0	0
01090001	Charles	955681.2	3867.5	MA	1	0	0
02030103	Hackensack-Passaic	725724.6	2936.9	NJ,NY	1	0	0
02030104	Sandy Hook-Staten Island	454261.8	1838.3	NJ,NY	1	0	0
02060002	Chester-Sassafras	833436.9	3372.8	DE,MD,PA	1	0	0
03050107	Tyger	517390.6	2093.8	SC	1	0	0
03050111	Lake Marion	351158.0	1421.1	SC	1	0	0
03050204	South Fork Edisto	555149.8	2246.6	SC	1	0	0
03090206	Florida Southeast Coast	2352752.2	9521.3	FL	1	0	0

HUC8	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
03160103	Buttahatchee	553396.1	2239.5	AL,MS	1	0	0
03160112	Upper Black Warrior	797270.7	3226.4	AL	1	0	0
03160113	Lower Black Warrior	929969.4	3763.5	AL	1	0	0
04060101	Pere Marquette-White	1333169.6	5395.1	MI	1	0	0
04080201	Tittabawassee	926364.9	3748.9	MI	1	0	0
04110003	Ashtabula-Chagrin	401605.3	1625.2	OH,PA	1	0	0
04120103	Buffalo-Eighteenmile	457151.3	1850.0	NY	1	0	0
04120200	Lake Erie	6483450.8	26237.6	CN,MI,NY,OH,PA	1	0	0
04130001	Oak Orchard-Twelvemile	685684.0	2774.9	CN,NY	1	0	0
04150403	Winooski River	680464.2	2753.7	VT	1	0	0
05020003	Upper Monongahela	296728.7	1200.8	PA,WV	1	0	0
05030101	Upper Ohio	1271402.1	5145.2	OH,PA,WV	1	0	0
05040006	Licking	499187.6	2020.1	OH	1	0	0
05050008	Lower Kanawha	591554.2	2393.9	WV	1	0	0
05080001	Upper Great Miami, Indiana, Ohio	1607903.9	6507.0	IN,OH	1	0	0
05080002	Lower Great Miami, Indiana, Ohio	883871.2	3576.9	IN,OH	1	0	0
05120201	Upper White	1740657.8	7044.2	IN	1	0	0
05140101	Silver-Little Kentucky	807385.6	3267.4	IN,KY	1	0	0
07120003	Chicago	419754.7	1698.7	IL,IN	1	0	0
07120006	Upper Fox	988245.7	3999.3	IL,WI	1	0	0
07140106	Big Muddy	1526746.1	6178.5	IL	1	0	0
08070201	Bayou Sara-Thompson	444709.9	1799.7	LA,MS	1	0	0
10190004	Clear	365027.3	1477.2	CO	1	0	0
11030017	Upper Walnut River	620982.8	2513.0	KS	1	0	0
11110104	Robert S. Kerr Reservoir	1128010.3	4564.9	AR,OK	1	0	0
11130303	Middle Washita	1605161.6	6495.9	OK	1	0	0
12030102	Lower West Fork Trinity	969001.7	3921.4	TX	1	0	0
12040201	Sabine Lake	636218.6	2574.7	LA,TX	1	0	0
12070104	Lower Brazos	1051241.4	4254.2	TX	1	0	0
12110201	North Corpus Christi Bay	111266.8	450.3	TX	1	0	0
12110202	South Corpus Christi Bay	322454.2	1304.9	TX	1	0	0
16020204	Jordan	520846.5	2107.8	UT	1	0	0
17020010	Upper Columbia-Entiat	958508.9	3878.9	WA	1	0	0
17050114	Lower Boise	850233.1	3440.8	ID	1	0	0
17110012	Lake Washington	388533.5	1572.3	WA	1	0	0
18050002	San Pablo Bay	784983.8	3176.7	CA	1	0	0

HUC8	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
18070102	Santa Clara	1040515.7	4210.8	CA	1	0	0
18070203	Santa Ana	1084241.9	4387.8	CA	1	0	0
PERC Monitoring Sites Only (n = 43 HUCs)							
02020004	Mohawk	1632666.9	6607.2	NY	0	1	1
02040105	Middle Delaware-Musconetcong	869995.3	3520.8	NJ,PA	0	1	3
02050205	Pine	627641.5	2540.0	PA	0	1	2
02050206	Lower West Branch Susquehanna	1158170.9	4687.0	PA	0	1	3
02050301	Lower Susquehanna-Penns	926808.1	3750.7	PA	0	1	6
02070004	Conococheague-Opequon	1457399.0	5897.9	MD,PA,VA,WV	0	2	6
04010201	St. Louis	1882043.1	7616.4	MN,WI	0	1	4
04010302	Bad-Montreal	832709.3	3369.9	MI,WI	0	1	4
04030101	Manitowoc-Sheboygan	1043247.9	4221.9	WI	0	1	4
04030204	Lower Fox	414795.8	1678.6	WI	0	1	3
04040002	Pike-Root	267751.0	1083.5	IL,WI	0	1	4
04050001	St. Joseph	3016829.4	12208.7	IN,MI	0	1	4
04050003	Kalamazoo	1300194.9	5261.7	MI	0	1	1
04080206	Saginaw	160773.8	650.6	MI	0	1	4
04090003	Clinton	510065.3	2064.2	MI	0	1	4
04090004	Detroit	567874.0	2298.1	CN,MI	0	1	4
04100009	Lower Maumee	689823.7	2791.6	OH	0	9	17
04100012	Huron-Vermilion	488453.3	1976.7	OH	0	1	3
04110001	Black-Rocky	572567.0	2317.1	OH	0	1	1
04110002	Cuyahoga	519309.5	2101.6	OH	0	1	3
04130003	Lower Genesee	682891.3	2763.6	NY	0	1	4
04140101	Irondequoit-Ninemile	445757.0	1803.9	NY	0	1	3
04140203	Oswego	93064.4	376.6	NY	0	1	4
06030003	Upper Elk	821468.2	3324.4	AL,TN	0	4	8
07090004	Sugar	486750.9	1969.8	IL,WI	0	1	3
07140102	Meramec	1375977.1	5568.4	MO	0	4	7
08040302	Castor	612659.1	2479.3	LA	0	2	3
10300102	Lower Missouri-Moreau	2176536.7	8808.1	MO	0	1	1
11140207	Lower Red-Lake Iatt	912489.8	3692.7	LA	0	3	3
11140209	Black Lake Bayou	579878.2	2346.7	LA	0	1	2
12100303	Lower San Antonio	950344.1	3845.9	TX	0	1	1
13020201	Rio Grande-Santa Fe	1197851.1	4847.5	NM	0	1	3
13020203	Rio Grande-Albuquerque	2057935.0	8328.2	NM	0	1	3

HUC8	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
14030005	Upper Colorado-Kane Springs	1455869.5	5891.7	CO,UT	0	5	9
14060008	Lower Green	1195181.0	4836.7	UT	0	1	2
15010008	Upper Virgin	1397207.4	5654.3	UT	0	2	2
15060106	Lower Salt	666211.2	2696.1	AZ	0	5	12
15070102	Aqua Fria	1758350.5	7115.8	AZ	0	7	11
17090001	Middle Fork Willamette	874861.9	3540.4	OR	0	1	1
17090002	Coast Fork Willamette	426542.2	1726.2	OR	0	2	2
17090003	Upper Willamette	1198500.4	4850.2	OR	0	3	5
17090004	Mckenzie	857010.6	3468.2	OR	0	4	5
21010005	Eastern Puerto Rico	914478.3	3700.8	PR	0	1	2

Table_Apx E-3. Occurrence of PCE Releases (Facilities) and Monitoring Sites By HUC-12.

HUC12	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
Co-located PERC Releases (Facilities) and Monitoring Sites (n = 1 HUC)							
040400010509	Willow Creek-Burns Ditch	13501.8	54.6	IN	1	1	1
PERC Releases (Facilities) Only (n =83 HUCs)							
010900010402	Outlet Saugus River	17633.5	71.4	MA	1	0	0
020301030802	Peckman River-Passaic River	22354.8	90.5	NJ	1	0	0
020301040204	Morses Creek-Arthur Kill	18931.5	76.6	NJ,NY	1	0	0
020301050306	Devils Brook	9890.5	40.0	NJ	1	0	0
020301050312	Lower Millstone River	31839.8	128.8	NJ	1	0	0
020301050504	Green Brook	32590.3	131.9	NJ	1	0	0
020301050505	Lawrence Brook	29837.9	120.8	NJ	1	0	0
020402010202	West Branch Neshaminy Creek	15964.6	64.6	PA	1	0	0
020402010404	Van Sciver Lake-Delaware River	16914.3	68.5	NJ,PA	1	0	0
020600020202	Little Elk Creek	26942.3	109.0	MD,PA	1	0	0
020600030902	Dead Run-Gywnns Falls	31450.3	127.3	MD	3	0	0
030501070305	Lower South Tyger River	29288.0	118.5	SC	1	0	0
030501110109	Lake Marion-Santee River	165146.0	668.3	SC	1	0	0
030502040108	Lower Shaw Creek	32220.3	130.4	SC	1	0	0
030902061003	Lake Worth Inlet-Boynton Inlet Frontal	39017.9	157.9	FL	1	0	0
031601030202	Cannon Mill Creek-Beaver Creek	28263.4	114.4	AL	1	0	0
031601120101	Headwaters Valley Creek	34201.6	138.4	AL	1	0	0
031601130204	Goose Pond-Black Warrior River	25818.5	104.5	AL	1	0	0
040500060712	Lloyd Bayou-Grand River	31929.6	129.2	MI	1	0	0
040601010904	White Lake-White River	39040.6	158.0	MI	1	0	0
040802010604	Prairie Creek-Tittabawassee River	25251.7	102.2	MI	1	0	0
041100030504	Doan Brook-Frontal Lake Erie	28193.7	114.1	OH	1	0	0
041201030401	Smoke Creek	21267.2	86.1	NY	1	0	0
041201040604	City of North Tonawanda-Niagara River	8541.4	34.6	NY	1	0	0
041201040605	Niagara Falls-Niagara River	21666.5	87.7	CN,NY	1	0	0
041202000300	Lake Erie	6359988.3	25738.0	CN,MI,NY,OH,PA	1	0	0
041300010703	Headwaters Eighteenmile Creek	15270.7	61.8	NY	1	0	0
041504030101	Headwaters Stevens Branch	22103.3	89.5	VT	1	0	0
050200030307	Cobun Creek-Monongahela River	21730.5	87.9	WV	1	0	0
050301011103	Carpenter Run-Ohio River	23323.8	94.4	OH,PA,WV	1	0	0
050302011004	Haynes Run-Ohio River	19386.4	78.5	OH,WV	2	0	0

HUC12	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
050400060409	Beaver Run-South Fork Licking River	19150.9	77.5	OH	1	0	0
050500080304	Scary Creek-Kanawha River	20472.1	82.8	WV	1	0	0
050800012005	Poplar Creek-Great Miami River	34854.0	141.1	OH	1	0	0
050800020105	Town of Oakwood-Great Miami River	16944.9	68.6	OH	1	0	0
051202011205	Dollar Hide Creek-White River	30882.8	125.0	IN	1	0	0
051401010903	Mill Creek Cutoff	20966.7	84.8	KY	1	0	0
070400010206	Town of Pine Bend	31880.6	129.0	MN	1	0	0
070900021402	Delavan Lake	22265.1	90.1	WI	1	0	0
070900021502	City of Beloit-Rock River	30612.6	123.9	IL,WI	1	0	0
071200030407	Grand Calumet River-Little Calumet River	17191.8	69.6	IL,IN	1	0	0
071200040905	Des Plaines River	23822.3	96.4	IL	3	0	0
071200050106	Walley Run-Aux Sable Creek	12878.4	52.1	IL	1	0	0
071200050705	Bills Run-Illinois River	33003.8	133.6	IL	1	0	0
071200061206	Jelkes Creek-Fox River	25551.9	103.4	IL	1	0	0
071401060407	Ewing Creek	14114.5	57.1	IL	1	0	0
080702010402	Devils Swamp-Bayou Baton Rouge	17328.4	70.1	LA	1	0	0
080702040101	Bayou Francois	16194.6	65.5	LA	1	0	0
080702040103	Grand Goudine Bayou-New River	17644.3	71.4	LA	1	0	0
080702040302	Hope Canal-Pipeline Canal	18663.6	75.5	LA	1	0	0
080802060301	Maple Fork-Bayou d'Inde	22308.4	90.3	LA	2	0	0
080802060302	Bayou Verdine-Calcasieu River	24546.0	99.3	LA	1	0	0
080802060303	Prien Lake-Calcasieu River	29606.9	119.8	LA	1	0	0
080903010307	Town of Westwego-Main Canal	39569.2	160.1	LA	2	0	0
101900030304	Cherry Creek-South Platte River	35554.2	143.9	CO	5	0	0
101900040404	Outlet Clear Creek	19355.3	78.3	CO	1	0	0
110300120204	Headwaters Dry Turkey Creek	30940.1	125.2	KS	1	0	0
110300170403	Constant Creek-Walnut River	28347.5	114.7	KS	1	0	0
111101040611	Massard Creek	10720.0	43.4	AR	1	0	0
111303030708	Outlet Caddo Creek	26104.7	105.6	OK	1	0	0
120200030406	Union Canal-Neches River	26733.6	108.2	TX	1	0	0
120200030407	Grays Bayou-Neches River	39760.5	160.9	TX	1	0	0
120301020206	Brogden Branch-Town Creek	14887.3	60.3	TX	1	0	0
120301050101	Headwaters Turtle Creek	21893.0	88.6	TX	2	0	0
120401040703	Vince Bayou-Buffalo Bayou	38130.8	154.3	TX	3	0	0
120401040706	Goose Creek-Frontal Galveston Bay	37289.7	150.9	TX	1	0	0

HUC12	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
120402010300	Salt Bayou	212334.8	859.3	TX	1	0	0
120402040100	Clear Creek-Frontal Galveston Bay	190566.3	771.2	TX	1	0	0
120402040400	Mustang Bayou	183973.7	744.5	TX	1	0	0
120701040505	Outlet Barzos River	35803.4	144.9	TX	1	0	0
121102010001	Rincon Bayou	28406.5	115.0	TX	1	0	0
121102020107	Tule Lake	12284.3	49.7	TX	1	0	0
150100150604	City of Las Vegas-Las Vegas Wash	69596.1	281.7	NV	2	0	0
160202040304	City Creek	11166.6	45.2	UT	1	0	0
170200100307	Rainey Spring-Columbia River	21142.9	85.6	WA	1	0	0
170501140403	Crane Creek-Boise River	18624.7	75.4	ID	1	0	0
171100120301	Bear Creek	30140.7	122.0	WA	1	0	0
180500020801	San Pablo Bay Estuaries	85721.1	346.9	CA	1	0	0
180701020507	Gorman Creek	23547.6	95.3	CA	1	0	0
180701060102	Lower Dominguez Channel	36125.6	146.2	CA	1	0	0
180701060701	Long Beach Harbor	33394.5	135.1	CA	1	0	0
180701060703	San Pedro Bay	40623.1	164.4	CA	1	0	0
180702031003	Greenville Banning Channel-Santa Ana River	22359.3	90.5	CA	1	0	0
PERC Monitoring Sites Only (n = 67 HUCs)							
020200040908	Lower Canajoharie Creek	13216.2	53.5	NY	0	1	1
020401050911	Buck Creek-Delaware River	15442.9	62.5	NJ,PA	0	1	3
020502050607	Furnace Run-Pine Creek	27631.1	111.8	PA	0	1	2
020502061103	Beaver Run-Chillisquaque Creek	26019.5	105.3	PA	0	1	3
020503010603	Lower West Branch Mahantango Creek	13445.1	54.4	PA	0	1	6
020700040702	Dennis Creek-Back Creek	32533.8	131.7	PA	0	1	4
020700041009	Sharmans Branch-Antietam Creek	36619.8	148.2	MD	0	1	2
040102011503	City of Cloquet-Saint Louis River	36671.5	148.4	MN	0	1	4
040103020702	Camerons Creek-Bad River	13498.0	54.6	WI	0	1	4
040301010605	Manitowoc River	11648.4	47.1	WI	0	1	4
040302040405	City of Green Bay-Fox River	19046.2	77.1	WI	0	1	3
040400010603	Calumet River-Frontal Lake Michigan	34563.8	139.9	IL,IN	0	1	4
040400020101	Wind Point-Frontal Lake Michigan	16148.3	65.3	WI	0	1	4
040500012210	City of Niles-Saint Joseph River	8758.5	35.4	MI	0	1	4
040500030911	Peach Orchid Creek-Kalamazoo River	15046.6	60.9	MI	0	1	1

HUC12	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
040500060708	Jubb Bayou-Grand River	11389.8	46.1	MI	0	1	4
040802060201	Crow Island-Saginaw River	33918.2	137.3	MI	0	1	4
040900030402	Cranberry Marsh Drain-Clinton River	21236.7	85.9	MI	0	1	4
040900040406	Ashcroft Sherwood Drain-River Rouge	12735.6	51.5	MI	0	1	4
041000090509	Lower Beaver Creek	10727.3	43.4	OH	0	1	2
041000090510	Lick Creek-Maumee River	14952.3	60.5	OH	0	1	2
041000090603	Haskins Road Ditch-Maumee River	10054.5	40.7	OH	0	1	1
041000090804	Heilman Ditch-Swan Creek	23569.6	95.4	OH	0	1	2
041000090903	Crooked Creek-Maumee River	12075.0	48.9	OH	0	2	5
041000090904	Delaware Creek-Maumee River	10576.9	42.8	OH	0	3	5
041000120204	Town of Vermilion-Vermilion River	17985.5	72.8	OH	0	1	3
041100010203	Rocky River	16199.9	65.6	OH	0	1	1
041100020602	Village of Independence-Cuyahoga River	10848.3	43.9	OH	0	1	3
041300030704	Genesee River	14336.9	58.0	NY	0	1	4
041401010703	Allen Creek	20188.5	81.7	NY	0	1	3
041402030204	Oswego River	11026.9	44.6	NY	0	1	4
060300030201	Bradley Creek	30268.8	122.5	TN	0	4	8
070400010102	Lock and Dam Number Three-Mississippi River	40106.3	162.3	MN,WI	0	1	1
070900040201	Badger Mill Creek	21661.8	87.7	WI	0	1	3
071401020703	Stater Creek-Meramec River	28521.9	115.4	MO	0	1	2
071401021001	Hamilton Creek-Meramec River	34956.9	141.5	MO	0	1	2
071401021002	Grand Glaize Creek-Meramec River	29896.0	121.0	MO	0	1	2
071401021004	Meramec River	27977.7	113.2	MO	0	1	1
080403020401	Caney Creek Reservoir	26803.0	108.5	LA	0	2	3
103001020709	Black Branch-Perche Creek	12012.4	48.6	MO	0	1	1
110300120303	110300120303-Little Arkansas River	23920.3	96.8	KS	0	1	4
110300120408	City of Sedgwick-Little Arkansas River	27404.6	110.9	KS	0	4	10
111402070401	Sibley Lake	24862.2	100.6	LA	0	3	3
111402090404	Grand Bayou	34707.7	140.5	LA	0	1	2
121003030306	Salt Creek-Ecleto Creek	18817.5	76.2	TX	0	1	1
130202010209	Canada de Cochiti-Rio Grande	20418.4	82.6	NM	0	1	3
130202030107	Town of Corrales-Rio Grande	26313.8	106.5	NM	0	1	3
140300050205	Outlet Courthouse Wash	18177.4	73.6	UT	0	1	1

HUC12	Name	Acres	Square km	States	No. of Facilities	No. of Monitoring Sites	No. of Monitoring Samples in HUC
140300050307	Negro Bill Canyon-Colorado River	19473.5	78.8	UT	0	1	2
140300051001	Little Canyon-Colorado River	32843.3	132.9	UT	0	2	4
140300051002	Bull Canyon-Colorado River	32166.0	130.2	UT	0	1	2
140600080708	Upheaval Canyon-Green River	20259.5	82.0	UT	0	1	2
150100080109	Lower North Fork Virgin River	34874.9	141.1	UT	0	2	2
150601060202	Upper Indian Bend Wash	27058.2	109.5	AZ	0	1	3
150601060306	City of Phoenix-Salt River	87618.1	354.6	AZ	0	2	4
150601060307	Town of Santa Maria-Salt River	34122.5	138.1	AZ	0	2	5
150701020606	Upper Arizona Canal Diversion Channel	15465.9	62.6	AZ	0	1	3
150701020607	Lower Arizona Canal Diversion Channel	19739.1	79.9	AZ	0	1	1
150701020806	Middle Skunk Creek	28304.4	114.5	AZ	0	1	3
150701020807	Lower Skunk Creek	24449.6	98.9	AZ	0	2	2
150701020809	City of Peoria-New River	38282.5	154.9	AZ	0	2	2
170900011003	Mill Race-Middle Fork Willamette River	12666.2	51.3	OR	0	1	1
170900020405	Papenfus Creek-Coast Fork Willamette River	17460.5	70.7	OR	0	2	2
170900030601	Sring Creek-Willamette River	29305.8	118.6	OR	0	3	5
170900040705	Camp Creek	16999.1	68.8	OR	0	1	1
170900040706	Walterville Canal-McKenzie River	33735.2	136.5	OR	0	3	4
210100050503	Cienaga de las Cucharillas Drainage Watershed	6557.0	26.5	PR	0	1	2

Table_Apx E-4 provides a list of states/territories with facilities that have releases of PCE and/or monitoring sites for the year of 2016.

Table_Apx E-4. States with Monitoring Sites or Facilities in 2016

State Name	PERC Facility[a]	PERC Monitoring Site	PERC Facility or Monitoring Site
Alabama	X		X
Arizona		X	X
Arkansas	X		X
California	X		X
Colorado	X		X
Florida	X		X
Idaho	X		X
Illinois	X		X
Indiana	X	X	X
Kansas	X	X	X
Kentucky	X		X
Louisiana	X	X	X
Maryland	X	X	X
Massachusetts	X		X
Michigan	X	X	X
Minnesota	X	X	X
Missouri		X	X
Nevada	X		X
New Jersey	X	X	X
New Mexico		X	X
New York	X	X	X
Ohio	X	X	X
Oklahoma	X		X
Oregon		X	X
Pennsylvania	X	X	X
Puerto Rico		X	X
South Carolina	X		X
Tennessee		X	X
Texas	X	X	X
Utah	X	X	X
Vermont	X		X
Washington	X		X
West Virginia	X		X
Wisconsin	X	X	X
Total	**28**	**19**	**34**

a. PERC Facility is based on the location of the facility mapped. For indirect releasers, the receiving facility was mapped if known.

A break-out of facility-specific modeling results organized by OES, with predicted surface water concentrations and associated days of COC exceedance, are included in Table_Apx E-5. These facility-specific modeling results are utilized and discussed in environmental risk conclusions presented in Section 4.4.1.

Table_Apx E-5. E-FAST Modeling Results for Known Direct and Indirect Releasing Facilities for 2016

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
OES: Manufacturing								
Axiall Corporation Westlake, LA NPDES: LA0000761	Surface Water or POTW	Direct (0% WWT removal): LA0000761 Indirect (88% WWT removal): Organic Chemicals Mfg	Surface Water	350	0.1 (max)	0.11	1,400	NA
							50	0
							360	0
						2.22	1,400	NA
							50	3
							360	0
				350	3.08E-02 (avg)	3.48E-02	1,400	NA
							50	0
							360	0
						0.68	1,400	NA
							50	0
							360	0
				20	0.54	0.61	1,400	NA
							50	0
							360	0
Greenchem West Palm Beach, FL NPDES: None (FRS 110056959634)	Surface Water or POTW	Direct and Indirect Surrogate: Organic Chemicals Mfg Receiving Facility: Unknown	Surface Water	350	0.1 (max)	18.48	1,400	NA
							50	25
							360	4
						2.22	1,400	NA
							50	3
							360	0
				350	3.08E-02 (avg)	5.69	1,400	NA
							50	12
							360	0
						0.68	1,400	NA
							50	0
							360	0
				20	0.54	99.82	1,400	NA
							50	4
							360	1
Occidental Chemical Corp Geismar Plant Geismar, LA	Surface Water	LA0002933	Surface Water	350	1.69E-03	6.84E-06	1,400	NA
							50	0
							360	0
				20	2.95E-02	1.19E-04	1,400	NA
							50	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
NPDES: LA0002933							360	0
Olin Blue Cube Freeport, TX NPDES: None (FRS 110066943605)	Non-POTW WWT	Receiving Facility: TX0006483	Surface Water	350	4.15E-02	1.91E-03	1,400	NA
							50	0
							360	0
				20	7.26E-01	3.34E-02	1,400	NA
							50	0
							360	0
Solvents & Chemicals Pearland, TX NPDES: Not available (TRI: 77588SLVNT4704S)	Surface Water or POTW	Direct and Indirect Surrogate: Organic Chemicals Mfg Receiving Facility: Unknown	Surface Water	350	3.0E-4 (max)	5.56E-2	1,400	NA
							50	0
							360	0
						6.65E-3	1,400	NA
							50	0
							360	0
				350	8.57E-05 (avg)	1.58E-02	1,400	NA
							50	0
							360	0
						1.90E-3	1,400	NA
							50	0
							360	0
				20	1.5E-3	0.28	1,400	NA
							50	0
							360	0
Univar USA Inc Redmond, WA NPDES: None (FRS: 110036000000)	Surface Water or POTW	Direct and Indirect Surrogate: Organic Chemicals Mfg Receiving Facility: Unknown	Surface Water	350	0.1 (max)	18.48	1,400	NA
							50	25
							360	4
						2.22	1,400	NA
							50	3
							360	0
				350	3.08E-02 (avg)	5.69	1,400	NA
							50	12
							360	0
						0.68	1,400	NA
							50	0
							360	0
				20	0.54	99.82	1,400	NA
							50	4
							360	1
OES: Import/Repackaging								
Chemtool Rockton, IL NPDES: IL0064564	Surface Water	IL0064564	Surface Water	250	1.20E-03	1.75E-03	1,400	NA
							50	0
							360	0
				20	0.015	0.0218	1,400	NA
							50	0
							360	0
Harvey Terminal Harvey, LA	Surface Water	Surrogate based on	Surface Water	250	8.00E-05	3.24E-07	1,400	NA
							50	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
NPDES: LA0056600		location: LA0005291					360	0
				20	0.001	4.05E-06	1,400	NA
							50	0
							360	0
Hubbard-Hall Inc Waterbury, CT NPDES: None (FRS 110000317194	Non-POTW WWT	Surrogate: Industrial POTW (for receiving facility FRS 110004250541)	Surface Water	250	1.12	17.32	1,400	NA
							50	6
							360	0
				20	13.95	215.72	1,400	NA
							50	11
							360	1
Vopak Terminal Westwego Inc Westwego, LA NPDES: LA0124583	Surface Water	Surrogate based on location: LA0003093	Surface Water	250	4.80E-03	1.94E-05	1,400	NA
							50	0
							360	0
				20	0.06	2.43E-04	1,400	NA
							50	0
							360	0
OES: Processing as a Reactant								
Akzo Nobel Surface Chemistry LLC Morris, IL NPDES: IL0026069	Surface Water	IL0026069	Surface Water	350	1.43E-04	2.98E-04	1,400	NA
							50	0
							360	0
				20	0.0025	0.00521	1,400	NA
							50	0
							360	0
Atkemix Ten Inc Louisville, KY NPDES: KY0002780	Surface Water	KY0002780	Surface Water	350	7.39E-02	3.96E-03	1,400	NA
							50	0
							360	0
				20	1.29	0.0691	1,400	NA
							50	0
							360	0
Bayer Corporation Haledon, NJ NPDES: NJG104451	Surface Water	Surrogate: Organic Chemical Mfg SIC	Surface Water	350	2.86E-05	5.29E-03	1,400	NA
							50	0
							360	0
				20	0.0005	0.0924	1,400	NA
							50	0
							360	0
Bayer MaterialScience New Martinsville, WV NPDES: WV0005169	Surface Water	WV0005169	Surface Water	350	7.14E-04	8.50E-05	1,400	NA
							50	0
							360	0
				20	1.25E-02	1.49E-03	1,400	NA
							50	0
							360	0
Chemtura North and South Plants Morgantown, WV NPDES: WV0004740	Surface Water	WV0004740	Surface Water	350	2.86E-05	4.15E-05	1,400	NA
							50	0
							360	0
				20	0.0005	0.000725	1,400	NA
							50	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
							360	0
Dupont-Chemours Montague Site Montague, MI NPDES: MI0000884	Surface Water	MI0000884	Still Water	350	1.68E-02	2.03	1,400	NA
							50	0
							360	0
				20	2.95E-01	35.07	1,400	NA
							50	0
							360	0
Eagle US 2 LLC - Lake Charles Complex Lake Charles, LA NPDES: LA0000761	Surface Water	LA0000761	Surface Water	350	1.33	1.5	1,400	NA
							50	0
							360	0
				20	23.27	26.3	1,400	NA
							50	0
							360	0
Flint Hills Resources Corpus Christi LLC - West Plant Corpus Christi, TX NPDES: TXU001146, TX0006289	Surface Water	TX0006289	Still Water	350	6.87E-02	2.96	1,400	NA
							50	0
							360	0
				20	1.2	51.65	1,400	NA
							50	20
							360	0
Flint Hills Resources Pine Bend LLC Rosemount, MN NPDES: MN0070246, MN0000418	Surface Water	MN0000418	Surface Water	350	1.17E-02	3.31E-03	1,400	NA
							50	0
							360	0
				20	2.04E-01	0.0566	1,400	NA
							50	0
							360	0
Honeywell International Inc - Geismar Complex Geismar, LA NPDES: LA0006181	Surface Water	LA0006181	Surface Water	350	2.03E-02	8.22E-05	1,400	NA
							50	0
							360	0
				20	3.56E-01	1.46E-03	1,400	NA
							50	0
							360	0
Honeywell International Inc- Baton Rouge Plant Baton Rouge, LA NPDES: LAR10E873, LA0000329	Surface Water	LA0000329	Surface Water	350	4.93E-02	4.87	1,400	NA
							50	0
							360	0
				20	8.62E-01	84.98	1,400	NA
							50	7
							360	0
Indorama Ventures Olefins, LLC Sulphur, LA NPDES: LA0069850	Surface Water	Surrogate: Organic Chemical Mfg SIC	Surface Water	350	1.14E-05	2.11E-03	1,400	NA
							50	0
							360	0
				20	0.0002	0.037	1,400	NA
							50	0
							360	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
Keeshan And Bost Chemical Co., Inc. Manvel, TX NPDES: TX0072168	Surface Water	TX0072168	Still Water	350	5.71E-05	5.71	1,400	NA
							50	0
							360	0
				20	0.001	100	1,400	NA
							50	20
							360	0
Phillips 66 Lake Charles Refinery Westlake, LA NPDES: LAR05P540, LA0003026	Surface Water	LA0003026	Surface Water	350	5.87E-02	9.26E-02	1,400	NA
							50	0
							360	0
				20	1.03	1.62	1,400	NA
							50	0
							360	0
Phillips 66 Los Angeles Refinery Wilmington Plant Wilmington, CA NPDES: CA0000035	POTW	Receiving Facility: CA0053856	Still Water	350	1.08E-01	0.19	1,400	NA
							50	0
							360	0
Premcor Refining Group Inc Port Arthur Port Arthur, TX NPDES: TX0005991	Surface Water	TX0005991	Surface Water	350	1.28E-01	1.99	1,400	NA
							50	0
							360	0
				20	2.25	34.41	1,400	NA
							50	1
							360	0
Solutia Nitro Site Nitro, WV NPDES: WV0116181	Surface Water	Surrogate: WV0000868	Surface Water	350	1.71E-04	5.03E-05	1,400	NA
							50	0
							360	0
				20	0.003	8.82E-04	1,400	NA
							50	0
							360	0
Solvay - Houston Plant Houston, TX NPDES: TX0007072	Surface Water	TX0007072	Surface Water	350	2.36E-02	4.37	1,400	NA
							50	0
							360	0
				20	4.14E-01	75.93	1,400	NA
							50	0
							360	0
OES: Incorporation into Formulation								
Lord Corp Saegertown, PA NPDES: PA0101800	Non-POTW WWT	Surrogate: Industrial POTW	Surface Water	300	5.26	81.34	1,400	NA
							50	81
							360	3
				20	78.93	1220.57	1,400	NA
							50	19
							360	10
		IL0002453		300	1.67E-03	7.00E-04	1,400	NA

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
Stepan Co Millsdale Road Elwood, IL NPDES: IL0002453	Surface Water		Surface Water				50	0
							360	0
				20	0.025	0.0105	1,400	NA
							50	0
							360	0
Weatherford Aerospace LLC Weatherford, TX NPDES: None (FRS 110000743740)	POTW	Receiving Facility: TX0047724	Surface Water	300	1.50E-03	2.94E-02	1,400	NA
							50	0
							360	0
OES: Open Top Vapor Degreasing (OTVD)								
601 Nassau St Assoc LLC North Brunswick Twp, NJ NPDES: NJG129127	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	9.39E-06	1.04E-03	1,400	NA
							50	0
							360	0
				20	1.22E-04	1.36E-02	1,400	NA
							50	0
							360	0
ASCO Valve Manufacturing Aiken, SC NPDES: SC0049026	Surface Water	SC0049026	Surface Water	260	1.42E-04	1.58E-02	1,400	NA
							50	0
							360	0
				20	1.85E-03	0.21	1,400	NA
							50	0
							360	0
Chemours - Beaumont Works Beaumont, TX NPDES: TX0004669	Surface Water	TX0004669	Surface Water	260	6.49E-03	9.22E-03	1,400	NA
							50	0
							360	0
				20	8.44E-02	0.12	1,400	NA
							50	0
							360	0
Delphi Harrison Thermal Systems Dayton, OH NPDES: OH0009431	Surface Water	OH0009431	Surface Water	260	6.46E-03	1.21E-02	1,400	NA
							50	0
							360	0
				20	0.084	0.16	1,400	NA
							50	0
							360	0
Equistar Chemicals LP La Porte, TX NPDES: TX0119792	Surface Water	Surrogate: TX0002836	Still Water	260	1.25E-02	0.25	1,400	NA
							50	0
							360	0
				20	1.62E-01	3.23	1,400	NA
							50	0
							360	0
Fairfield Works Fairfield, AL	Surface Water	AL0003646	Surface Water	260	4.09E-03	5.20E-03	1,400	NA
							50	0
							360	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
NPDES: AL0003646				20	5.32E-02	6.76E-02	1,400	NA
							50	0
							360	0
Gayston Corp Dayton, OH NPDES: OH0127043	POTW	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	3.12E-03	0.35	1,400	NA
							50	6
							360	0
				20	4.06E-02	4.51	1,400	NA
							50	2
							360	1
Getzen Co Inc Elkhorn, WI NPDES: None (FRS110000417291)	POTW	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	3.49E-04	4.65E-03	1,400	NA
							50	0
							360	0
GM Components Holdings LLC Lockport, NY NPDES: NY0000558	Surface Water	NY0000558	Surface Water	260	7.08E-02	5.97	1,400	NA
							50	0
							360	0
				20	9.21E-01	77.64	1,400	NA
							50	3
							360	0
HB Fuller Co Morris, IL NPDES: IL0079758	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	7.90E-04	8.78E-02	1,400	NA
							50	0
							360	0
				20	1.03E-02	1.14	1,400	NA
							50	1
							360	0
Hyster-Yale Group, Inc Sulligent, AL NPDES: AL0069787	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	9.03E-07	1.00E-04	1,400	NA
							50	0
							360	0
				20	1.17E-05	1.30E-03	1,400	NA
							50	0
							360	0
MEMC Electronic Materials Incorporated Moore, SC NPDES: SC0036145	Surface Water	SC0036145	Surface Water	260	2.61E-04	8.78E-03	1,400	NA
							50	0
							360	0
				20	3.39E-03	0.11	1,400	NA
							50	0
							360	0
Piano Factory-Grand Haven Grand Haven, MI NPDES: MI0054399	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	7.17E-04	7.97E-02	1,400	NA
							50	0
							360	0
				20	9.32E-03	1.04	1,400	NA
							50	1
							360	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
Rex Heat Treat Lansdale Inc Lansdale, PA NPDES: PA0052965	Surface Water	Surrogate: PA0026182	Surface Water	260	1.94E-03	5.23E-02	1,400	NA
							50	0
							360	0
				20	2.53E-02	0.68	1,400	NA
							50	0
							360	0
Styrolution America LLC Channahon, IL NPDES: IL0001619	Surface Water	IL0001619	Surface Water	260	6.37E-04	2.21E-04	1,400	NA
							50	0
							360	0
				20	8.28E-03	2.88E-03	1,400	NA
							50	0
							360	0
Trane Residential Solutions - Fort Smith Fort Smith, AR NPDES: AR0052477	Surface Water	Surrogate: Primary Metal Forming Manufacture	Surface Water	260	1.31E-05	1.46E-03	1,400	NA
							50	0
							360	0
				20	1.71E-04	1.90E-02	1,400	NA
							50	0
							360	0
US Steel Fairless Hills Facility Fairless Hills, PA NPDES: PA0013463	Surface Water	PA0013463	Surface Water	260	1.01E-03	1.68E-04	1,400	NA
							50	0
							360	0
				20	1.32E-02	2.20E-03	1,400	NA
							50	0
							360	0
OES: OTVDs (not in TRI/DMR)								
4,819 OTVD Sites	POTW or non-POTW WWT	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	0.25	1,400	NA
							50	0
							360	0
OES: Closed-Loop Vapor Degreasers (not in TRI/DMR)								
25,423 Closed-Loop Vapor Degreaser Sites	POTW or non-POTW WWT	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	0.25	1,400	NA
							50	0
							360	0
OES: Conveyorized Degreasers (not in TRI/DMR)								
445 Conveyorized Degreaser Sites	POTW or non-POTW WWT	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	0.25	1,400	NA
							50	0
							360	0
OES: Web Degreasers (not in TRI/DMR)								
445 Web Degreaser Sites	POTW or non-	Surrogate: Industrial POTW	Surface Water	260	1.60E-02	0.25	1,400	NA
							50	0
							360	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
	POTW WWT							
OES: Dry Cleaning (Commercial and Industrial)								
Chase Tower Dallas, TX NPDES: TX0119784	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	9.70E-03 (high end)	5.51	1,400	NA
							50	0
							360	0
				307	9.10E-03 (central tendency)	5.17	1,400	NA
							50	0
							360	0
				20	0.14	79.55	1,400	NA
							50	1
							360	0
San Jacinto Tower Dallas, TX NPDES: TX0127779	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	1.10E-05 (high end)	6.25E-03	1,400	NA
							50	0
							360	0
				307	1.00E-05 (central tendency)	5.68E-03	1,400	NA
							50	0
							360	0
				20	1.55E-04	8.81E-02	1,400	NA
							50	0
							360	0
The Martin Las Vegas, NV NPDES: NV0023558	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	1.30E-04 (high end)	7.39E-02	1,400	NA
							50	0
							360	0
				307	1.20E-02 (central tendency)	6.82E-02	1,400	NA
							50	0
							360	0
				20	1.90E-03	1.08	1,400	NA
							50	0
							360	0
The Stirling Club Las Vegas, NV NPDES: NV0023256	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	6.90E-04 (high end)	0.39	1,400	NA
							50	0
							360	0
				307	6.50E-04 (central tendency)	0.37	1,400	NA
							50	0
							360	0
				20	1.00E-02	5.68	1,400	NA
							50	0
							360	0
12,822 Commercial Dry cleaning Sites	POTW	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	307	1.60E-03 (high end)	0.11	1,400	NA
							50	0
							360	0
				289	5.55E-04 (central tendency)	3.78E-02	1,400	NA
							50	0
							360	0
Boise State University	Surface Water		Surface Water	289	2.05E-04 (high end)	0.12	1,400	NA
							50	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
Boise, ID NPDES: IDG911006		Surrogate: Laundry/Dry Cleaner SIC					360	0
				307	1.93E-04 (central tendency)	0.11	1,400	NA
							50	0
							360	0
				20	2.97E-03	1.69	1,400	NA
							50	0
							360	0
Unifirst Williamstown, VT NPDES: VT0000850	Surface Water	Surrogate: Laundry/Dry Cleaner SIC	Surface Water	289	4.73E-05 (high end)	2.69E-02	1,400	NA
							50	0
							360	0
				307	4.45E-05 (central tendency)	2.53E-02	1,400	NA
							50	0
							360	0
				20	6.84E-04	0.39	1,400	NA
							50	0
							360	0
OES: Adhesives, Paints, and Coatings								
Roll Coating 60 Sites NPDES: None	POTW	Surrogate: Adhesives and Sealants Manufacturer	Surface Water	250	1.80	27.76	1,400	NA
							50	0
							360	0
Spray Coating with Water Curtain Capture 60 Sites NPDES: None	POTW	Surrogate: Adhesives and Sealants Manufacturer	Surface Water	250	1.40	21.59	1,400	NA
							50	0
							360	0
OES: Chemical Maskant								
Alliant Techsystems Operations LLC Elkton, MD NPDES: MD0000078	Surface Water	MD0000078	Surface Water	172	5.81E-06	5.34E-04	1,400	NA
							50	0
							360	0
				20	0.00005	4.60E-03	1,400	NA
							50	0
							360	0
Ducommun Aerostructures Inc Orange Facility Orange, CA NPDES: None (110070089239)	POTW	Surrogate: Metal Finishing SIC (surrogate for receiving facility CA0110604)	Surface Water	172	0.00262	0.12	1,400	NA
							50	0
							360	0
GE Aviation Lynn, MA NPDES: MA0003905	Surface Water	MA0003905	Still Water	172	8.72E-04	3.70E-03	1,400	NA
							50	0
							360	0
				20	0.0075	3.18E-02	1,400	NA
							50	0
							360	0
				172	4.07E-04	0.15	1,400	NA

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
McCanna Inc. Carpentersville, IL NPDES: IL0071340	Surface Water	Surrogate: Metal Finishing SIC	Surface Water				50	0
							360	0
				20	0.0035	1.33	1,400	NA
							50	0
							360	0
Weatherford Aerospace LLC Weatherford, TX NPDES: None (FRS 110000743740)	POTW	Receiving Facility: TX0047724	Surface Water	208	0.0109	0.21	1,400	NA
							50	0
							360	0
OES: Industrial Processing Aid								
Chevron Products Co - Salt Lake Refinery *Salt Lake City, UT* NPDES: UTG070261, UT0000175	Surface Water	UT0000175	Surface Water	300	5.80E-03	0.18	1,400	NA
							50	0
							360	0
				20	0.087	2.69	1,400	NA
							50	0
							360	0
Chevron Products Co Richmond Refinery Richmond, CA NPDES: CA0005134	Surface Water	CA0005134	Surface Water	300	3.03E-03	0.18	1,400	NA
							50	0
							360	0
				20	4.55E-02	2.64	1,400	NA
							50	0
							360	0
CHS McPherson Refinery McPherson, KS NPDES: KS0000337	Surface Water	KS0000337	Surface Water	300	0.0003	4.41E-02	1,400	NA
							50	0
							360	0
				20	0.0045	0.66	1,400	NA
							50	0
							360	0
ExxonMobil Oil Beaumont Refinery Beaumont, TX NPDES: None (FRS 110056963683)	Surface Water	TX0068934	Surface Water	300	2.42E-02	6.70	1,400	NA
							50	0
							360	0
				20	3.63E-01	100.55	1,400	NA
							50	2
							360	0
HollyFrontier El Dorado Refining LLC El Dorado, KS NPDES: KS0000761	Surface Water	KS0000761	Surface Water	300	3.03E-03	0.60	1,400	NA
							50	0
							360	0
				20	4.55E-02	8.97	1,400	NA
							50	0
							360	0
Hunt Refining Co - Tuscaloosa Refinery Tuscaloosa, AL	Surface Water	AL0000973	Surface Water	300	1.34E-02	4.44E-02	1,400	NA
							50	0
							360	0
				20	2.01E-01	0.66	1,400	NA

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NPDES: AL0000973							50	0
							360	0
Marathon Petroleum Co LP Garyville, LA NPDES: LAU009485, LA0045683	Surface Water	LA0045683	Still Water	300	9.07E-03	0.43	1,400	NA
							50	0
							360	0
				20	1.36E-01	6.62	1,400	NA
							50	0
							360	0
Occidental Chemical Corp Niagara Plant Niagara Falls, NY NPDES: NY0003336	Surface Water and POTW	Direct (0% WWT Removal): NY0003336 Indirect (88% WWT Removal): Organic Chemicals Mfg (surrogate for NY0026336)	Still Water	300	1.74E-01	1.29	1,400	NA
							50	0
							360	0
			Surface Water	300	1.74E-01	3.77	1,400	NA
							50	6
							360	0
			Still Water	20	2.61	19.80	1,400	NA
							50	0
							360	0
Tesoro Los Angeles Refinery-Carson Operations Carson, CA NPDES: CA0000680	Surface Water and POTW	Direct (0% WWT removal): Petroleum Refining Indirect (88% WWT removal): CA0053813	Surface Water	300	2.87E-02	11.39	1,400	NA
							50	16
							360	2
			Surface Water	300	2.87E-02	1.39E-05	1,400	NA
							50	0
							360	0
			Surface Water	20	4.31E-01	170.63	1,400	NA
							50	7
							360	2
The Dow Chemical Co Midland, MI NPDES: MI0000868	Surface Water	MI0000868	Surface Water	300	3.48E-02	5.51E-02	1,400	NA
							50	0
							360	0
				20	5.22E-01	0.82	1,400	NA
							50	0
							360	0
Valero Refining Co -Oklahoma Valero Ardmore Refinery Ardmore, OK NPDES: OK0001295	Surface Water	OK0001295	Surface Water	300	7.57E-03	0.49	1,400	NA
							50	0
							360	0
				20	1.14E-01	7.37	1,400	NA
							50	0
							360	0
Valero Refining Co -Oklahoma Valero Ardmore Refinery	Surface Water	Surrogate: Organic Chemicals Mfg	Surface Water	300	9.10E-03	1.68	1,400	NA
							50	1
							360	0
				20	1.37E-01	25.88	1,400	NA

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Ardmore, OK NPDES: OK0001295							50	2
							360	0
OES: Other Industrial Uses								
ExxonMobil Oil Corp JoiIet Refinery Channahon, IL NPDES: ILR10H432	Surface Water	ILR10H432	Surface Water	250	4.72E-03	1.64E-03	1,400	NA
							50	0
							360	0
				20	0.059	2.05E-02	1,400	NA
							50	0
							360	0
Natrium Plant New Martinsville, WV NPDES: WV0004359	Surface Water	WV0004359	Surface Water	250	3.15E-02	3.75E-03	1,400	NA
							50	0
							360	0
				20	3.94E-01	4.64E-02	1,400	NA
							50	0
							360	0
Oxy Vinyls LP - Deer Park PVC Deer Park, TX NPDES: TX0007412	Surface Water	TX0007412	Surface Water	250	0.31	1.00	1,400	NA
							50	0
							360	0
				20	3.88	12.55	1,400	NA
							50	0
							360	0
Princeton Plasma Physics Lab (FF) Princeton, NJ NPDES: NJ0023922	Surface Water	Surrogate: Industrial POTW	Surface Water	250	5.30E-04	6.83E-02	1,400	NA
							50	0
							360	0
				20	6.63E-03	0.85	1,400	NA
							50	0
							360	0
Tree Top Inc Wenatchee Plant Wenatchee, WA NPDES: WA0051527	Surface Water	Industrial POTW	Surface Water	250	3.04E-05	3.92E-03	1,400	NA
							50	0
							360	0
				20	3.80E-04	4.90E-02	1,400	NA
							50	0
							360	0
Vesuvius USA Corp Buffalo Plant Buffalo, NY NPDES: NY0030881	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.23E-04	1.59E-02	1,400	NA
							50	0
							360	0
				20	1.54E-03	0.20	1,400	NA
							50	0
							360	0
William E. Warne Power Plant Los Angeles County, CA NPDES: CA0059188	Surface Water	CA0059188	Surface Water	250	1.13E-06	0.11	1,400	NA
							50	0
							360	0
				20	1.41E-05	1.41	1,400	NA
							50	0
							360	0

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OES: Other Commercial Uses								
Union Station North Wing Office Building Denver, CO NPDES: COG315293	Surface Water	Surrogate: Industrial POTW	Surface Water	250	2.87E-03	0.37	1,400	NA
							50	0
							360	0
				20	3.59E-02	4.63	1,400	NA
							50	0
							360	0
Confluence Park Apartments Denver, CO NPDES: COG315339	Surface Water	Surrogate: Industrial POTW	Surface Water	250	0.0003	0.0387	1,400	NA
							50	0
							360	0
				20	3.75E-03	0.48	1,400	NA
							50	0
							360	0
Wynkoop Denver LLCP St Denver, CO NPDES: COG603115	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.54E-04	1.98E-02	1,400	NA
							50	0
							360	0
				20	1.92E-03	0.25	1,400	NA
							50	0
							360	0
100 Saint Paul Denver County, CO NPDES: COG315289	Surface Water	Surrogate: Industrial POTW	Surface Water	250	4.27E-05	5.50E-03	1,400	NA
							50	0
							360	0
				20	5.34E-04	6.88E-02	1,400	NA
							50	0
							360	0
BPI-Westminster, LLC(Owner)/Arcadis (Op) Denver, CO NPDES: COG315146	Surface Water	Surrogate: Industrial POTW	Surface Water	250	3.44E-05	4.43E-03	1,400	NA
							50	0
							360	0
				20	4.30E-04	5.54E-02	1,400	NA
							50	0
							360	0
Safeway Inc Denver, CO NPDES: COG315260	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.56E-05	2.01E-03	1,400	NA
							50	0
							360	0
				20	1.95E-04	2.51E-02	1,400	NA
							50	0
							360	0
Illinois Central Railroad Thompsonville, IL NPDES: IL0070696	Surface Water	Surrogate: Industrial POTW	Surface Water	250	1.31E-05	1.69E-03	1,400	NA
							50	0
							360	0
				20	1.64E-04	2.11E-02	1,400	NA
							50	0
							360	0
OES: Waste Handling, Disposal, Treatment, and Recycling								
Clean Harbors Deer Park LLC			Surface Water	250	3.49E-01	5.41	1,400	NA
							50	1

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La Porte, TX NPDES: TX0005941	Non-POTW WWT	Surrogate: Industrial POTW					360	0
				20	4.37	67.58	1,400	NA
							50	4
							360	0
Clean Harbors El Dorado LLC El Dorado, AR NPDES: AR0037800	Non-POTW WWT	Surrogate: Industrial POTW	Surface Water	250	3.71E-02	0.57	1,400	NA
							50	0
							360	0
				20	4.64E-01	7.11	1,400	NA
							50	0
							360	0
Clean Harbors Recycling Services of Ohio LLC Hebron, OH NPDES: None (FRS 110070118494)	POTW	Receiving Facility: OH0021539	Surface Water	250	4.00E-05	2.58E-04	1,400	NA
							50	0
							360	0
Clean Water Of New York Inc Staten Island, NY NPDES: NY0200484	Surface Water	Surrogate: Industrial POTW SIC code	Surface Water	250	3.76E-03	0.48	1,400	NA
							50	0
							360	0
				20	0.047	6.06	1,400	NA
							50	0
							360	0
Clifford G Higgins Disposal Service Inc SLF Kingston, NJ NPDES: NJG160946	Surface Water	Surrogate: Industrial POTW SIC code	Surface Water	250	0.0002	2.58E-02	1,400	NA
							50	0
							360	0
				20	0.0025	0.32	1,400	NA
							50	0
							360	0
Durez North Tonawanda Occidental Chemical Corporation North Tonawanda, NY NPDES: NY0001198	Surface Water	NY0001198	Surface Water	250	4.00E-05	2.13E-02	1,400	NA
							50	0
							360	0
				20	0.00050	0.27	1,400	NA
							50	0
							360	0
Heritage Thermal Services East Liverpool, OH NPDES: OH0107298	POTW	Receiving Facility: OH0024970	Surface Water	250	4.00E-07	5.80E-09	1,400	NA
							50	0
							360	0
Oiltanking Houston Inc Houston, TX NPDES: TX0091855	Surface Water	Surrogate location: TX0005941	Surface Water	250	3.32E-03	0.36	1,400	NA
							50	0
							360	0
				20	4.15E-02	4.54	1,400	NA
							50	0

Name, Location, and ID of Active Releaser Facility[a]	Release Media[b]	Modeled Facility or Industry Sector in E-FAST[c]	E-FAST Waterbody Type[d]	Days of Release[e]	Release (kg/day)[f]	7Q10 SWC (ppb)[g]	COC (ppb)	Days of Exceedance (days/year)[h]
							360	0
Pinewood Site Custodial Trust Pinewood, SC NPDES: SC0042170	Surface Water	Surrogate: Industrial POTW SIC code	Surface Water	250	6.00E-04	7.73E-02	1,400	NA
							50	0
							360	0
				20	0.0075	0.97	1,400	NA
							50	0
							360	0
Safety-Kleen Systems Inc Smithfield, KY NPDES: KY0098345	Non-POTW WWT	Surrogate: Industrial POTW SIC code (surrogate for receiving facility MDU000011)	Surface Water	250	1.35	20.88	1,400	NA
							50	9
							360	0
				20	16.92	261.65	1,400	NA
							50	13
							360	2
Safety-Kleen Systems Inc, East Chicago, IN NPDES: Unknown	POTW	Receiving Facility: IN0022829	Surface Water	250	2.73E-01	0.48	1,400	NA
							50	7
							360	3
Tier Environmental LLC Bedford, OH NPDES: None (FRS 110000388232)	POTW	Surrogate: Industrial POTW SIC code	Surface Water	250	0.12	1.86	1,400	NA
							50	0
							360	0
Tradebe Treatment & Recycling LLC East Chicago, IN NPDES: None (FRS 110070334821)	Non-POTW WWT	Surrogate: Industrial POTW SIC code (surrogate for FRS 110020159852	Surface Water	250	5.44E-03	8.41E-02	1,400	NA
							50	0
							360	0
				20	0.068	1.05	1,400	NA
							50	0
							360	0

a. Facilities actively releasing PCE were identified via DMR, TRI and CDR databases for the 2016 reporting year.
b. Release media are either direct (release from active facility directly to surface water) or indirect (transfer of wastewater from active facility to a receiving POTW or non-POTW WWTP facility). A wastewater treatment removal rate of 88% is applied to all indirect releases, as well as direct releases from WWTPs.
c. If a valid NPDES of the direct or indirect releaser was not available in E-FAST, the release was modeled using either a surrogate representative facility in E-FAST (based on location) or a representative industry sector. If available in TRI, the NPDES of the receiving facility is provided.
d. E-FAST 2014 (U.S. EPA, 2014b) uses the "surface water" model for free-flowing water bodies such as rivers and streams, and the "still water" model for lakes, bays, and oceans. The surface water model uses stream flow values to calculate the concentration, whereas the still water model uses dilution factors. The dilution factor used in E-FAST is provided in parentheses.
e. Modeling was conducted with the maximum days of release per year estimated. For direct releasing facilities, a minimum of 20 days was also modeled.
f. The daily release amount was calculated from the reported annual release amount divided by the number of release days per year.

g. For releases discharging to lakes, bays, estuaries, and oceans, the acute scenario mixing zone water concentration was reported in place of the 7Q10 SWC. For discharges to free-flowing water using an industry sector flow, the 10^{th} percentile 7Q10 is reported.
h. To determine the PDM days of exceedance for still bodies of water, the release days provided by the EPA Engineers is equal to the days of exceedance only if the predicted surface water concentration exceeds the COC. Otherwise, the days of exceedance can be assumed to be zero.

Appendix F BENCHMARK DOSE ANALYSIS

The following is a summary of the cancer dose response modeling from Appendix D of U.S. EPA (2012d).

F.1 Model Selection Details for Tumor Sites from JISA (1993)

Table_Apx F-1. Model predictions for hepatocellular tumors in male mice (JISA, 1993)[a], using several dose metrics and multistage cancer model

Model stages	Goodness of fit			BMD_{10}	$BMDL_{10}$	Conclusion
	p-value[b]	Largest standardized residual(s)	AIC			
Total liver oxidative metabolism (mg/kg$^{0.75}$-day)						
One	**0.24**	**1.1, low-dose −1.2, mid-dose**	**239.7**	**2.9**	**2.1**	All three fits were adequate by conventional criteria.[b] There was no statistical improvement in adding higher-order coefficients (using likelihood ratio test); one-stage fit was selected.
Two	0.16	−0.7, control 1.1, low-dose	240.8	6.4	2.2	
Three	0.18	−0.7, control 1.0, low-dose	240.6	6.5	2.2	
TCA AUC in liver (mg-hr/L-day)						
One	**0.25**	**1.0, low-dose −1.2, mid-dose**	**239.7**	**97.1**	**68.8**	All three fits were adequate by conventional criteria.[b] There was no statistical improvement in adding higher-order coefficients (using likelihood ratio test); one-stage fit was selected.
Two	0.17	−0.7, control 1.1, low-dose	240.8	209.9	72.8	
Three	0.19	−0.7, control 1.0, low-dose	240.6	213.9	73.8	
Administered PCE concentration (ppm)						
One	**0.27**	**1.2, low-dose −1.0, mid-dose**	**239.5**	**3.9**	**2.7**	All three fits were adequate by conventional criteria.[b] There was no statistical improvement in adding higher-order coefficients (using likelihood ratio test); one-stage fit was selected.
Two	0.16	−0.8, control 1.1, low-dose	240.9	9.0	2.8	
Three	0.17	−0.8, control 1.1, low-dose	240.8	8.2	2.9	

[a] Incidence data and human equivalent continuous exposure estimates provided in Table 3-6.

[b] Goodness-of-fit *p*-values <0.05 for a preferred model, or <0.10 when considering many models, fail to meet conventional goodness-of-fit criteria. In addition, visual fit and residuals (within ±2 units) are considered. Best-fit model is highlighted in bold; output for best-fit models provided in following pages.

AIC = Akaike's Information Criteria, BMD = benchmark dose, BMDL = lower bound benchmark dose.

F.1.1 Modeling Output for Male Mice, Hepatocellular Tumors (JISA, 1993)

F.1.1.1 With total oxidative metabolism in liver as dose metric

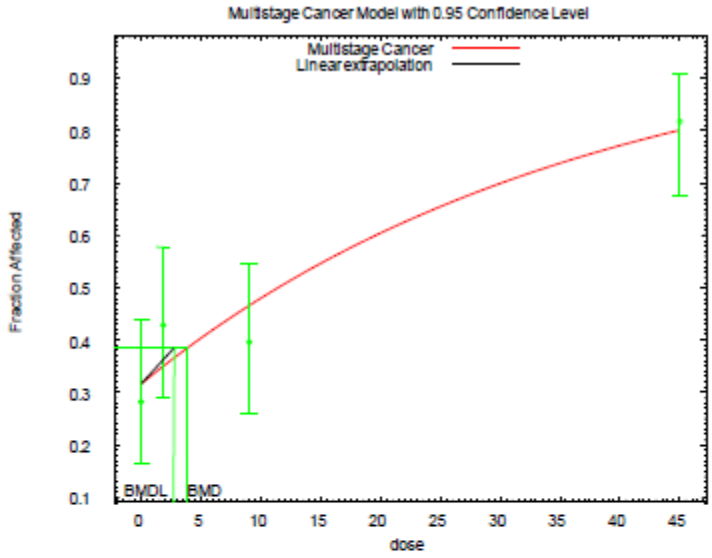

Figure D-1 One-degree multistage model fit to hepatocellular tumors in male mice (JISA, 1993), with BMD and BMDL at 10% extra risk, using total oxidative metabolism in liver (mg/kg$^{0.75}$-day).

```
=================================================================
        Multistage Cancer Model. (Version: 1.7;  Date: 05/16/2008)
=================================================================

   The form of the probability function is:

   P[response] = background + (1-background)*[1-EXP(
                -beta1*dose^1)]

   The parameter betas are restricted to be positive


   Dependent variable = Response
   Independent variable = Dose

Total number of observations = 4
Total number of records with missing values = 0
Total number of parameters in model = 2
Total number of specified parameters = 0
Degree of polynomial = 1
```

Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008

Default Initial Parameter Values
Background = 0.285739
Beta(1) = 0.0395068

Asymptotic Correlation Matrix of Parameter Estimates

	Background	Beta(1)
Background	1	-0.53
Beta(1)	-0.53	1

Parameter Estimates

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval Lower Conf. Limit	Upper Conf. Limit
Background	0.301268	*	*	*
Beta(1)	0.0361674	*	*	*

* - Indicates that this value is not calculated.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-116.442	4			
Fitted model	-117.844	2	2.80477	2	0.246
Reduced model	-132.99	1	33.0977	3	<.0001
AIC:	239.688				

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.3013	13.858	13.000	46	-0.276
2.2500	0.3559	17.438	21.000	49	1.063
8.3000	0.4825	23.158	19.000	48	-1.201
33.6000	0.7927	38.844	40.000	49	0.408

Chi^2 = 2.81 d.f. = 2 P-value = 0.2448

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 2.91314

BMDL = 2.06187

BMDU = 4.49484

Taken together, (2.06187, 4.49484) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0484996

F.1.1.2 With TCA AUC in liver as dose metric

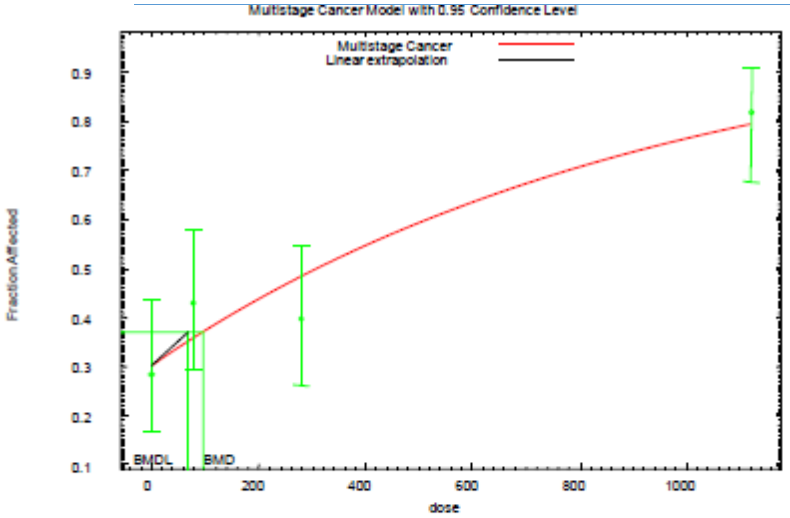

Figure D-2. One-degree multistage model fit to hepatocellular tumors in male mice (JISA, 1993), with BMD and BMDL at 10% extra risk, using TCA AUC as dose metric (mg-hr/L-d).

```
=============================================================
        Multistage Cancer Model. (Version: 1.7;  Date: 05/16/2008)
=============================================================

  The form of the probability function is:

  P[response] = background + (1-background)*[1-EXP(
               -beta1*dose^1)]

  The parameter betas are restricted to be positive


  Dependent variable = Response
  Independent variable = Dose

Total number of observations = 4
Total number of records with missing values = 0
Total number of parameters in model = 2
Total number of specified parameters = 0
Degree of polynomial = 1


Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008


                Default Initial Parameter Values
                   Background =     0.283935
                      Beta(1) =   0.00118591

          Asymptotic Correlation Matrix of Parameter Estimates
```

	Background	Beta(1)
Background	1	-0.53
Beta(1)	-0.53	1

Parameter Estimates

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval Lower Conf. Limit	Upper Conf. Limit
Background	0.299803	*	*	*
Beta(1)	0.0010848	*	*	*

* - Indicates that this value is not calculated.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-116.442	4			
Fitted model	-117.833	2	2.78303	2	0.2487
Reduced model	-132.99	1	33.0977	3	<.0001
AIC:	239.666				

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.2998	13.791	13.000	46	-0.255
78.4900	0.3570	17.491	21.000	49	1.046
279.7000	0.4831	23.186	19.000	48	-1.209
1121.1000	0.7925	38.832	40.000	49	0.411

Chi^2 = 2.79 d.f. = 2 P-value = 0.2477

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 97.1242

BMDL = 68.7915

BMDU = 149.76

Taken together, (68.7915, 149.76) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.00145367

F.1.1.3 With administered PCE concentration (ppm) as dose metric

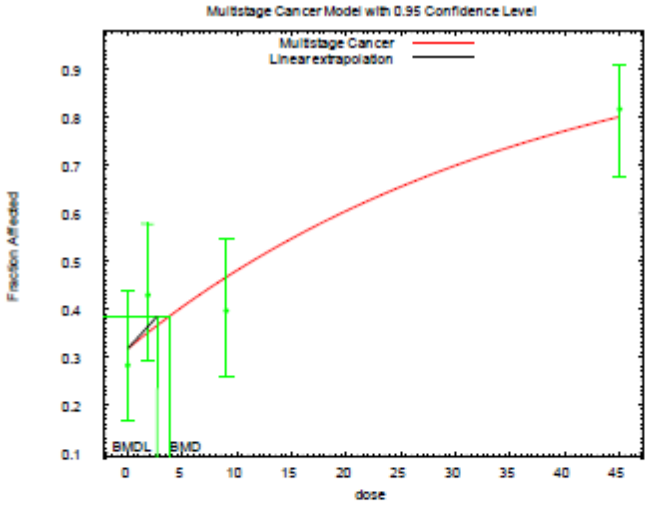

Figure D-3. One-degree multistage model fit to hepatocellular tumors in male mice (JISA, 1993), with BMD and BMDL at 10% extra risk, using administered tetrachloroethylene concentration (ppm).

```
=================================================================
        Multistage Cancer Model. (Version: 1.7;  Date: 05/16/2008)
=================================================================

   The form of the probability function is:

   P[response] = background + (1-background)*[1-EXP(-beta1*dose^1)]

   The parameter betas are restricted to be positive


   Dependent variable = Response
   Independent variable = Dose

Total number of observations = 4
Total number of records with missing values = 0
Total number of parameters in model = 2
Total number of specified parameters = 0
Degree of polynomial = 1


Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008


                 Default Initial Parameter Values
                   Background =     0.307193
                      Beta(1) =    0.0290723
```

```
          Asymptotic Correlation Matrix of Parameter Estimates

            Background      Beta(1)

Background           1        -0.48

   Beta(1)       -0.48             1


                          Parameter Estimates

                                                        95.0% Wald Confidence
Interval
      Variable         Estimate        Std. Err.     Lower Conf. Limit   Upper Conf.
Limit
    Background         0.316506             *                   *                 *
       Beta(1)        0.0273229             *                   *                 *

* - Indicates that this value is not calculated.


                       Analysis of Deviance Table

      Model      Log(likelihood)  # Param's  Deviance  Test d.f.   P-value
    Full model         -116.442          4
  Fitted model         -117.738          2       2.59226       2          0.2736
 Reduced model         -132.99           1       33.0977       3          <.0001

          AIC:         239.476


                              Goodness of Fit
                                                                    Scaled
    Dose      Est._Prob.     Expected    Observed     Size        Residual
  ----------------------------------------------------------------------
   0.0000      0.3165        14.559     13.000          46        -0.494
   1.8000      0.3493        17.116     21.000          49         1.164
   9.0000      0.4655        22.344     19.000          48        -0.968
  45.0000      0.8001        39.206     40.000          49         0.284

 Chi^2 = 2.62      d.f. = 2        P-value = 0.2704


   Benchmark Dose Computation

Specified effect =           0.1

Risk Type        =      Extra risk

Confidence level =          0.95

             BMD =       3.85613

            BMDL =       2.70709

            BMDU =       5.98909

Taken together, (2.70709, 5.98909) is a 90      % two-sided confidence
interval for the BMD

Multistage Cancer Slope Factor =       0.03694
```

Table_Apx F-2. Model predictions for hepatocellular tumors in female mice (JISA, 1993)[a], using several dose metrics and multistage cancer model

Model stage	Goodness of fit			BMD_{10}	$BMDL_{10}$	Comments	Conclusions
	p-value[b]	Largest standardized residual(s)	AIC				
Total liver oxidative metabolism (mg/kg$^{0.75}$-day)							
One-stage	0.14	-1.4, mid-dose	154.9	3.7	2.8	Adequate fit	Selected two-degree multistage, based on likelihood ratio test.
Two-stage	**0.82**	**-0.18, low-dose**	**152.8**	**8.4**	**4.0**	Adequate fit	
Three-stage	0.82	-0.18, low-dose	152.8	8.4	3.9	Adequate fit	
TCA AUC in liver (mg-hr/L-day)							
One-stage	0.13	-1.4, mid-dose	155.1	129	98	Adequate fit	Selected two-degree multistage,
Two-stage	**0.82**	**-0.18, low-dose**	**152.9**	**292**	**141**	Adequate fit	

Three-stage	0.82	-0.18, low-dose	152.9	292	139	Adequate fit	based on likelihood ratio test.
Administered PCE concentration (ppm)							
One-stage	**0.36**	**−1.1, mid-dose**	**153.0**	**5.0**	**3.8**	Adequate fit	Selected one-degree multistage; no statistical improvement in adding higher order parameters.
Two-, three-stage	0.83	−0.1, low-dose	152.8	9.7	4.3	Identical fits resulted from both models	

[a] Incidence data provided in Table 5-13, and dose metrics provided in Table 3-6; both are included in following output.

[b] Values <0.05 for a preferred model, or <0.10 when considering a suite of models, fail to meet conventional goodness-of-fit criteria. In addition, visual fit and residuals (within ±2 units) are considered. Best-fit model is highlighted in bold; output for best-fit models provided in following pages.

F.1.2 Modeling Output for Female Mice, Hepatocellular Tumors (JISA, 1993)

F.1.2.1 With total oxidative metabolism in liver as dose metric

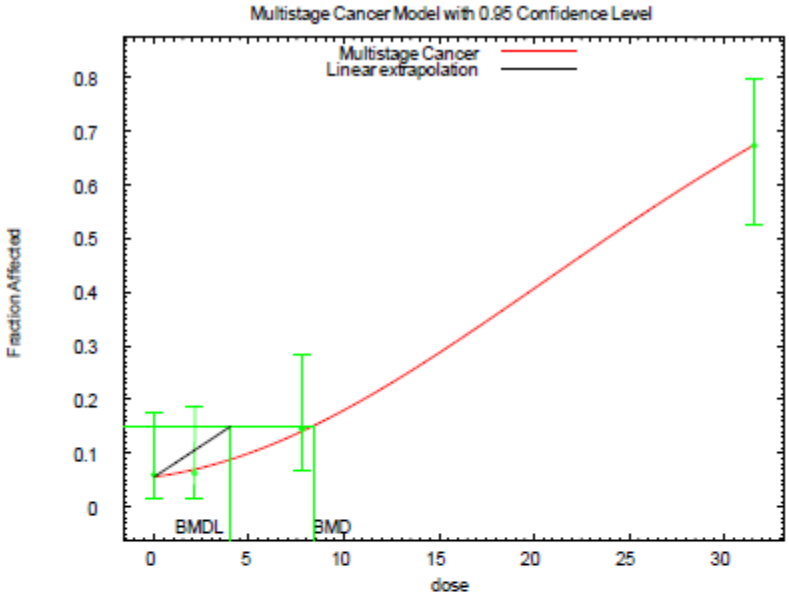

Figure D-4. Two-degree multistage model fit to hepatocellular tumors in female mice (JISA, 1993), with BMD and BMDL at 10% extra risk.

```
        Multistage Cancer Model. (Version: 1.7;  Date: 05/16/2008)
        Input Data File: C:\Usepa\BMDS21\msc_JISA1993_MF_HepAC_oxmet_Perc3_MultiCanc2_0.1.(d)

   The form of the probability function is:

   P[response] = background + (1-background)*[1-EXP(
                 -beta1*dose^1-beta2*dose^2)]

   The parameter betas are restricted to be positive


   Dependent variable = Response
   Independent variable = Dose

Total number of observations = 4
Total number of records with missing values = 0
Total number of parameters in model = 3
Total number of specified parameters = 0
Degree of polynomial = 2


Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008
```

Default Initial Parameter Values
Background = 0.0554081
Beta(1) = 0.00569729
Beta(2) = 0.000883583

Asymptotic Correlation Matrix of Parameter Estimates

	Background	Beta(1)	Beta(2)
Background	1	-0.69	0.59
Beta(1)	-0.69	1	-0.97
Beta(2)	0.59	-0.97	1

Parameter Estimates

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval Lower Conf. Limit	Upper Conf. Limit
Background	0.0566119	*	*	*
Beta(1)	0.00500318	*	*	*
Beta(2)	0.000907152	*	*	*

* - Indicates that this value is not calculated.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-73.398	4			
Fitted model	-73.4233	3	0.050713	1	0.8218
Reduced model	-106.26	1	65.7232	3	<.0001
AIC:	152.847				

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0566	2.831	3.000	50	0.104
2.1300	0.0704	3.311	3.000	47	-0.177
7.8000	0.1414	6.789	7.000	48	0.087
31.6000	0.6744	33.048	33.000	49	-0.015

Chi^2 = 0.05 d.f. = 1 P-value = 0.8230

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 8.36661

BMDL = 4.02336

BMDU = 11.6726

Taken together, (4.02336, 11.6726) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0248549

F.1.2.2 With TCA AUC in liver as dose metric

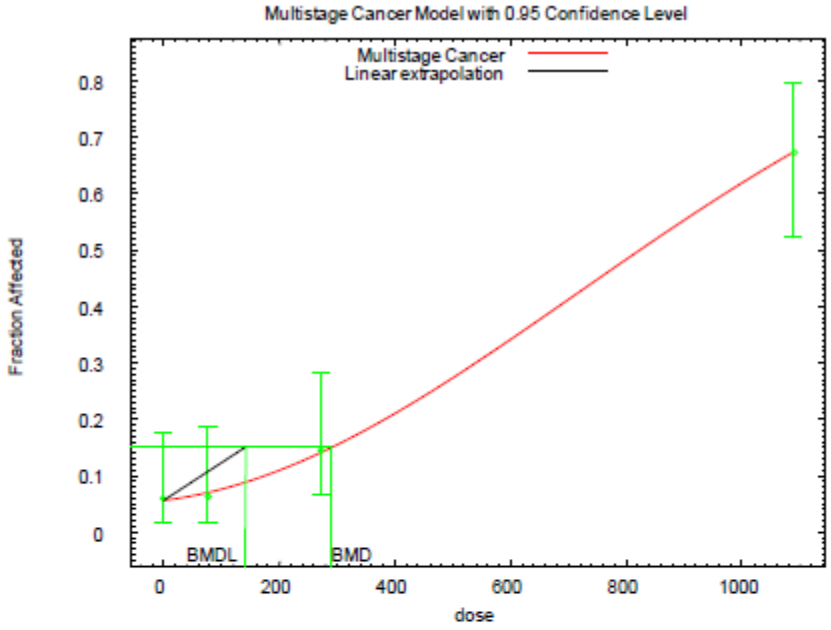

Figure D-5. Two-degree multistage model fit to hepatocellular tumors in female mice (JISA, 1993), with BMD and BMDL at 10% extra risk.

```
=============================================================================
        Multistage Cancer Model. (Version: 1.7;  Date: 05/16/2008)
        Input Data File: C:\Usepa\BMDS21\msc_JISA1993_MF_HepAC_tcaAUC_Perc3_MultiCanc2_0.1.(d)
=============================================================================

   The form of the probability function is:

   P[response] = background + (1-background)*[1-EXP(
                -beta1*dose^1-beta2*dose^2)]

   The parameter betas are restricted to be positive


   Dependent variable = Response
   Independent variable = Dose

Total number of observations = 4
Total number of records with missing values = 0
Total number of parameters in model = 3
Total number of specified parameters = 0
Degree of polynomial = 2


Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008


                 Default Initial Parameter Values
                    Background =    0.0553149
                       Beta(1) =  0.000156854
```

Beta(2) = 7.50947e-007

Asymptotic Correlation Matrix of Parameter Estimates

	Background	Beta(1)	Beta(2)
Background	1	-0.69	0.6
Beta(1)	-0.69	1	-0.97
Beta(2)	0.6	-0.97	1

Parameter Estimates

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval Lower Conf. Limit	Upper Conf. Limit
Background	0.0565811	*	*	*
Beta(1)	0.000135812	*	*	*
Beta(2)	7.71737e-007	*	*	*

* - Indicates that this value is not calculated.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-73.398	4			
Fitted model	-73.4249	3	0.0538645	1	0.8165
Reduced model	-106.26	1	65.7232	3	<.0001

AIC: 152.85

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0566	2.829	3.000	50	0.105
76.9500	0.0706	3.320	3.000	47	-0.182
271.8000	0.1412	6.776	7.000	48	0.093
1089.6000	0.6745	33.051	33.000	49	-0.016

Chi^2 = 0.05 d.f. = 1 P-value = 0.8177

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 291.833

BMDL = 141.409

BMDU = 402.749

Taken together, (141.409, 402.749) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.000707168

F.1.2.3 With administered PCE concentration (ppm) as dose metric

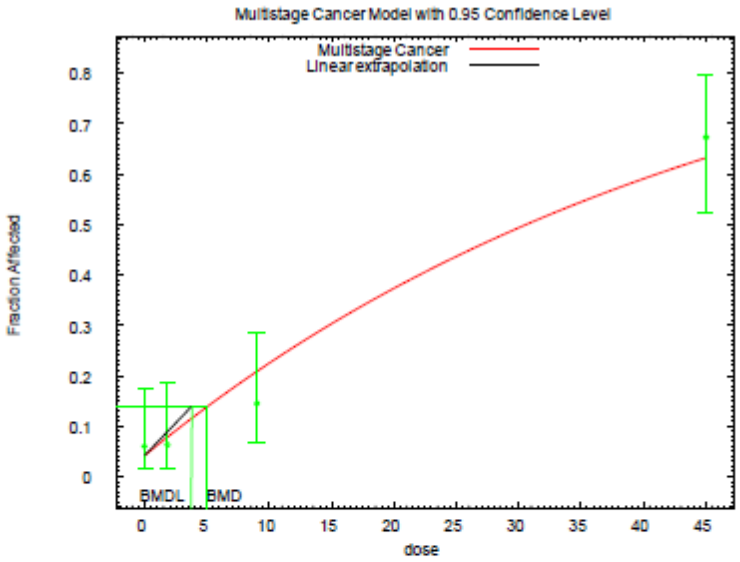

Figure D-6. One-degree multistage model fit to hepatocellular tumors in female mice (JISA, 1993), with BMD and BMDL at 10% extra risk.

```
================================================================
        Multistage Cancer Model. (Version: 1.7;  Date: 05/16/2008)
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   The form of the probability function is:

   P[response] = background + (1-background)*[1-EXP(-beta1*dose^1)]

   The parameter betas are restricted to be positive


   Dependent variable = Response
   Independent variable = Dose

Total number of observations = 4
Total number of records with missing values = 0
Total number of parameters in model = 2
Total number of specified parameters = 0
Degree of polynomial = 1


Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008


                Default Initial Parameter Values
                   Background =    0.0124442
```

Beta(1) = 0.0242761

Asymptotic Correlation Matrix of Parameter Estimates

	Background	Beta(1)
Background	1	-0.47
Beta(1)	-0.47	1

Parameter Estimates

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval Lower Conf. Limit	Upper Conf. Limit
Background	0.0427836	*	*	*
Beta(1)	0.0212108	*	*	*

* - Indicates that this value is not calculated.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-73.398	4			
Fitted model	-74.4575	2	2.11904	2	0.3466
Reduced model	-106.26	1	65.7232	3	<.0001
AIC:	152.915				

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0428	2.139	3.000	50	0.602
1.8000	0.0786	3.696	3.000	47	-0.377
9.0000	0.2091	10.038	7.000	48	-1.078
45.0000	0.6315	30.942	33.000	49	0.610

Chi^2 = 2.04 d.f. = 2 P-value = 0.3609

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 4.96731

BMDL = 3.75394

BMDU = 6.8242

Taken together, (3.75394, 6.8242) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0266387

Appendix G Cancer Study Summaries

G.1 Epidemiological Data

This section is a synthesis of the findings from the older epidemiological literature, as presented in the 2012 IRIS Assessment (U.S. EPA, 2012c) combined with the results of the newer studies described above. Epidemiological studies provide suggestive evidence for an association between PCE exposure and tumor development in humans. Tumor types in humans with varying degrees of supporting evidence for an association with PCE exposure include NHL, MM, and bladder, esophagus, lung, liver, cervical, and breast cancer according to (U.S. EPA, 2012c) and references cited therein, as well as the newer studies (Purdue et al., 2017; Mattei et al., 2014; Silver et al., 2014; Vizcaya et al., 2013; Vlaanderen et al., 2013; Gallagher et al., 2011; Lipworth et al., 2011).

G.1.1 Bladder

(U.S. EPA, 2012c) concluded that, with respect to bladder cancer, the pattern of results from the studies available at that time was consistent with an elevated risk for PCE of a relatively modest magnitude (*i.e.*, a 10−40% increased risk). The effect estimates from five of the six studies with relatively high-quality exposure assessment methodologies ranged from 1.44 to 4.03 ((Calvert et al., 2011; Lynge et al., 2006; Blair et al., 2003; Pesch et al., 2000; Aschengrau et al., 1993) all as cited in (U.S. EPA, 2012c)). An exposure-response gradient was observed in a large case-control study by Pesch et al. ((2000) as cited in (U.S. EPA, 2012c)), using a semiquantitative cumulative exposure assessment, with adjusted ORs of 0.8 (95% CI = 0.6-1.2), 1.3 (95% CI = 0.9-1.7), and 1.8 (95% CI = 1.2-2.7) for medium, high, and substantial exposure, respectively, compared to low exposure. A similar exposure-response pattern was not observed in the study by Lynge et al. ((1995) as cited in (U.S. EPA, 2012c)) that examined exposure duration, in contrast with the previously described data based on varied exposure concentration. Relative risk estimates between bladder cancer risk and ever having a job title of dry cleaner or laundry worker in four large cohort studies ranged from 1.01 to 1.44 ((Pukkala et al., 2009; Wilson et al., 2008; Ji et al., 2005a; Travier et al., 2002) all as cited in (U.S. EPA, 2012c)). As expected, the results from the smaller studies are more variable and less precise, reflecting their reduced statistical power. Confounding by smoking is an unlikely explanation for the findings, given the included adjustment for smoking ((Pesch et al., 2000) as cited in (U.S. EPA, 2012c)) and in other case-control studies (U.S. EPA, 2012c).

More recent studies provide little support for an association between bladder cancer and PCE exposure. The SMR was 0.84 (95% CI = 0.49-1.35) based on 17 observed deaths from bladder and other urinary cancers and 20.2 expected in the subset (n=5,830, sex and race combined) of a cohort of aircraft manufacturing workers judged based on detailed exposure assessment to have had routine or intermittent exposure to PCE while employed for at least 1 year between 1960 and 1996 at the Lockheed Martin aircraft manufacturing facilities in Burbank, California and followed for mortality experience through 2008 (Lipworth et al., 2011). Similarly, a cohort of workers employed 91 days or more at a microelectronics and business machine facility in New York state between 1969 and 2001 and followed through 2009 showed no association between cumulative PCE exposure score estimated from detailed exposure assessment and deaths from malignant neoplasms of the bladder and other urinary organs (HR = 0.89, 95% CI = 0.37-2.13) relative to internal referents (Silver et al., 2014). A large case-control study of incident bladder cancer cases extracted from the NOCCA cohort, which relied on a standardized job exposure matrix to estimate cumulative occupational exposure to PCE (and other agents), reported HRs of 1.00 (95% CI = 0.92-1.09, 747 cases/3,560 controls), 1.12 (95% CI = 1.02-1.23, 660 cases/2,783 controls), and 0.94 (95% CI = 0.73-1.22, 159 cases/702 controls) in low, medium, and high PCE exposure groups, respectively; the p-level for dose-response trend was 0.10 (Hadkhale et al., 2017). These results show a slight significant increase in risk of bladder cancer in the medium PCE exposure category, but no increase in the high-exposure group and no significant dose-related trend, suggesting a

cause other than PCE exposure for the slight association observed in the medium-exposure group. Results from other newer studies were not informative due to small numbers of bladder cancer cases with exposure to PCE (Bove et al., 2014a, b; Christensen et al., 2013).

G.1.2 NHL

(U.S. EPA, 2012c) concluded that results from studies of NHL available at that time indicated an elevated risk for PCE. The results from five cohort studies that used a relatively high-quality exposure assessment methodology generally reported relative risks between 1.7 and 3.8 ((Calvert et al., 2011; Seldén and Ahlborg, 2011; Radican et al., 2008; Boice et al., 1999; Anttila et al., 1995) all as cited in (U.S. EPA, 2012c)). There is some evidence of exposure-response gradients, with higher NHL risks observed in the highest exposure categories, in studies with PCE-specific exposure measures based on intensity, duration, or cumulative exposure ((Seidler et al., 2007; Miligi et al., 2006; Boice et al., 1999) all as cited in (U.S. EPA, 2012c)). Effect estimates in studies with broader exposure assessments showed a more variable pattern ((Seldén and Ahlborg, 2011; Pukkala et al., 2009; Ji and Hemminki, 2006; Blair et al., 2003; Travier et al., 2002; Cano and Pollán, 2001; Lynge and Thygesen, 1990) all as cited in (U.S. EPA, 2012c)). Confounding by life-style factors is an unlikely explanation for the observed results because common behaviors, such as smoking and alcohol use, are not strong risk factors for NHL ((Besson et al., 2006; Morton et al., 2005) both as cited in (U.S. EPA, 2012c)).

Newer studies provide some support for an association between NHL and PCE exposure. In the cohort of aircraft manufacturing workers initially studied by (Boice et al., 1999) and updated by (Lipworth et al., 2011), there was a marginally significant increase in risk of death due to NHL among workers with routine or intermittent exposure to PCE (SMR = 1.43, 95% CI = 1.00-1.98) based on 36 observed cases and 25.1 expected. An internal analysis based on duration of exposure (<1, 1-4, ≥5 years) to PCE, however, did not support an association with NHL; relative risks were 1.26 (95% CI = 0.65-2.45, 11 observed), 1.00 (95% CI = 0.05-2.00, 10 observed), and 1.02 (95% CI = 0.53-1.99, 12 observed) in the low- to high-duration exposure groups compared with unexposed factory workers (P_{trend} >0.2). In the New York state cohort studied by (Silver et al., 2014), the overall hourly male workers from the cohort showed a significant increase in mortality due to NHL (SMR = 1.49, 95% CI = 1.15-1.89, 65 observed). The HR for NHL risk for the measure of cumulative exposure to PCE relative to internal referents was 1.25 (95% CI = 0.90-1.73). The other chemical exposures assessed in this study (trichloroethylene, methylene chloride, chlorinated hydrocarbons, and other hydrocarbons) also did not show statistically significant changes in NHL risk with increasing cumulative exposure in the internal analysis; HRs were less than 1.0 and ranged from 0.71 to 0.90. A large case-control study of incident NHL cases extracted from the NOCCA cohort found no association with cumulative PCE exposure in men, women, or both sexes combined when analyzed by tertiles, but did find a significant or near significant risk increase in men (but not women) with high (90^{th} percentile) PCE exposure (HR = 1.54, 95% CI = 0.99-2.42 based on 25 cases using a cumulative exposure metric; HR = 1.74, 95% CI = 1.15-2.64 based on 30 cases using a metric of average intensity × prevalence) (Vlaanderen et al., 2013). A study of Marine and Navy personnel exposed to contaminated drinking water at Camp Lejeune, North Carolina between 1975 and 1985 found no association between NHL deaths (1979-2008) and exposure to PCE, as estimated by water system modeling and housing records, but fewer than 6% of the cohort had died by the end of the study (Bove et al., 2014a, b). Results from other newer studies were not informative, primarily due to small numbers of NHL cases with exposure to PCE (Bulka et al., 2016; Christensen et al., 2013; Morales-Suárez-Varela et al., 2013; Ruckart et al., 2013).

G.1.3 MM

(U.S. EPA, 2012c) concluded that results from studies of MM available at that time indicated an elevated risk for PCE, although this was based on a smaller set of studies than available for NHL. The

larger cohort studies that used a relatively nonspecific exposure measure (broad occupational title of launderers and dry cleaners, based on census data) did not report an increased risk of MM, with effect estimates ranging from 0.99 to 1.07 ((Pukkala et al., 2009; Ji and Hemminki, 2006; Andersen et al., 1999) all as cited in (U.S. EPA, 2012c)). Some uncertainty in these estimates arises from these studies' broader exposure assessment methodology. U.S. EPA (2012c) cited a set of results from cohort and case-control studies by Radican et al. (2008) and Gold et al. (2010) (as cited in (U.S. EPA, 2012c)) as providing evidence of an association between PCE exposure and MM. Gold et al. ((2010) as cited in (U.S. EPA, 2012c)) was a case-control study that reported an OR of 1.5 (95% CI = 0.8-2.9) MM among those ever exposed to PCE based on 16 cases, with a significantly increasing trend for risk with cumulative PCE exposure (P_{trend} = 0.02) and a significant increase in risk in the highest exposure quartile (OR = 3.3, 95% CI = 1.2-9.5) based on 10 cases. A second case-control study had too few MM cases with PCE exposure (n=3) to perform a meaningful analysis ((Seidler et al., 2007) as cited in (U.S. EPA, 2012c)).

Among the newer studies, the large case-control study by (Vlaanderen et al., 2013) derived from the NOCCA cohort found no association of MM with cumulative PCE exposure in men, women, or both sexes combined when analyzed by tertiles. For other exposure measures, a hazard ratio (HR) of 1.14 (95% CI = 0.84-1.54 based on 52 cases) was observed for women with high (90^{th} percentile) PCE exposure, and an HR of 1.28 (95% CI = 0.92-1.78 based on 44 cases) was found using a metric of average intensity × prevalence. Results in men were based on smaller numbers of cases and were less stable, with high exposure based on the cumulative metric giving a HR of 1.22 (95% CI = 0.65-2.30, 12 cases) and high exposure based on average intensity × prevalence giving a HR of 0.85 (95% CI = 0.42-1.72, 9 cases).

The newer cohort studies provided no support for an association between MM and PCE exposure. (Lipworth et al., 2011) reported an SMR of 1.07 (95% CI = 0.58-1.79) for MM in aircraft manufacturing workers with routine or intermittent exposure to PCE based on 14 observed and 13.2 expected cases, and no relation to duration of exposure among observed cases (RR = 0.87, 1.14, and 0.34 in low-, medium-, and high-exposure duration groups). Studies by (Silver et al., 2014), (Bove et al., 2014a), and (Bove et al., 2014b) were also negative for an association between PCE exposure and MM.

G.1.4 Esophagus

(U.S. EPA, 2012c) concluded there was limited suggestive evidence for an association between esophageal cancer and PCE exposure, based on studies available at that time. The SIR in a large cohort study (n=95 cases) using broad exposure categories was 1.18 (95% CI = 0.96-1.46) ((Pukkala et al., 2009) as cited in (U.S. EPA, 2012c)). The point estimates of the association in seven of eight smaller studies, four studies with specific exposure assessments, and four other studies with less precise assessments were between 1.16 and 2.44 ((Calvert et al., 2011; Seldén and Ahlborg, 2011; Pukkala et al., 2009; Sung et al., 2007; Blair et al., 2003; Travier et al., 2002; Boice et al., 1999; Lynge and Thygesen, 1990) all as cited in (U.S. EPA, 2012c)). Two small case-control studies with relatively high-quality exposure assessment approaches, Lynge et al. ((2006) as cited in (U.S. EPA, 2012c)) and Vaughan et al. ((1997) as cited in (U.S. EPA, 2012c)), reported ORs of 0.76 (95% CI = 0.34-1.69) based on 8 exposed cases and 6.4 (95% CI = 0.6-68.9) based on 2 exposed cases, respectively. Some uncertainties in these estimates arise from the lack of job title information for 25% of the cases and 19% of the controls in the Lynge et al. ((2006) as cited in (U.S. EPA, 2012c)) study and the small number of exposed cases in the Vaughan et al. ((1997) as cited in (U.S. EPA, 2012c)) study. One study examining exposure-response suggested a positive relationship, with SMRs of 2.16 (95% CI = 0.85-4.54, 5 cases) and 4.78 (95% CI = 2.68-7.91, 11 cases) for durations of <5 years and ≥5 years, respectively ((Calvert et al., 2011) as cited in (U.S. EPA, 2012c)). In contrast, Lynge et al. ((2006) as cited in (U.S. EPA, 2012c)) did not find a trend with exposure duration, but included only 0-3 cases per duration category. Blair et

al. ((2003) as cited in (U.S. EPA, 2012c)) found similar risks in subjects with little to no exposure (RR = 2.1, 95% CI = 0.9-4.4, 7 cases) and medium to high exposure (RR = 2.2, 95% CI = 1.2-3.5, 16 cases). None of the cohort studies can exclude possible confounding from alcohol and smoking—risk factors for squamous cell carcinoma of the esophagus, however based on smoking rates in blue-collar workers, the 2-fold estimated increase in relative risk reported in Calvert et al. ((2011) as cited in (U.S. EPA, 2012c)) (RR = 2.44, 95% CI = 1.40-3.97) and Blair et al. ((2003) as cited in (U.S. EPA, 2012c)) (RR = 2.2, 95% CI = 1.5-3.3) were higher than levels which could reasonably be attributed solely to smoking.

Findings in newer studies were generally unsupportive of an association between esophageal cancer and PCE exposure. In an update of the (Boice et al., 1999) study, (Lipworth et al., 2011) reported an SMR of 1.13 (95% CI = 0.72-1.68) for esophageal cancer among aircraft manufacturing workers with routine or intermittent exposure to PCE (24 cases versus 21.3 expected). In the internal analysis from this study based on duration of exposure, relative risk for esophageal cancer was significantly increased in workers with less than 1 year of exposure (RR = 2.30, 95% CI = 1.14-4.66, 11 cases), but decreased with increasing exposure duration (in the high-duration group with exposure of 5 years or more, RR = 0.66, 95% CI = 0.22-1.96, 4 cases). Similarly, (Bove et al., 2014a) and (Bove et al., 2014b) reported decreasing HRs of 1.27 (95% CI = 0.57-2.81, 11 cases), 0.55 (95% CI = 0.20-1.55, 5 cases), and 0.41 (95% CI = 0.13-1.26, 4 cases) for esophageal cancer in low, medium, and high cumulative PCE exposure groups, respectively, in the Camp Lejeune cohort exposed by drinking water. The only other newer study that evaluated this endpoint was not informative due to lack of observed cases with PCE exposure (Christensen et al., 2013).

G.1.5 Kidney

(U.S. EPA, 2012c) acknowledged mixed results in studies of kidney cancer available at that time, concluding that overall the evidence was suggestive but limited. One primary study supporting an association between PCE exposure and kidney cancer, a large international case-control study (245 exposed cases from Australia, Denmark, Germany, Sweden, and the United States), reported a relative risk of 1.4 (95% CI = 1.1-1.7) for any exposure to dry cleaning solvents ((Mandel et al., 1995) as cited in (U.S. EPA, 2012c)). This study was able to adjust for smoking history, body mass index, and other risk factors for kidney cancer. Results from the large cohort studies, using a more general exposure classification based on national census occupation data, presented more variable results, with relative risks of 0.94, 1.11, and 1.15 in Pukkala et al. ((2009) as cited in (U.S. EPA, 2012c)), Travier et al. ((2002) as cited in (U.S. EPA, 2012c)), and Ji et al. ((2005b) as cited in (U.S. EPA, 2012c)), respectively. The results from the smaller studies using a relatively specific exposure assessment approach to refine classification of potential PCE exposure in dry cleaning settings were mixed, with some studies reporting little or no evidence of an association ((Lynge et al., 2006; Pesch et al., 2000; Boice et al., 1999; Dosemeci et al., 1999; Aschengrau et al., 1993) all as cited in (U.S. EPA, 2012c)), and other studies reporting elevated risks ((Calvert et al., 2011; Blair et al., 2003; Anttila et al., 1995; Schlehofer et al., 1995) all as cited in (U.S. EPA, 2012c)). An increasing trend in relative risk with increasing exposure surrogate was not observed in any of the larger occupational exposure studies with three or more exposure categories ((Lynge et al., 2006; Mandel et al., 1995) both as cited in (U.S. EPA, 2012c)), but some indication of higher risk with higher exposure (or duration) was observed in other studies ((Blair et al., 2003) as cited in (U.S. EPA, 2012c)).

Mixed results were obtained in newer studies as well. A case-control study of kidney cancer cases from Detroit, Michigan and Chicago, Illinois using detailed exposure assessment methodology found no significant association with probability of exposure to PCE, or with PCE exposure duration, average weekly exposure or cumulative exposure for those with ≥50% probability of exposure, but did observe a significant increase in kidney cancer risk for those in the highest tertile of cumulative hours exposed when the analysis was restricted to those with high-intensity exposure to PCE (OR = 3.1, 95% CI = 1.3-

7.4, 14 cases/8 controls, P_{trend} = 0.03) (Purdue et al., 2017). This relationship was also seen in additional analyses that incorporated 5-year (OR = 3.5, 95% CI = 1.3-10.0, P_{trend} = 0.03) or 15-year (OR = 6.2, 95% CI = 1.8-21.3, P_{trend} = 0.003) exposure lag periods, included only jobs assigned an exposure probability with high confidence (OR = 5.1, 95% CI = 1.5-7.2, P_{trend} = 0.12), or excluded participants with ≥50% probability of exposure to trichloroethylene (OR = 3.0, 95% CI = 0.99-9.0, 17 cases/ 14 controls, P_{trend} = 0.08), a potential confounder. Results in other newer studies were negative. The large case-control study by (Vlaanderen et al., 2013) derived from the NOCCA cohort found no association of kidney cancer with cumulative PCE exposure in men, women, or both sexes combined when analyzed by tertiles or when the analysis was restricted to those with high (90^{th} percentile) exposure (HR = 0.81, 95% CI = 0.65-1.01 based on 88 cases using a cumulative exposure metric; HR = 1.01, 95% CI = 0.82-1.25 based on 103 cases using a metric of average intensity × prevalence). In cohort studies, (Lipworth et al., 2011) found no association between kidney cancer mortality and routine or intermittent exposure to PCE in aircraft manufacturing workers (SMR = 0.80, 95% CI = 0.43-1.37, 13 cases versus 16.3 expected) and no relation to exposure duration among the observed cases, and (Silver et al., 2014) found no association between kidney cancer and cumulative PCE exposure among electronics workers (HR = 0.15, 95% CI = 0.01-4.04). (Bove et al., 2014a) and (Bove et al., 2014b) reported HRs greater than one for kidney cancer that were unrelated to cumulative PCE exposure in the Camp Lejeune cohort (HR = 1.40, 95% CI = 0.54-3.58, 8 cases; 1.82, 95% CI = 0.75-4.42, 11 cases; and 1.59, 95% CI = 0.66-3.86, 11 cases in low, medium, and high groups, respectively). The only other newer study that evaluated this endpoint was not informative due to few observed cases with PCE exposure (Christensen et al., 2013).

A meta-analysis of five selected epidemiologic studies (Purdue et al., 2017; Silver et al., 2014; Vlaanderen et al., 2013; Dosemeci et al., 1999; Aschengrau et al., 1993) considered to be reliable and informative for the association of kidney cancer and exposure to PCE was performed as part of the current assessment. Applying a fixed-effects model to the five informative studies produced a meta-RR of 0.96 (95% CI = 0.85-1.07) for overall exposure to PCE, with no heterogeneity among studies (I^2=0.0%, p=0.72). Estimates of the association of kidney cancer with high exposure to PCE were available for two studies (Purdue et al., 2017; Vlaanderen et al., 2013). A fixed-effects model based on the association of kidney cancer with high exposure in those two studies and with any exposure in the remaining studies produced a meta-RR of 1.07 (95% CI = 0.89-1.28) with moderate heterogeneity (I^2=45.9%, p=0.12). These results are consistent with no association or weak positive association between the occurrence of kidney cancer and exposure to PCE, but should be interpreted with caution due to the small number of informative studies.

G.1.6 Lung

(U.S. EPA, 2012c) concluded there was limited suggestive evidence for an association between lung cancer risk and PCE exposure. The results from seven large cohort studies of dry cleaners available at that time were consistent with an elevated lung cancer risk of 10−40% ((Calvert et al., 2011; Seldén and Ahlborg, 2011; Pukkala et al., 2009; Ji et al., 2005b; Blair et al., 2003; Travier et al., 2002; Schlehofer et al., 1995; Lynge and Thygesen, 1990) all as cited in (U.S. EPA, 2012c)). Similar results were observed in four of the five occupational studies that were identified as having a relatively strong exposure assessment methodology ((Calvert et al., 2011; Blair et al., 2003; Boice et al., 1999; Anttila et al., 1995) all as cited in (U.S. EPA, 2012c)). However, Seldén and Ahlborg ((2011) as cited in (U.S. EPA, 2012c)) observed similar, but slightly higher relative risks identified for laundry workers compared with dry cleaning workers in a separate comparison. These studies were unable to control for potential confounding from cigarette smoking, however, and the magnitude of the association in these studies is consistent with that expected assuming the prevalence of smoking among dry cleaners and laundry workers was slightly higher (*e.g.*, 10% higher) than among the general population. Features of the selection of study participants and study analysis in the available case-control studies reduce the

potential for confounding by smoking. Two case-control studies were limited to either nonsmokers or ex-smokers and both of these studies indicate an approximate 2-fold increased risk with a history of work in the dry cleaning industry (OR = 1.8, 95% CI = 1.1-3.0 in Brownson et al. (1993) and OR = 1.83, 95% CI = 0.98-3.40 among women in Pohlabeln et al. (2000) both as cited in (U.S. EPA, 2012c)). The other case-control studies adjusted for smoking history, and the results for these (somewhat smaller studies) are similar to the previously cited estimates. Among the studies that evaluated exposure-response gradients, the evidence for a trend in risk estimates was mixed ((Calvert et al., 2011; Blair et al., 2003; Travier et al., 2002; Boice et al., 1999; Paulu et al., 1999; Brownson et al., 1993) all as cited in (U.S. EPA, 2012c)).

Newer case-control studies of lung cancer support a relationship with PCE exposure. A study of lung cancer cases from Montreal that included adjustment for smoking (Comprehensive Smoking Index) reported ORs of 2.5 (95% CI = 1.2-5.6, 23 cases) for "any" exposure to PCE and 2.4 (95% CI = 0.8-7.7, 10 cases) for "substantial" exposure (Vizcaya et al., 2013). A larger study from France that also included adjustment for smoking (Comprehensive Smoking Index) reported ORs of 1.26 (95% CI = 0.87-1.82, 107 cases) in men and 2.74 (95% CI = 1.23-6.09, 26 cases) in women ever exposed to PCE (Mattei et al., 2014). In additional analyses by cumulative PCE exposure (split into high and low groups based on median cumulative exposure), ORs for men were 1.14 (95% CI = 0.67-1.94, 45 cases) in the low-dose group and 1.36 (95% CI = 0.84-2.22, 62 cases) in the high-dose group, while ORs for women were 3.80 (95% CI = 1.41-10.24, 21 cases) in the low-dose group and 1.43 (95% CI = 0.37-5.50, 5 cases) in the high-dose group. Further analyses stratified by overlapping exposure to multiple solvents suggested that the observed increase in lung cancer risk was due to PCE, and not co-exposure to other chlorinated solvents (trichloroethylene, methylene chloride, chloroform, carbon tetrachloride). Newer cohort studies that investigated lung cancer risk were negative. (Lipworth et al., 2011) found no association between lung cancer mortality and routine or intermittent exposure to PCE in aircraft manufacturing workers (SMR = 0.94, 95% CI = 0.81-1.07, 206 cases versus 220.3 expected) and no relation to exposure duration among the observed cases. (Bove et al., 2014a) and (Bove et al., 2014b) reported HRs greater than one for lung cancer that were unrelated to cumulative PCE exposure in the Camp Lejeune drinking water cohort (HR = 1.33, 95% CI = 0.93-1.90, 56 cases; 1.27, 95% CI = 0.88-1.83, 55 cases; and 1.08, 95% CI = 0.75-1.57, 51 cases in low, medium, and high groups, respectively).

G.1.7 Liver

(U.S. EPA, 2012c) cited results available at that time showing a mixed pattern of results for liver cancer, concluding that there was suggestive but limited evidence of an association. One case-control study with a large number of exposed liver cancer cases and a relatively high-quality exposure assessment methodology reported an OR estimate of 0.76 (95% CI = 0.38-1.72) for liver cancer and dry cleaning ((Lynge et al., 2006) as cited in (U.S. EPA, 2012c)). Cohort studies of Nordic subjects with broad exposure assessment approaches, and whose subjects overlapped with Lynge et al. ((2006) as cited in (U.S. EPA, 2012c)) reported SIRs of 1.02 (95% CI = 0.84-1.24), 1.22 (95% CI = 1.03-1.45), and 1.23 (95% CI = 1.02-1.49) for liver and biliary tract cancer and work as a dry cleaner or laundry worker in Travier et al. ((2002) as cited in (U.S. EPA, 2012c)), Ji and Hemminki ((2005) as cited in (U.S. EPA, 2012c)), and Pukkala et al. ((2009) as cited in (U.S. EPA, 2012c)), respectively. Three other studies with strong exposure assessment approaches specific to PCE, but whose risk estimates are based on fewer observed liver cancer cases or deaths, reported risk estimates of 1.21-2.05 for the association between liver cancer and PCE ((Seldén and Ahlborg, 2011; Boice et al., 1999; Bond et al., 1990; Blair et al., 1979) all as cited in (U.S. EPA, 2012c)). However, dry cleaning workers did not have a higher liver cancer risk estimate than laundry workers ((Seldén and Ahlborg, 2011; Lynge et al., 2006) both as cited in (U.S. EPA, 2012c)). Exposure response was not observed, and the SIR for PCE-exposed subjects with the longest employment duration in Seldén and Ahlborg ((2011) as cited in (U.S. EPA, 2012c)) was lower than that for subjects with shorter employment duration. Potential confounding may be an

alternative explanation, as no study adjusted for known and suspected risk factors for liver cancer ((Seldén and Ahlborg, 2011; Pukkala et al., 2009; Lynge et al., 2006; Ji and Hemminki, 2005; Travier et al., 2002; Boice et al., 1999; Bond et al., 1990) all as cited in (U.S. EPA, 2012c)). Nine other cohort and case-control studies with fewer observed events and/or a broad exposure assessment methodology carried less weight in the analysis and reported a mixed pattern of results ((Calvert et al., 2011; Lindbohm et al., 2009; Sung et al., 2007; Blair et al., 2003; Lee et al., 2003; Lynge et al., 1995; Vartiainen et al., 1993; Suarez et al., 1989; Stemhagen et al., 1983) all as cited in (U.S. EPA, 2012c)). Lee et al. ((2003) as cited in (U.S. EPA, 2012c)) reported a risk estimate of 2.57 (95% CI = 1.21-5.46) for the association between liver cancer and residence in a village with groundwater contamination, but subjects were from a region with a high prevalence of hepatitis C infection, and hepatitis C status may confound the observed association.

Among the newer studies, the large case-control study by (Vlaanderen et al., 2013) derived from the NOCCA cohort reported the following HRs for liver cancer risk: an HR of 1.18 (95% CI = 0.97-1.44, 121 cases) for the second tertile of cumulative PCE exposure (both sexes combined) and an HR = 1.13 (95% CI = 0.92-1.38, 114 cases) for the third tertile. Also, in those with high (90^{th} percentile) PCE exposure, the authors reported an HR of 1.11 (95% CI = 0.79-1.57) based on 40 cases using a cumulative exposure metric; and an HR of 1.26 (95% CI = 0.88-1.80 based on 38 cases using a metric of average intensity × prevalence). (Lipworth et al., 2011) found no association between liver cancer mortality and routine or intermittent exposure to PCE in aircraft manufacturing workers (SMR = 0.93, 95% CI = 0.56-1.45, 19 cases versus 20.5 expected). There was no significant relationship with exposure duration among the observed cases (P_{trend} >0.20) in this study, but relative risk was highest in workers with the longest (≥5 years) duration of exposure (RR = 1.29, 95% CI = 0.60-2.78, 10 cases). (Silver et al., 2014) found no association between liver cancer and cumulative PCE exposure among electronics workers (HR = 0.79, 95% CI = 0.27-2.30). (Bove et al., 2014a) and (Bove et al., 2014b) reported decreasing HRs of 1.17 (95% CI = 0.55-2.49, 12 cases), 0.96 (95% CI = 0.43-2.14, 10 cases), and 0.82 (95% CI = 0.36-1.89, 9 cases) for liver cancer in low, medium, and high cumulative PCE exposure groups, respectively, in the Camp Lejeune cohort exposed by drinking water. The only other newer study that evaluated this endpoint was not informative because there was only a single observed case with PCE exposure (Christensen et al., 2013).

G.1.8 Cervix

(U.S. EPA, 2012c) included cervical cancer among the tumor types with limited suggestive evidence for an association with PCE exposure. The results from two large cohort studies with a broad exposure assessment were consistent with an elevated cervical cancer risk of 20-30%: SIR = 1.20 (95% CI = 1.08-1.34) in Pukkala et al. ((2009) as cited in (U.S. EPA, 2012c)) and SIR = 1.34 (95% CI = 1.12-1.60) in Travier et al. ((2002) as cited in (U.S. EPA, 2012c)). Results from four smaller cohort and case-control studies with a relatively high-quality exposure assessment methodology presented a pattern of more variable results, with relative risks of 0.98 (95% CI = 0.65-1.47), 1.19 (95% CI = 0.64-1.93), 2.10 (95% CI = 0.68-4.90), and 3.20 (95% CI = 0.39-11.6) in Lynge et al. ((2006) as cited in (U.S. EPA, 2012c)), Seldén and Ahlborg ((2011) as cited in (U.S. EPA, 2012c)), Calvert et al. ((2011) as cited in (U.S. EPA, 2012c)), and Anttila et al. ((1995) as cited in (U.S. EPA, 2012c)), respectively. A fourth study with higher quality exposure assessment specific to PCE did not observe any cervical cancer deaths among women, but less than one death was expected ((Boice et al., 1999) as cited in (U.S. EPA, 2012c)). Calvert et al. ((2011) as cited in (U.S. EPA, 2012c)) was the only study to report an increasing exposure response gradient with employment duration. Dry cleaning workers did not have higher cervical cancer risks compared with laundry workers ((Seldén and Ahlborg, 2011; Lynge et al., 2006) both as cited in (U.S. EPA, 2012c)). None of the cohort studies of cervical cancer considered socioeconomic or lifestyle factors such as smoking or exposure to the human papilloma virus (HPV), a known risk factor for cervical cancer that is correlated with socioeconomic status. A case-control study ((Lynge et al., 2006)

as cited in (U.S. EPA, 2012c)) included controls similar in socioeconomic status as cases, and the OR estimate in that study for dry cleaners did not support an association with PCE (U.S. EPA, 2012c). The only newer study that evaluated this endpoint ((Lipworth et al., 2011), update of (Boice et al., 1999)) was not informative because there was only a single observed case with PCE exposure.

G.1.9 Breast

Breast cancer was among the endpoints considered by (U.S. EPA, 2012c) to have suggestive but limited evidence of an association with PCE exposure based on studies available at that time. Results from the large studies of breast cancer risk in women in relation to PCE exposure were mixed. The largest study, based on 1,757 breast cancer cases in female dry cleaners and laundry workers, reported a statistically significant deficit in the risk of breast cancer incidence compared to the populations of Nordic countries ((Pukkala et al., 2009) as cited in (U.S. EPA, 2012c)). Findings in the other four studies were based on fewer events or exposed cases; two of four studies with a nonspecific exposure assessment methodology provided evidence for association between breast cancer in females and PCE exposure ((Sung et al., 2007; Chang et al., 2005; Aschengrau et al., 2003; Andersen et al., 1999; Lynge and Thygesen, 1990) all as cited in (U.S. EPA, 2012c)), but no association to PCE was observed in two other large cohort studies with a relatively high-quality exposure assessment methodology ((Seldén and Ahlborg, 2011; Blair et al., 2003) both as cited in (U.S. EPA, 2012c)). Small studies also observed mixed findings ((Calvert et al., 2011; Radican et al., 2008; Peplonska et al., 2007; Sung et al., 2007; Aschengrau et al., 2003; Band et al., 2000; Boice et al., 1999) all as cited in (U.S. EPA, 2012c)). Although cohort studies were unable to control for potential confounding from reproductive history or menopausal status, observations in case-control studies controlled for these potential confounders in statistical analyses and provided support for an association between female breast cancer and PCE compared to controls ((Peplonska et al., 2007; Aschengrau et al., 2003; Band et al., 2000) all as cited in (U.S. EPA, 2012c)). Three studies examined exposure-response relationships (U.S. EPA, 2012c), and two of these studies with semiquantitative or quantitative exposure assessment approaches reported that risk estimates in females were monotonically increased in higher exposure groups ((Aschengrau et al., 2003; Blair et al., 2003) both as cited in (U.S. EPA, 2012c)). A third study examining exposure duration observed an inverse relation ((Peplonska et al., 2007) as cited in (U.S. EPA, 2012c)), but exposure duration is more uncertain than use of a semiquantitative surrogate given increased potential for bias associated with exposure misclassification.

Few data on breast cancer were found in newer studies. (Gallagher et al., 2011) conducted a case-control study that included an updated exposure assessment and reanalysis of breast cancer data previously evaluated by (Aschengrau et al., 2003), (Aschengrau et al., 1998), and (Paulu et al., 1999). They found no increase in breast cancer risk for women "ever" exposed to PCE versus unexposed. In women with high cumulative exposure defined as 90th percentile, ORs were mostly 1.3-1.5 depending on latency, although not statistically significant. As a higher cut point identified by curve smoothing analysis, ORs were 1.3-1.4 with 0-7 year latency and 1.6-2.0 with 9-15-year latency. The (Lipworth et al., 2011) update of the (Boice et al., 1999) cohort of aircraft manufacturing workers identified an SMR of 1.52 in breast cancer risk (95% CI = 0.78-2.65) based on only 12 cases (versus 7.9 expected). However, there was no significant trend based on exposure duration (P_{trend} >0.20) in an analysis limited by the small number of cases per exposure duration category. The only other newer study that evaluated this endpoint was not informative due to few observed cases with PCE exposure (Bove et al., 2014a, b).

Because of the limitation in statistical power, none of the older ((Seldén and Ahlborg, 2011; Pukkala et al., 2009; Chang et al., 2005; Andersen et al., 1999; Lynge and Thygesen, 1990) all as cited in (U.S. EPA, 2012c)) or newer (Ruckart et al., 2015) studies reporting on male breast cancer was adequate to examine PCE exposure.

G.1.10 Other

No other cancers were identified by (U.S. EPA, 2012c) as having potential associations with PCE exposure. Among the newer studies, case-control studies by (Barul et al., 2017), (Carton et al., 2017) and (Christensen et al., 2013) presented results suggesting potential associations between PCE exposure and prostate cancer in men and pharyngeal/laryngeal cancers in both sexes. However, these findings were based on small numbers of cases (≤10) and so are highly uncertain. Other studies did not report supporting results. (Lipworth et al., 2011) found no increase in risk of death due to cancers of the buccal cavity and pharynx (SMR = 0.77, 95% CI = 0.41-1.32, 13 observed and 16.8 expected), larynx (SMR = 0.90, 95% CI = 0.36-1.84, 7 observed and 7.8 expected), or prostate (SMR = 0.92, 95% CI = 0.72-1.16, 71 observed and 77.1 expected) in their cohort of aircraft manufacturing workers exposed to PCE. No significant relationship between cumulative exposure to PCE and risk of prostate or oral cancers was evident in the Camp Lejeune cohort (Bove et al., 2014a, b).

G.1.11 Detailed Summary Epidemiologic Evidence on Cancer Published after the 2012 IRIS Toxicological Assessment on PCE

Lipworth et al. (2011) conducted a follow-up analysis of the aircraft manufacturing worker cohort originally evaluated by (Boice et al., 1999) and described in (U.S. EPA, 2012c). The cohort consisted of 77,943 employees who had worked for at least 1 year at a Lockheed Martin manufacturing facility in California on or after January 1, 1960. The cohort included both exposed factory workers (n=45,318) and unexposed non-factory workers (n=32,625). Subjects were identified using employee work history records, personnel files, and retirement records. Deaths through December 31, 2008 (n=34,298) were determined using the California Death Statistical Master File (CDSMF), National Death Index (NDI), and Social Security Administration Death Master File (SSADMF), as well as company pension records and a commercial service specializing in death record location. Workers for whom no death records were identified were traced using Social Security Administration Service to Epidemiologic Researchers and LexisNexis records to confirm that they were alive; these methods confirmed the identification of 42,309 living workers. The vital status of the remaining 1,336 workers (1.7% of cohort) was not determined. For deaths after 1978, underlying cause of death was available in the NDI; the CDSMF provided cause of death for subjects who died in California, and death certificates were obtained for the remaining subjects (and for a small number of subjects whose records in NDI were incomplete).

Exposures were determined based on historical job descriptions, chemical usage patterns, environmental assessment reports, industrial hygiene records, interviews with long-term workers, and walk-throughs of aircraft manufacturing facilities; details of the exposure assessment were published by (Marano et al., 2000). Approximately 12.9% of factory workers (n=5,830) had some exposure to PCE. According to (Marano et al., 2000), many PCE-exposed workers also had exposure to chromate (76%), trichloroethylene (39%), mixed solvents (56%), and/or asbestos (5%). Relative exposure to each worker was assigned based on length of time in specific jobs with potential for exposure to each substance. (Marano et al., 2000) indicated that exposures were categorized as either routine or intermittent, and that approximately 55% of the PCE-exposed workers were classified as having intermittent exposure. Thus, there may have been a wide range of cumulative exposure levels in the group exposed to PCE, which could bias the analysis toward the null. No information was available to the researchers regarding smoking, alcohol consumption, or other lifestyle factors.

For standard mortality ratio (SMR) calculations, expected numbers of deaths were obtained using age, race, calendar year, and sex-specific rates from California (for white workers) or the U.S. general population (for non-white workers, to better match the racial composition of the worker population) (Lipworth et al., 2011). For internal analyses examining the influence of exposure duration, the comparison group consisted of factory workers without exposure to solvents or chromates (n=9,520).

The model included date of birth, date of hire, date of termination, sex, and race. There was no explicit consideration of latency.

There were 2,641 deaths among the workers exposed to PCE (Lipworth et al., 2011). SMRs for all causes of death and all malignant neoplasms were 0.93 and 0.96, respectively, possibly suggestive of a healthy worker effect. An SMR of 1.43 (95% CI = 1.00-1.98; n=36 cases**)** for NHL was observed. Other cancers of the breast, connective and other soft tissues, ovary and other female genital and testes and other male genital cancers were not statistically significant, but the SMRs ranged from 1.28 to 2.18 and the numbers of cases were very low. Other sites, including bladder, kidney, liver, lung, esophagus, and cervix and MM had SMRs below or close to 1.0 (SMR ≤1.13).

Analyses based on duration of exposure (<1, 1-4, ≥5 years) to PCE did not support an association between PCE and NHL or any other tumor type examined, including MM and cancers of the breast, kidney, liver, lung, or esophagus (Lipworth et al., 2011). For NHL, relative risks were 1.26 (95% CI = 0.65-2.45, 11 observed), 1.00 (95% CI = 0.05 2.00, 10 observed), and 1.02 (95% CI = 0.53-1.99, 12 observed) in the low- to high-duration exposure groups compared with unexposed factory workers (Ptrend >0.2). Interpretation of the duration of exposure analysis was limited for most other tumor types (all of those listed above, except lung) by small numbers of observed tumors (≤4) in one or more of the duration groups.

In another cohort study, (Silver et al., 2014) evaluated the association between PCE exposure and cancer mortality in a cohort of 34,494 microelectronics workers in New York state. The workers were engaged in business machine production and manufacture of circuit boards and substrates between 1906 and 2001. Machine production involved exposure to dust, solvents, and metals, while circuit board production involved exposure to chlorinated solvents and other industrial chemicals. Facility records indicated that use of trichloroethylene in circuit board production began in the mid-1960s, and that use of PCE increased in 1974 when substrate manufacturing began.

Members of the cohort included all direct employees who had worked at least 91 days between January 1, 1969 and December 31, 2001 and were U.S. citizens (Silver et al., 2014). The Social Security Administration, NDI, and Internal Revenue Service were used to determine vital status of cohort members through December 31, 2009. Cause of death was determined from the NDI for deaths after 1979 and from death certificates for earlier deaths and coded according to the International Classification of Diseases (ICD) revision in effect at the time of death.

Higher percentages of hourly than salaried workers were ever potentially exposed to a compound considered in the study; however, even among hourly workers, the prevalence of PCE exposure was low (Silver et al., 2014). Among male hourly workers, 15.1% were exposed to PCE, compared with 60.5% exposed to “other hydrocarbons.” Chemical exposure was estimated using work histories from electronic personnel databases, chemical use and exposure information from the company, industrial hygiene monitoring results/documents, and company environmental impact assessments, as well as interviews of former employees and results from an Agency for Toxic Substances and Disease Registry (ATSDR) study of volatile organic compound (VOC) use at the plant from 1969 to 1980. An exposure database linking chemical use with department and year was developed and used to assign each subject to an exposed/unexposed category for PCE, trichloroethylene, methylene chloride, and chlorinated hydrocarbons as a class. Cumulative exposure duration was modified by a parameter categorizing the extent of chemical use in a department and another that categorized the extent of exposure by job function.

SMRs were calculated for all cohort members, but these analyses were not chemical-specific (Silver et al., 2014). Internal analyses by chemical exposure were performed using conditional logistic regression based on full risk sets (equivalent to Cox proportional hazards analysis). In these analyses, chemical exposure of cases was compared with those of "controls": workers who began at an age younger than the cases and survived longer (these could include cases from other risk sets). Age was controlled using risk set selection, and models were adjusted for sex and pay code (as it is potentially associated with exposure, smoking, and other potential confounders). Smoking, alcohol consumption, and other lifestyle factors were not explicitly considered. The authors did not control for other chemical exposures or evaluate correlations among them. Hazard ratios (HRs) at 5 modified exposure years were reported, along with the regression coefficient, with a 10-year lag time incorporated for all outcomes apart from leukemia (for which a 2-year lag was used).

SMRs for all cause and all cancer mortality were significantly decreased in the cohort relative to U.S. general population rates, showing the expected healthy worker effect (Silver et al., 2014). Also among the cohort as a whole, the SMR for NHL was significantly increased in hourly male workers (SMR = 1.49, 95% CI = 1.15-1.89, 65 observed). In the analyses for specific chemical exposures, PCE showed an HR for NHL of 1.25 (95% CI = 0.90-1.73). The other chemical exposures assessed in this study (trichloroethylene, methylene chloride, chlorinated hydrocarbons, and other hydrocarbons) also did not show statistically significant changes in NHL risk with increasing cumulative exposure in the internal analysis; HRs were less than 1.0 and ranged from 0.71 to 0.90. PCE showed no association (HR $\leq$1.0) with other cancers, including bladder, kidney, liver, brain, or MM. The study was limited by the young age of the cohort (only 17% had died at the end of follow-up), as well as by the low prevalence of PCE exposure and failure to control for co-exposures.

(Gallagher et al., 2011) performed a case-control study that included a reanalysis of breast cancer data previously evaluated by (Aschengrau et al., 1998), (Aschengrau et al., 2003), and (Paulu et al., 1999) and described in (U.S. EPA, 2012c), updating the exposure assessment of the Cape Cod population exposed to PCE leaching from the vinyl lining of drinking water distribution pipes. Briefly, while earlier assessments used the Webler and Brown model to estimate residential PCE exposures based on the configuration, size, age, and water flow rate in contaminated pipe serving each residence, (Gallagher et al., 2011) employed the EPANET software to provide more robust modeling of water flow throughout the entire distribution system. Participant selection was identical to earlier assessments, except that subjects from the earlier analyses were excluded if information needed for EPANET modeling was missing. Eligible persons consisted of permanent female residents of eight affected towns in Cape Cod. Incident breast cancer cases between 1983 and 1993 were identified using the state cancer registry; controls of comparable age and vital status were identified through random digit dialing (for controls up to 64 years of age), Medicare records (65 years of age and older), or death certificates (deceased controls). Of 1,192 cases and 7,869 controls initially identified, 87 cases and 1,125 controls could not be located; 31 cases and 4,404 controls were not eligible based on residential criteria; 8 cases and 34 controls lacked exposure information; and 136 cases and 338 controls declined to participate (or their physicians declined consent). Finally, 666 eligible controls identified by random digit dialing were excluded because the target number of controls had already been reached. Of the 930 cases and 1,302 controls included in previous analyses, 19 lacked information needed for EPANET exposure modeling and were excluded, leaving 920 cases and 1,293 controls for the reanalysis.

From each subject, detailed residential history, history of occupational exposure to PCE, risk factors for breast cancer, and other demographic information was obtained via interview (Gallagher et al., 2011). Using the EPANET software to model water flow in the distribution system and leaching components from the Webler-Brown model, the study authors estimated relative delivered dose (RDD) to each

residence. The RDD is a relative dose estimate intended to approximate the amount of PCE delivered to each residence. Odds ratios (ORs) were evaluated using multiple logistic regression controlling for the following variables: age at diagnosis or index year, vital status at interview, family history of breast cancer, personal history of prior breast cancer, age at first live birth or stillbirth, occupational PCE exposure, and study of origin (first study or second expanded study). Use of bottled water was considered by stratifying the results. Other potential confounders, including education, hormone use, and parity were considered, but did not modify effect estimates by at least 10% and were excluded from the final model. ORs were calculated with and without latency periods of 5-19 years, based on ever/never exposed, cumulative RDD, peak RDD, and duration of exposure to PCE. The impact of PCE leaching rate was evaluated by sensitivity analysis, and smoothing analysis was used to refine the cut points for high exposure.

The updated exposure assessment using the EPANET software categorized larger percentages of cases and controls as exposed (48.8% and 50.1%, respectively) compared to the earlier method (20.5% and 16.7%, respectively), which had assumed that residences not in close proximity to a source pipe were not exposed (Gallagher et al., 2011). Because most of the participants whose status shifted from non-exposed to exposed were exposed at low levels, the EPANET method yielded a downward shift in RDD distribution percentiles compared to the earlier method; for example, 75th and 90th percentile RDD estimates (unitless) with no latency period were 7.1 and 19.5, compared with 15.5 and 41.8 (respectively) using the earlier method.

Using the updated exposure estimates, no increases in the adjusted ORs for breast cancer were observed for women "ever" versus never exposed, regardless of latency period considered (adjusted OR = 1.0 for all latencies) (Gallagher et al., 2011). Compared to unexposed subjects, adjusted ORs of mostly 1.3-1.5 (depending on latency) were observed for cumulative RDDs above the 90th percentile and adjusted ORs of 0.9-1.5 were determined for peak RDD above the 90th percentile, but not the lower exposure levels. Analysis for duration of exposure showed an adjusted OR of 1.8 (95% CI = 0.7-4.4) for breast cancer risk in women with more than 10 years of exposure when a 13-year latency period was included; none of the women had more than 10 years of exposure when longer latency periods were considered. No associations were found between shorter durations of exposure and breast cancer, regardless of latency period. When the cut points for higher cumulative exposure were redefined based on smoothing analysis (RDD >35), adjusted ORs (non-significant) were 1.3-1.4 with 0-7-year latency and 1.6-2.0 with 9-15-year latency. Results were reported to be similar for peak exposure, but data were not shown. Finally, slightly higher risks were seen for exposed women who did not drink bottled water regularly (adjusted ORs = 1.1 1.3 across latency periods) when compared with those who did (adjusted ORs = 0.6-0.8). As in the previous studies conducted on these data, this study suggests a modest association between high drinking water exposure to PCE and breast cancer risk in women.

(Ruckart et al., 2013) conducted a case-control study of childhood hemopoietic cancers (leukemia and NHL) in children exposed prenatally and in early childhood to contaminated drinking water at the Marine Corps Base at Camp Lejeune, North Carolina. Contaminated water at the camp, which opened in the 1940s, was discovered in the early 1980s in wells of the Camp's Hadnot Point and Tarawa Terrace distribution systems. The Tarawa Terrace system was primarily contaminated with PCE (up to 215 µg/L) from a nearby dry cleaner, while Hadnot Point was primarily contaminated with trichloroethylene (up to 1,400 µg/L), with lesser amounts of vinyl chloride, 1,2-dichlorethylene, PCE, and benzene. These authors did not detail other contaminants in the Tarawa Terrace system; however, (Ruckart et al., 2015) estimated that low levels (≤20 µg/L) of dichloroethylene, trichloroethylene, and vinyl chloride were present along with PCE.

The study population consisted of children born alive between 1968, when North Carolina began computerizing birth certificates, and 1985, when the contaminated wells were closed, and whose mothers had lived at Camp Lejeune during pregnancy (Ruckart et al., 2013). A total of 12,493 children whose mothers lived on base when they delivered were identified by birth certificates, and an additional 4,000 children whose mothers had moved off base prior to delivery were identified via media campaigns and referrals from enrolled subjects. Telephone interviews of parents were conducted by ATSDR to obtain information on childhood (before age 20) leukemia and NHL and residential histories. Of 12,498 subjects whose parents were contacted, 76% agreed to participate, including 10,044 identified by birth certificates and 2,554 identified by referral.

Exposures to contaminated water were estimated by ATSDR via base-wide models of groundwater fate and transport and drinking water distribution systems, which yielded monthly average concentration estimates at each residence (Ruckart et al., 2013). Base housing records and parental interview information were combined with the concentrations to estimate average exposure to each subject across pregnancy and the first year of life. The study authors did not isolate subjects by water distribution system, so the study population included those using the Hadnot Point system with exposure primarily to trichloroethylene. Exposures were estimated for each trimester, for the whole gestation period, and for the first year of life.

A total of 14 childhood hematopoietic cancers were reported by parents (Ruckart et al., 2013). Of these, 13 cases were confirmed via vital and medical records, including 11 leukemias and 2 NHL. The parents of 651 potential control subjects were contacted; 103 refused or could not be contacted, so 548 were interviewed. Subsequently, 14 control children were excluded because their parents reported in the interview that the mother had not resided on the base during pregnancy; 6 were excluded because the parents were interviewed about the wrong child; and two lacked residential history during pregnancy, leaving 526 controls. ORs were estimated using unconditional logistic regression. Potential confounders considered in the analysis were not reported, and adjusted results were only reported if the difference from the crude estimates was more than 20%.

The median estimated average PCE exposure of subjects was 44 µg/L (Ruckart et al., 2013). Using the average first trimester exposure estimate, the unadjusted OR for exposed versus unexposed was 1.6 (95% CI = 0.5-4.8) based on 7 cases (total for childhood leukemia and NHL combined), and the unadjusted ORs for exposure above and below the median, compared with unexposed, were similar and also imprecise (OR = 1.4, 95% CI 0.3-5.6 for exposure ≥44 µg/L based on 3 cases; OR=1.8, 95% CI = 0.5-6.6 for exposure >0 and <44 µg/L based on 4 cases). Other metrics for first trimester exposure (maximum, unexposed including exposure <1 µg/L) yielded comparable effect estimates (data not reported), while no association with childhood leukemia and NHL was seen using cumulative exposure to PCE through pregnancy or the first year of life (data not reported). These data are highly uncertain due to the small number of observed cases exposed to PCE.

(Ruckart et al., 2015) assessed male breast cancer risk in a case-control study of U.S. Marine Corps personnel stationed at Camp Lejeune. Cases and controls were identified using the Veteran's Affairs Central Cancer Registry (VACCR). The study population was defined as male Marines diagnosed or treated for cancers between January 1, 1995 (when the VACCR began) and May 5, 2013 at a medical facility run by the Veterans Administration (VA). Those who were not old enough to have been at Camp Lejeune during the time of water contamination (*e.g.*, at least 17 years old by December 31, 1985) were excluded. A total of 78 incident cases of male breast cancer were identified. Controls were diagnosed with cancers not known to be related to solvent exposure, including non-melanoma skin cancer, bone cancer, and pleural or peritoneal mesothelioma. To achieve the targeted 5 controls per case, the study

authors included all 32 bone cancer cases, all 76 mesothelioma cases, and a random sample of 292 skin cancers from among the 555 identified in VACCR, yielding a total of 400 controls.

All information was obtained from databases; no subject interviews were conducted (Ruckart et al., 2015). Military personnel records were used to determine whether and when subjects had been stationed at Camp Lejeune before 1986, as well as their marital status at each time period stationed there; these records were missing for 7 cases and 27 controls. The VACCR and VA patient treatment files were examined for information on tumor histological confirmation, date of birth, age at diagnosis, race, and medical conditions (*e.g.*, diabetes, obesity, gynecomastia, and Klinefelter syndrome) potentially related to male breast cancer development. Finally, information on service in Vietnam (with potential exposure to dioxin via Agent Orange) and military occupational specialties with potential exposure to solvents and electromagnetic fields was obtained from military personnel records.

The same historical reconstruction method used by (Ruckart et al., 2013) was used to estimate monthly average exposure concentrations at each residence (Ruckart et al., 2015). The residential histories of cases and controls were developed from base housing records, military personnel records, and unit-specific housing records. Exposure began with the earliest time each subject was stationed at Lejeune and ended either when his tour ended or on December 31, 1985. Cumulative and average exposures were estimated for each subject; exposure-response analysis was performed by categorizing exposures above and below the median. The study authors employed exact logistic and conditional regression methods to estimate associations, but since results were similar, only the exact logistic method results were presented. Results were adjusted for age at diagnosis, race, and service in Vietnam; other potential covariates (case/control status, ethnicity, rank, diabetes, or gynecomastia) did not alter risk estimates by at least 10%. Finally, proportional hazards analysis, adjusted for race and service in Vietnam, was used to assess whether PCE exposure resulted in earlier age at breast cancer diagnosis. While latency was not explicitly included in the assessment, the authors noted that an implicit latency of at least 10 years was considered, because exposures ended in 1985, and cases were diagnosed after 1995 (when the VACCR commenced operation).

The final analysis included 71 cases and 373 controls, but only 4 cases exposed to PCE (Ruckart et al., 2015). For cumulative PCE exposure, the adjusted ORs for low (>0 and <36 μg/L-months) and high (≥36 μg/L-months) exposure were 1.05 (95% CI = 0.14-5.14) and 1.20 (95% CI = 0.16-5.89), respectively. For monthly average exposure, the adjusted ORs for low (>0 and <2 μg/L) and high (≥2 μg/L) exposure were 0.91 (95% CI = 0.13-4.21) and 1.47 (95% CI = 0.18-7.91). In the evaluation for reduced age at diagnosis, the adjusted HRs were 1.19 (95% CI = 0.2-7.07) for low and 2.08 (95% CI = 0.31 14.00) for high cumulative exposures. All of these results are highly uncertain, as they are based on only 2 cases per exposure group.

A retrospective cohort study of military personnel at Camp Lejeune was conducted by (Bove et al., 2014a) and (Bove et al., 2014b). A primary focus of the study was standardized mortality analysis of personnel stationed at Camp Lejeune (with exposure to drinking water contaminated with PCE, trichloroethylene, and other solvents) and analyses comparing personnel at Camp Lejeune with those stationed at Camp Pendleton (without exposure to contaminated water); these analyses are not discussed here, because they do not provide hazard identification information specific to PCE. The study authors also conducted an internal analysis of Camp Lejeune with chemical-specific effect estimates, as described here.

The study population was defined as all Marine and Navy personnel who were stationed for active duty at Camp Lejeune between April 1975 and December 1985 (Bove et al., 2014a, b). A total of 154,932

subjects were identified using personnel files that included date of birth, sex, race/ethnicity, marital status, rank, active duty start date, total months of service, and military occupation. Vital status was determined using Social Security Administration data and a commercial tracing service, and deaths and causes (underlying and contributing) were identified using the NDI. Subjects whose vital status could not be determined contributed person-years until the last date known to be alive.

Exposure assessment employed the same historical reconstruction methods used by (Ruckart et al., 2015) and (Ruckart et al., 2013). Residential histories were determined using base housing records together with rank, gender, marital status, and dates of service. For each subject, monthly average exposure concentrations at each residence were combined with duration at each residence to estimate cumulative exposure. Exposure estimates for PCE exhibited correlations (0.44-0.53) with other contaminants; the authors noted that the Tarawa Terrace system, with the highest PCE levels (up to 158 µg/L, with mean monthly average estimate of 75.7 µg/L), had low levels of other contaminants (*e.g.*, mean estimated monthly averages of 3.1 µg/L trichlorethylene and 5.6 µg/L vinyl chloride). The other contaminated system at the Camp, Hadnot Point, was primarily contaminated with trichloroethylene (mean monthly average estimate of 358.7 µg/L; means for PCE, vinyl chloride, and benzene were 15.7, 24.0, and 5.4 µg/L, respectively).

The study authors analyzed the association between cancer mortality and PCE exposure as HRs using Cox extended regression models with age as the time variable and cumulative exposure as a time-varying variable (Bove et al., 2014a, b). Lag periods of 0, 10, 15, and 20 years were considered in assessments of cumulative exposures. Confounders were incorporated into the model if they altered the effect estimate by 10% or more; these included sex, race, rank, and education. Because the data sources used for the study lacked information on smoking, the HR for smoking-related diseases (stomach cancer, cardiovascular disease, chronic obstructive pulmonary disease [COPD]) were subtracted from the HR for the disease of interest to assess potential confounding by smoking. The validity of this method to control for confounding by smoking is uncertain. No information on alcohol consumption or non-service-related occupational exposures was available in the data sources used in the study.

The analysis based on cumulative exposure to PCE showed no significant exposure-related increase in cancer risk for any tumor type, including bladder, kidney, liver, esophagus, breast, brain, lung, MM, NHL, Hodgkin's disease, and leukemia (Bove et al., 2014a, b). HRs for kidney cancer risk for all cumulative exposure levels of PCE were HRs were 1.40 (95% CI = 0.54-3.58, 8 cases), 1.82 (95% CI = 0.75-4.42, 11 cases), and 1.59 (95% CI = 0.66-3.86, 11 cases) for low (>1 to 155 µg/L-month), medium (>155-380 µg/L-month), and high (>380 8,585 µg/L-month) exposures, respectively. Risk did not increase with estimated exposure. The authors reported that similar results were observed when exposure was quantified as average exposure or duration of exposure (data not shown). Findings from this study should be considered preliminary, as fewer than 6% of the cohort had died by the end of the study, with 97% remaining under the age of 55 years.

(Christensen et al., 2013) performed a case-control study to examine the relationship between occupational solvent exposure and multiple cancer types in residents of Montreal, Canada. Among 4,576 eligible Canadian males aged 35-70 years diagnosed with any of 11 different types of cancer (bladder, NHL, liver, pancreas, kidney, esophagus, stomach, colon, rectum, prostate, melanoma) between 1979 and 1985 in the 18 largest hospitals in Montreal, 3,730 (82%) were successfully interviewed (proportion by proxy varied with tumor type from low of 11.6% for melanoma to high of 60.4% for liver cancer). Population controls, stratified by sex and age to the distribution of cases, were randomly sampled from electoral lists; 533 (72%) of 740 eligible controls were interviewed (12.6% by proxy). Interviews were conducted to obtain information on lifestyle factors and job history (company, products, nature of work

site, subject's main and secondary tasks, use of protective equipment, etc.), which was translated into potential exposures to chlorinated solvents (PCE and 5 other individual chemicals, chlorinated alkanes, chlorinated alkenes) by a team of chemists and industrial hygienists, blinded to a subject's case or control status. Exposures were graded with respect to confidence that the exposure had occurred (possible, probable, definite), frequency of exposure in a normal work week (<5%, 5-30%, >30% of the time), and intensity of exposure (low, medium, or high). Exposures that were probable or definite, with frequency and intensity of medium or high and duration of 5 or more years were considered to be "substantial" for the analysis.

The authors did not discuss the extent of overlap of exposures (Christensen et al., 2013), but review of the occupations with highest prevalence of exposure for each material analyzed showed considerable overlap in occupations that is likely to have extended to exposures as well. Analyses were performed using both population and cancer controls, as well as a pooled control group with cancer controls given equal weight to population controls. Cancer controls for a given tumor type were cancer cases with other tumors that were: (1) not lung cancer, (2) not from adjacent sites in the body to the site in question, and (3) selected so that no more than 20% were from any one cancer site. All models were adjusted for age, ethnicity (French Canadian or other), socioeconomic status, and respondent (proxy or self). Models for some cancer types (not NHL) were also adjusted for smoking and consumption of alcohol, coffee, and/or tea. Models were not adjusted for co-exposures to other solvents. Most cases and controls were current or former smokers.

Numbers of cases and population controls with "substantial" or even "any" exposure to PCE were low for all tumor types, 4 or lower in most cases (Christensen et al., 2013), which limits the conclusions that can be drawn based on reported ORs for most endpoints in this study, whether above or below 1.0. However, a significant increase was found for risk of prostate cancer with "substantial" exposure to PCE relative to both population controls (OR = 6.0, 95% CI = 1.2-30 based on 9/449 cases and 2/533 controls) and cancer controls (OR = 4.3, 95% CI = 1.4-13 based on 9/1,550 controls). None of the other chemicals evaluated showed a significant association with prostate cancer, and neither did chlorinated alkenes or alkanes collectively. Confidence in the suggested association between PCE exposure and prostate cancer is low due to small numbers of cases and controls.

(Vizcaya et al., 2013) published separate and pooled analyses of lung cancer from two population-based case-control studies performed in Montreal, Quebec. Analyses of non-pulmonary cancer types in one of the case-control studies (referred to as Study I) were published by (Christensen et al., 2013); details of the case and control selection, participation rates, and exposure assessment for Study I are discussed in that study description. Study II was conducted using nearly identical procedures but from 1995 to 2001 (Study I was 1980-1986). A total of 851 male lung cancer cases and 533 male controls (79% and 70% of eligible subjects, respectively) were identified in Study I, while 735 male and 430 female lung cancer cases and 898 male and 570 female controls (86% and 70% of eligible subjects, respectively) were identified in Study II. Next-of-kin proxies responded for about one-third of cases and one-tenth of controls. ORs were calculated using unconditional logistic regressions adjusted for age, income, ethnicity, educational attainment, questionnaire respondent (self versus proxy), tobacco smoking (Comprehensive Smoking Index), exposure to occupational lung carcinogens (never, ever, or substantial occupational exposure to any of the 8 known or probable International Agency for Research on Cancer (IARC) lung carcinogens: asbestos, crystalline silica, chromium VI, arsenic compounds, diesel exhaust emissions, soot, wood dust, or benzo[a]pyrene), and in the pooled analysis, study (I versus II). The authors noted that sample sizes were limited and there was overlapping exposure to multiple solvents, and thus it was not possible to evaluate risks to subjects exposed to only one solvent.

Prevalence of exposure to any chlorinated solvent was 14.4% in male and 9.6% in female population controls across both studies (Vizcaya et al., 2013). Because there were fewer women included and their exposure prevalence was lower, the study had little power to detect an effect in women and results were presented for men only. The lifetime prevalence of PCE exposure in controls was very low (0.9% across both studies). ORs for lung cancer with PCE exposure were 4.3 (95% CI = 1.1-16) based on 11/667 cases and 4/403 controls with "any" exposure and 5.7 (95% CI = 0.9-36) based on 6/667 cases and 2/403 controls with "substantial" exposure in Study I, 2.3 (95% CI = 0.8-6.2) based on 12/646 cases and 9/822 controls with "any" exposure and 1.6 (95% CI = 0.3-8.3) based on 4/646 cases and 4/822 controls with "substantial" exposure in Study II, and 2.5 (95% CI = 1.2-5.6) based on 23/1,313 cases and 13/1,225 controls with "any" exposure and 2.4 (95% CI = 0.8-7.7) based on 10/1,313 cases and 6/1,225 controls with "substantial" exposure in the pooled analysis. Similar results were observed when the analysis was restricted to subjects who completed the questionnaires themselves (no proxy respondents). Among the other chemicals evaluated, only carbon tetrachloride showed a significant association with lung cancer, with results comparable to those for PCE among those with "substantial" exposure. There was no association with lung cancer for chlorinated alkenes or alkanes collectively. These findings suggest an association between exposure to PCE and lung cancer, but are limited by the low numbers of cases and controls with PCE exposure.

(Mattei et al., 2014) performed a large, multicenter population-based case-control study of lung cancer and solvent exposure in France. Cases were recruited from health care providers associated with French cancer registries. A total of 4,865 eligible cases (ages 18-75 years) of incident, histologically-confirmed lung cancer were identified between 2001 and 2007; of these, 3,357 living subjects were located and healthy enough to be interviewed, and 2,926 (87%) were willing to participate. Controls were selected by incidence density sampling and frequency-matched by age and gender. Investigators were able to contact 4,411 (94%) of 4,673 eligible controls and 3,555 (81%) agreed to participate. Analyses were based on 2,274 male and 622 female cases, and 2,780 male and 760 female controls. Exposure assessment employed standardized questionnaires administered by trained interviewers for collection of data regarding smoking history, sociodemographic characteristics, and lifetime occupational history (company, tasks, specific exposures). The only chlorinated solvent specifically listed in the questionnaire was trichloroethylene, although subjects could self-report other known exposures, such as PCE. A short-form questionnaire without the detailed job information was used for proxy interviews (5% of men and 3% of women). Job histories were mapped to a job-exposure matrix to classify solvent exposures by probability, intensity, frequency, and duration. Cumulative exposure indices were calculated as the product of probability, frequency, intensity, and duration for each job, and then categorized using deciles of the distribution in the control subjects. Lag times of 0, 5, and 10 years were analyzed. Covariates considered in the analyses included age at interview, location, smoking history (Comprehensive Smoking Index), number of jobs held, occupational exposure to asbestos, and in some cases, socioeconomic status.

Among controls, prevalence of lifetime exposure to chlorinated solvents was 8.5% for men and 2.1% for women (Mattei et al., 2014). The individual solvent with the highest prevalence of exposure was trichloroethylene (7.6% of male and 1.1% of female controls). Only 0.3% of male and 0.9% of female controls had any exposure to PCE, and almost all of these were exposed to other solvents as well. Men were exposed to PCE primarily as printers, while women were exposed primarily as launderers and dry cleaners. Trichloroethylene was the only individual solvent with a significant number of study subjects that were not exposed to any other chlorinated solvents. In order to elucidate effects of other solvents (such as PCE) individually, despite the multiple overlapping chemical exposures, the researchers performed stratified analysis of mutually exclusive multiple solvent exposures (*e.g.*, trichloroethylene

alone, versus trichloroethylene plus PCE, versus trichloroethylene plus PCE and methylene chloride, etc.).

After adjustment for covariates, including socioeconomic status, the OR for PCE comparing ever exposed to never exposed was 1.26 for men (95% CI = 0.87-1.82) based on 107 lung cancer cases and 94 controls with PCE exposure and 2.74 for women (95% CI = 1.23-6.09) based on 26 cases and 13 controls (Mattei et al., 2014). In analyses by cumulative PCE exposure (split into high and low groups based on median cumulative exposure), ORs for men were 1.14 in the low-dose group (95% CI = 0.67-1.94, 45 cases and 47 controls) and 1.36 in the high-dose group (95% CI = 0.84-2.22, 62 cases and 47 controls), while ORs for women were 3.80 in the low-dose group (95% CI = 1.41-10.24, 21 cases and 7 controls) and 1.43 in the high-dose group (95% CI = 0.37-5.50, 5 cases and 6 controls). In analyses stratified by overlapping exposure to multiple solvents, ORs were elevated for women exposed to PCE with trichloroethylene (2.39, 95% CI = 0.47 12.18, 6 cases and 3 controls) and with both trichloroethylene and methylene chloride (4.57, 95% CI = 1.14-18.34, 12 cases and 3 controls), but not those exposed to trichloroethylene alone (1.16, 95% CI = 0.64-2.11, 49 cases and 32 controls) or with methylene chloride (0.73, 95% CI = 0.29-1.87, 12 cases and 17 controls) or methylene chloride and chloroform and carbon tetrachloride (1.12, 95% CI = 0.31-4.08, 6 cases and 7 controls). In men, ORs were also higher in the PCE groups (OR = 1.28-1.32) than the others (OR = 0.79-0.95), although the difference was less pronounced than in women. These findings suggest an association between lung cancer and PCE exposure, but are limited by low prevalence of PCE exposure among study subjects.

(Ruder et al., 2013) conducted a population-based case-control study focused on the association between exposure to chlorinated aliphatic solvents, including PCE, and risk of glioma. Eligible participants were residents of non-metropolitan counties in the states of Iowa, Michigan, Minnesota, and Wisconsin who were diagnosed with glioma between 1995 and 1997 (cases) or were residents of the counties on January 1, 1995 (controls). Histologically-confirmed primary intracranial glioma cases were identified from neurosurgery offices and other participating health care facilities. A pool of candidate controls was established prior to case enrollment based on the age and sex distribution of glioma cases from an earlier time period, using state driver license records (ages 18-64 years) or Medicare data tapes (ages 65 80 years). Persons diagnosed with cancers other than glioma (20.6% of controls) were eligible to participate. Participants included 798 cases (91.5% of eligible cases) and 1,175 controls (70.4% of eligible controls). Interviews of cases (n=438), case next-of-kin (n=360), and controls (n=1,141) were performed to obtain occupational history. Standardized questionnaires were used to establish details (employer name, industry, job title, tasks, materials used, and employment frequency) of jobs held for at least 1 year between 16 years of age and 1992; the questionnaires asked explicit questions regarding exposures to solvents, thinners, glues, inks, varnishes, stains, and paint strippers. An industrial hygienist blinded to case status combined the job history information with the authors' exposure database (from published literature sources) to estimate probability, frequency, and intensity of exposure, as well as confidence in the probability and frequency of exposure. Cumulative exposures were estimated as the product of employment duration, employment frequency, exposure frequency, and exposure intensity. Analyses were adjusted for sex, age, and education. Sensitivity analyses were performed excluding cases with job history based on proxy questionnaires (to improve validity of the exposure estimates) or limiting the exposed group to those with high probability (>0.5) of exposure. Types of gliomas observed in cases included glioblastoma multiforme (equivalent to stage 4 glioma) (58%), astrocytoma (22%), oligodendroglioma (11%), and other (8%). A subset of participants agreed to provide blood samples for GST genotyping; these data were used to analyze the influence of GST on the association between glioma risk and chlorinated solvent exposure.

ORs for PCE exposure and glioma risk were <1.0 in all analyses, including: when all subjects were considered together (OR = 0.75, 95% CI = 0.62-0.91, 299 cases and 500 controls); when stratified by sex; when analyzed as "any" versus no exposure; when analyzed by cumulative exposure; when cases with proxy exposure data were excluded; and when exposed subjects were limited to those with high probability of exposure (Ruder et al., 2013). GST genotype did not influence the relationship between solvent exposure and glioma risk. Results were similarly negative for any chlorinated solvent and for the other solvents considered individually. In this study, the large proportion of case questionnaires completed by proxy (next of kin) is problematic, although excluding proxy interviews did not affect results. Potential memory impairment (induced by glioma) among cases who did complete the questionnaires may have affected exposure estimates in cases relative to controls. In addition, controls were older than cases, and thus had greater chance of higher exposure from working during earlier eras, and cases had slightly more education than controls, and therefore lower probability of solvent-related employment. These limitations would tend to bias the risk estimates toward the null.

(Neta et al., 2012) evaluated associations between solvent exposure and risk of glioma and meningioma in a hospital-based study. Cases were patients at one of four hospitals (referral centers for brain cancers in Massachusetts, Pennsylvania, and Arizona) who had received a histologically-confirmed diagnosis of primary glioma or other neuroepitheliomatous neoplasm or meningioma within the previous 8 weeks. A total of 484 cases of glioma (92% of eligible cases) and 197 cases of meningioma (94% of eligible cases) agreed to participate. Controls were patients at the same hospitals who were receiving treatment for non-cancer conditions. Controls were frequency matched on sex, age at interview, race/ethnicity, hospital, and residential proximity to the hospital. A total of 797 controls (86% of eligible subjects) agreed to participate. Trained interviewers administered questionnaires to patients (or a proxy if the patient was too ill or deceased) to document jobs in which the patients worked for at least 6 months after the age of 16 years; details included employer, dates of employment, job title, full or part time work status, type of business, tasks, and materials and equipment used. Proxy interviews were conducted for 16% (n=78) of glioma cases, 8% (n=15) of meningioma cases and 3% (n=23) of controls. When respondents indicated employment in jobs with chemical exposures, more detailed industry- or job-specific questions were asked to obtain information on frequency and duration of solvent-related tasks as well as other information pertaining to exposure (*e.g.*, potential for dermal exposure, sensory descriptions) or mitigation of exposure (engineering controls, personal protective equipment). Results were reviewed by expert industrial hygienists who identified incomplete or inconsistent answers; investigators followed up with supplementary subject phone interviews to resolve these discrepancies. Using the finalized job histories and exposure data from occupational health literature, industrial hygienists assigned exposure levels for six solvents including PCE. Analyses were adjusted for age at diagnosis, sex, race/ethnicity, hospital site, residential zone/proximity to hospital, and estimated cumulative occupational exposure to potential confounders: lead, magnetic fields, herbicides, and insecticides. Analyses by any/no exposure to a given solvent were also adjusted for exposure to other solvents. The investigators determined that adjustment for education and smoking did not result in changes to the effect estimates, so these covariates were not included in the final models. ORs comparing high to low exposure were also calculated (in addition to any/none) to control for potential unidentified differences between exposed and unexposed subjects. Finally, a lag time of 10 years was analyzed by excluding exposures in the 10 years prior to diagnosis.

The OR for glioma was 0.7 (95% CI = 0.5-0.9, 136 cases and 255 controls) for study subjects with "possible" exposure to PCE and 0.7 (95% CI = 0.3-1.6, 9 cases and 20 controls) for those with "probable" exposure (Neta et al., 2012). Results were similar when stratified by sex and various measures of exposure (years exposed, cumulative exposure, average weekly exposure, highest exposure). For meningioma, the ORs for "possible" and "probable" exposure were 0.9 (95% CI = 0.6-

1.3, 52 cases and 255 controls) and 0.5 (95% CI = 0.1-1.7, 3 cases and 20 controls), respectively, without adjustment for exposure to other solvents and 1.0 (95% CI = 0.5-2.2) and 0.3 (95% CI = 0.1-1.7), with the adjustment. Similarly, no clear associations were seen for the other solvents analyzed or for the solvents collectively. Because relatively few subjects had exposures characterized as high, the study had limited power to evaluate dose-response relationships (*e.g.*, only 10 controls and 3 glioma cases were classified as having high cumulative PCE exposure). The researchers noted that the complexity of use of these solvents, which have been used interchangeably and at times together, makes evaluation of specific exposures difficult. Exposure misclassification and potential memory impairment (induced by glioma) among cases would tend to bias the risk estimates toward the null.

(Carton et al., 2017) investigated the relationship between occupational solvent exposure and head and neck cancer in a case-control study in France. The final study group included 296 women with squamous cell carcinoma of the oral cavity, oropharynx, hypopharynx, or larynx and 775 controls. Incident cases were women aged 18-75 years at diagnosis between 2001 and 2007 identified from cancer registries in 10 geographic areas in France and whose cancers were histologically confirmed. Controls were chosen at random from the same geographic areas with age and sex distribution comparable to cases and distribution of socioeconomic status similar to the general population. Participation rate was 82.5% for cases and 80.6% for controls. Subjects were interviewed in person using a standardized questionnaire for detailed occupation history, residential history, and lifetime alcohol and tobacco consumption. Job-exposure matrices developed for the French population by the French Institute of Health Surveillance were used to estimate probability, intensity, and frequency of exposure to PCE and other solvents for each job held at least 1 month. The products of duration, probability, intensity, and frequency of exposure for each job were summed to give cumulative exposure, and cumulative exposure was divided by total duration of employment to calculate the mean intensity of exposure.

Controls smoked significantly less and drank alcohol significantly less than cases and were of significantly higher socioeconomic status (Carton et al., 2017). Age and geographic distributions differed significantly as well. Analyses were performed by unconditional logistic regression and adjusted for geographical area, age, smoking status (never smoker, former smoker, and current smoker), tobacco consumption in pack-years, and alcohol consumption in drink-years. Socioeconomic status, assessed by the last occupation held and by the longest held occupation, was included in preliminary models, but removed from the final models because it did not significantly affect results.

There was a significant association between “ever” exposed to PCE and head and neck cancer (OR = 2.97, 95% CI = 1.05-8.45), based on 10 cases and 13 controls (Carton et al., 2017). Of these, however, no cases and only 3 controls were exposed to PCE alone without other chlorinated solvents. The rest were exposed to PCE in combination with trichloroethylene (OR = 4.47, 95% CI = 1.27-15.8, 9 cases and 7 controls) or with trichloroethylene and methylene chloride (OR = 2.16, 95% CI = 0.19-24.1, 1 case and 3 controls). “Ever” exposed to trichloroethylene was also significantly associated with head and neck cancer (OR = 2.15, 95% CI = 1.21-3.81) based on many more subjects (38 cases and 60 controls). For “ever” exposed to trichloroethylene alone, the OR was 1.81 (95% CI = 0.81 4.04) based on 20 cases and 32 controls. The 10 cases “ever” exposed to PCE (with trichloroethylene and/or methylene chloride) included 1 oral cavity (OR = 0.98, 95% CI = 0.11-8.47), 5 oropharynx (OR = 3.43, 95% CI = 1.01-11.8), 0 hypopharynx, and 4 larynx (OR = 7.95, 95% CI = 1.92-32.9). The 38 trichloroethylene cases were split primarily between oral cavity (12 cases, OR = 2.12, 95% CI = 0.97-4.60), oropharynx (13 cases, OR = 1.66, 95% CI = 0.78-3.54), and larynx (10 cases, OR = 3.80, 95% CI = 1.55-9.32). There was no association between duration, mean intensity of exposure, or cumulative exposure index for PCE and head and neck cancer. There was a small significant relationship between

mean intensity of trichloroethylene exposure and head and neck cancer (OR = 1.30, 95% CI = 1.01-1.66). These results suggest a relationship between trichloroethylene and head and neck cancer. The apparent relationship for "ever" exposed to PCE may reflect co-exposure to trichloroethylene.

A companion analysis of head and neck cancers in men was performed as part of the same study (Barul et al., 2017). Methods were the same as reported by (Carton et al., 2017). The analysis included a total of 1,857 cases and 2,780 controls. As for the women, cases smoked more than controls and had higher alcohol consumption. There was no relationship between "ever" exposed to PCE and head and neck cancer in men (OR = 1.04, 95% CI = 0.69-1.59, 70 cases/89 controls). Analysis based on cumulative PCE exposure, however, showed an OR of 1.81 (95% CI = 0.68-4.82, 14 cases/11 controls) for head and neck cancer risk in the high-exposure that was traced to a significant increase in laryngeal cancer in this group (OR = 3.86, 95% CI = 1.30-11.48, 8 cases). All subjects exposed to PCE were exposed to other chlorinated solvents as well, primarily trichloroethylene. In contrast to the results in women, however, there was no evidence in the men of an association between trichloroethylene exposure and laryngeal cancer or head and neck cancers more broadly.

(Talibov et al., 2014) studied occurrence of acute myeloid leukemia (AML) relative to occupational solvent exposure in a large population-based case-control study in four Nordic countries. The study population comprised a subset of the NOCCA (Nordic Occupational Cancer Study) cohort of 14.9 million individuals from Finland, Iceland, Norway, Denmark, and Sweden who participated in population censuses in 1960, 1970, 1980/1981, and/or 1990. For this study, all incident AML cases diagnosed from 1961 to 2005 were extracted from the NOCCA cohort (the researchers did not have access to individual records from Denmark, so those data were not included). Cases included in the study were at least 20 years of age at diagnosis and had occupational information from at least one census record (n=14,982). Five controls were randomly selected per case, matched for year of birth, sex, and country (n=74,505). Controls were alive and free from AML on the date of diagnosis of the case. Cases and controls could have a history of any cancer other than AML. Occupational exposures to solvents were estimated based on the NOCCA job exposure matrix (developed by national experts from the Nordic countries), which characterizes proportion of exposed (P) and mean level of exposure for exposed persons (L) for 29 exposure agents in 300 specific occupations over 4 time periods from 1945 to 1994, but does not account for heterogeneity of exposure within an occupation (*e.g.*, with tasks performed or workplace). Cumulative exposure for each subject was calculated by multiplying employment period (T) in years by P × L for each job held and summing the products over their working career (assumed to be ages 20-65 years), based on occupational codes in census records for each subject. The census records provide snapshots in time, but do not provide a complete picture of work history; for this study, it was assumed that when occupation changed from one census to the next that the change occurred in the middle of the time period between censuses. Exposures in the 10 years prior to diagnosis were not counted (alternative lag times of 0, 3, 5, 7, and 20 years were also used, but these data were not shown). Subjects were split into low (0-50th percentile), moderate (50-90th percentile), and high (>90th percentile) cumulative exposure groups in the analysis for each agent. Unexposed subjects served as the reference group, although these data were not shown. Conditional logistic regression was used to estimate HRs. Models included adjustment for exposure to other solvents and also ionizing radiation and formaldehyde. The models did not adjust for suspected lifestyle (*e.g.*, smoking) or genetic risk factors because that information was not available for study subjects.

No significant association was found between PCE exposure and AML (Talibov et al., 2014). HRs in the low (>0-<12.1 ppm/year), medium (12.1-106 ppm/year), and high (>106 ppm/year) cumulative exposure groups were 1.07 (95% CI = 0.83-1.38, 89 cases/472 controls), 0.83 (95% CI = 0.61-1.12, 67 cases/381 controls), and 0.72 (95% CI = 0.39-1.34, 16 cases/96 controls), respectively, and the p-level for dose-

response trend was 0.39. There were also no significant findings for other solvents in this study, including benzene, which has shown evidence of a positive association in other studies. The HR for AML risk high cumulative exposure to toluene was 1.35 (95% CI = 0.74-2.46, 76 cases/400 controls). Although the study included a large number of subjects, the low prevalence of occupational exposure to solvents in general, and PCE in particular, limits confidence in these results.

A similar study was performed by (Vlaanderen et al., 2013) to investigate the association between solvent exposure and NHL, MM, and kidney and liver cancer in a subset of the NOCCA cohort. For this study, incident cases of NHL, MM, kidney and liver cancer were extracted from the cohort, which included all NOCCA subjects aged 30-64 years who participated in the 1960, 1970, 1980-1981, and/or 1990 census in Finland, Iceland, Norway, or Sweden and were still alive on January 1 of the year following the census. The study included 76,130 kidney cancer cases, 23,896 liver cancer cases, 69,254 NHL cases, and 35,534 MM cases. For each case, five controls were randomly selected from all cohort members alive and cancer free at the time of diagnosis of the case, matched for age, sex, and country. Occupational exposures to solvents were estimated based on the NOCCA job exposure matrix, as described above. Cumulative exposure was calculated by adding annual exposures, starting at age 20 years or start of working career, whichever occurred later, and ending at incidence date of case or at age 65 years, whichever occurred first. For this study, it was assumed that individuals continued in the same occupation reported in the census until the calendar year in which the census was updated, and that workers had worked in the job they reported in the first census since age of entry into the cohort (30 years). Conditional logistic regression was used to estimate HRs. For analysis, subjects were split into tertiles with approximately equal numbers of exposed controls based on cumulative exposure. Alternatively, high-exposure groups were defined based on 90th percentile of cumulative exposure or 90th percentile of average intensity × prevalence of exposure (calculated by dividing cumulative exposure by duration of exposure). Unexposed subjects served as the reference group in all analyses, although these data were not shown. Pearson correlation coefficients were calculated to describe the association between potential confounding exposures between agents (solvents and ionizing radiation). The models did not adjust for lifestyle (*e.g.*, smoking, alcohol intake) risk factors because that information was not available for study subjects. Model fit was not affected by lagging calculation of cumulative exposure by 0, 1, 5, 10, or 20 years, so unlagged results were presented.

In the analysis by tertiles of cumulative exposure, no significant associations were found between first, second, or third tertile of cumulative exposure to PCE and NHL, MM, or liver or kidney cancer in men, women, or both sexes combined (Vlaanderen et al., 2013). In the analysis of high-exposure groups, significant or near significant associations were found for NHL in men (HR = 1.54, 95% CI = 0.99-2.42 based on 25 cases using the cumulative exposure metric; HR = 1.74, 95% CI = 1.15-2.64 based on 30 cases using the average intensity × prevalence metric), but not in women (HR = 0.94, 95% CI = 0.74-1.20 based on 77 cases using the cumulative exposure metric; HR = 1.12, 95% CI = 0.88-1.42 based on 83 cases using the average intensity × prevalence metric). Using the PCE exposure measure of intensity x prevalence, the HR (both sexes) for liver cancer is 1.26 (95^{th} CI: 0.88-1.80) and the HR for MM is 1.18 (95^{th} CI: 0.87-1.59). Among the other agents analyzed, slight associations were noted between ionizing radiation and liver cancer and MM and between benzene and liver cancer. Although PCE exposure in this study was correlated with exposure to trichloroethylene and other chlorinated solvents (no tumor associations found for these agents), it was not correlated with exposure to ionizing radiation or benzene. These results suggest an association between exposure to PCE and NHL in men, and possibly to MM and liver cancer as well, although those data are much weaker. As in the previously described study, the low prevalence of occupational exposure to PCE is a limiting factor for this study.

In another case-control study based on the NOCCA cohort, (Hadkhale et al., 2017) studied the potential link between solvent exposure and bladder cancer. All incident cases of bladder cancer were extracted from the NOCCA cohort, and persons with a minimum age of 20 years at diagnosis and having occupation information from at least one census record before diagnosis were included in the study. Five controls were randomly selected for each case from among individuals alive and free from bladder cancer at the date of diagnosis of the case, matched by birth year and sex. Cases and controls could have a history of any cancer type other than bladder cancer. A total of 113,343 cases and 566,715 controls were included. Occupational exposures to solvents were estimated based on the NOCCA job exposure matrix, as described above. Exposure was assumed to start at the age of 20 years and end at the date of diagnosis or at 65 years, whichever occurred first. If there were different occupational codes in the census records for a given person, the individual was assumed to have changed occupations at the mid-point between two known census years. Cumulative exposure was estimated by summing annual exposure estimates for the entire employment period. In addition to organic solvents, other exposures assessed were ionizing radiation, asbestos, benzo[a]pyrene, diesel engine exhaust, and sulfur dioxide, all considered to be potential confounders. Subjects were split into low (0-50th percentile), moderate (50-90th percentile), and high (>90th percentile) cumulative exposure groups in the analysis for each agent, which was performed by conditional logistic regression. Unexposed subjects served as the reference group. Exposures in the 10 years prior to diagnosis were not counted (lag times of 0 or 20 years were also performed, but these results were not presented). Models were adjusted for exposure to other solvents and agents, but not nonoccupational risk factors (*e.g.*, smoking, alcohol consumption) because that information was not available for study subjects.

HRs for bladder cancer in the low (>0<13.6 ppm/year), medium (13.6-87.55 ppm/year), and high (>87.5 ppm/year) cumulative PCE exposure groups were 1.00 (95% CI = 0.92-1.09, 747 cases/3,560 controls), 1.12 (95% CI = 1.02-1.23, 660 cases/2,783 controls), and 0.94 (95% CI = 0.73-1.22, 159 cases/702 controls), respectively, and the p-level for dose-response trend was 0.10 (Hadkhale et al., 2017). These results show a slight significant increase in risk of bladder cancer in the medium PCE exposure category, but no increase in the high-exposure group and no significant dose-related trend, suggesting a cause other than PCE exposure for the slight association observed in the medium-exposure group. Bladder cancer risks were significantly elevated in the high-exposure groups for trichloroethylene, benzene, toluene, and ionizing radiation. Although the models included adjustment for co-exposure to other agents, the researchers noted the difficulty of disentangling the effects of PCE and trichloroethylene (structurally similar chemicals with overlapping uses) using the available data. There were approximately 5 times more cases with trichloroethylene exposure than PCE exposure.

(Morales-Suárez-Varela et al., 2013) studied the potential association between occupational solvent exposure and mycosis fungoides (MF, the most common form of cutaneous T-cell lymphoma, a heterogenous group of NHL). Cases were patients aged 35 to 69 years diagnosed with MF in 25 selected areas from six European countries between January 1, 1995, and June 30, 1997. Of 118 pathologically-confirmed cases, 100 agreed to be interviewed for this study (85% participation rate). Population controls were randomly selected from the same areas as cases, frequency matched by sex and age. The study was part of a larger study of seven cancers: MF, gall bladder, small intestine, bone, eye melanoma, thymus, and breast cancer. The controls served as a common pool of controls for all seven groups of cancer cases included in the larger study. In all, 4,629 eligible controls were identified and 3,156 were interviewed (participation rate = 68%). For the MF study, only controls in the strata defined by age and study area where at least one MF case was diagnosed were included (2,846 controls, including 1,957 men and 889 women). Due to illness, 4 case and 95 control interviews were conducted with surrogates. Interviews were performed using standardized questionnaires that included questions on lifestyle factors (smoking, alcohol consumption, etc.) and lifelong occupational history, including details regarding

specific tasks performed, products used, etc. Occupational exposures to solvents were assessed for each job held over 6 months using a job exposure matrix developed by the French Institute of Health Surveillance, which provided semiquantitative indicators of exposure probability, frequency, and intensity for each solvent and occupation. A cumulative exposure score for each solvent was calculated for each study subject as the sum of the job-specific exposure scores over his or her lifetime job history. Subjects were split into high- and low-exposure groups based on median cumulative exposure in the analysis for each agent. Unexposed subjects served as the reference group. The analysis was conducted by unconditional logistic regression, with adjustments for age, sex, country, smoking habit, alcohol intake, body mass index, and level of education. No adjustment for co-exposure to other chemicals was noted. Alternative analyses were performed introducing lag times of 5, 10, or 15 years and excluding jobs with low probability of exposure, but these were not shown because they did not affect findings.

For PCE, the results suggested a significant elevation of MF risk in high-dose women (OR = 11.38, 95% CI = 1.04-124.85), but this finding is highly uncertain, as indicated by the extremely wide confidence interval, because it is based on only 2 cases (Morales-Suárez-Varela et al., 2013). There were no female cases with low-dose exposure to PCE. Among men, there were 2 cases with low-dose exposure (OR = 1.80, 95% CI = 0.22-14.80) and 2 with high-dose exposure (OR = 1.60, 95% CI = 0.30-13.60). The low prevalence of PCE exposure and small number of cases in this study limit interpretation of these findings.

(Purdue et al., 2017) conducted an analysis for associations between exposure to PCE and other chlorinated solvents and kidney cancer within the U.S. Kidney Cancer Study, a population-based case-control study conducted in Detroit, Michigan and Chicago, Illinois. Cases were histologically confirmed incident kidney cancer newly diagnosed in Detroit from February 2002 until July 2006 (white cases) or January 2007 (black cases) and in Chicago during 2003. Eligible controls in both locations were selected from the general population, frequency matched to cases based on sex, age (5-year intervals), and race. The study was designed to maximize the number of black participants. Controls were frequency matched to cases at a 2:1 ratio for blacks and a 1:1 ratio for whites. A total of 1,217 cases (77% of the 1,571 that the researchers attempted to recruit) and 1,235 controls (54% of the 2,269 that the researchers attempted to recruit) participated in the study. Copies of medical records were obtained for all cases to confirm the kidney cancer diagnosis, and the original diagnostic slides were obtained for 706 cases for review by an experienced pathologist. Participants were interviewed for a wide variety of topics including work history for all jobs held for at least 12 months starting at age 16 years. For selected occupations, detailed histories were collected related to solvent exposures.

Job and task exposure matrices were developed for each of the six solvents included in the study by an industrial hygienist using information from a systematic review of the industrial hygiene literature (Purdue et al., 2017). Using the literature review, the exposure matrices, the occupational histories, and the information collected in the job modules, the industrial hygienist assessed levels of exposure probability, frequency, and intensity for each chlorinated solvent for each job. The job-specific estimates of probability, frequency, and intensity for each participant were integrated to develop metrics of exposure for each participant for each chlorinated solvent, including duration of exposure (sum of number of years worked at each job across all jobs with exposure probability ≥50%), cumulative hours exposed (sum of the product of the job-specific frequency midpoint and the job duration in weeks across all jobs with an exposure probability ≥50%), and average weekly exposure (cumulative hours exposed divided by the duration of exposure in weeks).

For the analysis, solvent exposures were split into tertiles among exposed controls, and unexposed participants were used as referents (Purdue et al., 2017). Unconditional logistic regression modelling

was performed, including adjustment for location, age, race, sex, education, smoking history, body mass index, and self-reported history of hypertension. Additional analyses incorporated 5- or 15-year exposure lags, restricted participants to individuals with high confidence of exposure, or excluded participants with ≥50% probability of exposure to trichloroethylene.

Prevalence of PCE exposure was low, with <4% of cases and controls assessed as having exposure probability ≥50% (Purdue et al., 2017). Prevalence of exposure was low for other solvents as well, including trichloroethylene. The most common tasks associated with PCE exposure were degreasing and dry cleaning, accounting for 41% and 32% of exposures, respectively. Degreasing also accounted for most exposures to trichloroethylene, carbon tetrachloride, and 1,1,1-trichloroethane. In analyses among controls, after excluding participants unexposed to any chlorinated solvent, solvent exposure probabilities were moderately correlated with one another.

No significant association was found between kidney cancer risk and probability of exposure to PCE (*e.g.,* OR = 1.2, 95% CI = 0.6-2.3, 22 cases/16 controls for those with probability of exposure ≥90%) or PCE exposure duration (*e.g.,* OR = 1.1, 95% CI = 0.5-2.5, 13 cases/11 controls for those exposed ≥10 years), average weekly exposure (*e.g.,* OR = 1.1, 95% CI = 0.4-3.1, 11 cases/14 controls for those exposed >15 hours/week), or cumulative hours of exposure (*e.g.,* OR = 0.9, 95% CI = 0.3-3.3, 8 cases/11 controls for those in highest tertile) for those with ≥50% probability of exposure (Purdue et al., 2017). When the analysis was restricted to those with high-intensity exposure to PCE, however, there was a statistically significant increase in kidney cancer risk for those in the highest tertile of cumulative hours exposed (OR = 3.1, 95% CI = 1.3-7.4, 14 cases/8 controls, Ptrend = 0.03). This relationship was also seen in additional analyses that incorporated 5-year (OR = 3.5, 95% CI = 1.3 10.0, Ptrend = 0.03) or 15-year (OR = 6.2, 95% CI = 1.8-21.3, Ptrend = 0.003) exposure lag periods, included only jobs assigned an exposure probability with high confidence (OR = 5.1, 95% CI = 1.5-7.2, Ptrend = 0.12), or excluded participants with ≥50% probability of exposure to trichloroethylene (OR = 3.0, 95% CI = 0.99-9.0, 17 cases/14 controls, Ptrend = 0.08). Similar analyses performed for trichloroethylene found no significant associations or exposure-response trends, although an OR of 1.7 (95% CI = 0.8-3.8, 18 cases and 8 controls, Ptrend = 0.28) for kidney cancer risk was seen in the high tertile of cumulative hours exposed among those with high-intensity exposure to trichloroethylene.

This study found no evidence of association between kidney cancer risk and exposure to chlorinated solvents other than PCE and trichloroethylene, and only limited evidence for trichloroethylene (Purdue et al., 2017). High exposure to PCE, however, was associated with kidney cancer, and the result was independent of exposure to trichloroethylene.

Heck et al. (2013) conducted an exploratory study of exposure to air toxics during pregnancy in relation to risk of neuroblastoma in offspring. Cases of neuroblastoma among California residents younger than 6 years old, born and diagnosed between 1990 and 2007, and listed in the California Cancer Registry were matched to California birth certificates using first and last names and date of birth (89% matching rate). Controls, frequency matched by year of birth to all childhood cancer cases for the same time period, were randomly selected from California birth records of children who had no cancer diagnosis before the age of 6 years and matched to California death records to exclude those (n=1,522) who died of other causes prior to the age of 6. Birth address, as listed on the birth certificate, was used to estimate exposure to air toxics, including PCE, based on distance from each address to monitors in California's air toxics monitoring network (39 air monitors across the state, primarily positioned near heavily trafficked highways, industrial areas, and agriculturally intense rural regions) and measurements made at the nearest monitor to each residence, which were used to calculate average exposures for each trimester and the entire pregnancy period for each participant using date of birth and gestational age obtained

from the birth certificate. The study included a total of 75 cases and 14,602 controls who lived within 5 km of a monitor and had measurement values for at least one pollutant. Unconditional logistic regression was used to calculate ORs and CIs, adjusted for mother's age, mother's race, birth year, and method of payment for prenatal care (proxy for family income). No increase in risk of neuroblastoma was seen with PCE exposure for cases within 5 km of a monitor (OR = 1.06, 95% CI = 0.84-1.33, 67 cases/12,041 controls) or within 2.5 km of a monitor (OR = 1.01, 95% CI = 0.62-1.64, 21 cases/3,635 controls).

(Bulka et al., 2016) looked at spatial patterns of diffuse large B-cell lymphoma (DLBCL) incidence in relation to residential proximity to toxic release sites in Georgia. The Georgia Comprehensive Cancer Registry was used to identify all DLBCL cases in adults (≥20 years) residing in Georgia at diagnosis during 1999-2008. Subjects without age, sex, or race information were excluded from the analysis. Included cases (n=3581) were aggregated by census tract, and standardized incidence ratios (SIR) were calculated for each tract by dividing the number of observed cases by expected cases, derived by standardizing DLBCL incidence rates from Georgia to national DLBCL incidence rates by age, sex, and race. GIS (geographic information system) software was used to examine the spatial distribution of TRI (Toxics Release Inventory) sites and SIRs by census tract. From 1988 to 1998, Georgia facilities reported the release of PCE at 33 TRI sites, with releases ranging from 5 to 1,575,644 lb. TRI sites for the other chemicals studied ranged from 3 to 86 sites. The study found that relative risk of DLBCL decreased as mean distance to TRI sites increased for TRI sites for most (8/9) of the contaminants studied, including PCE. The strongest such relationship was found for formaldehyde, which showed a 0.58% decrease in DLBCL risk for every mile of increase in distance to release site. For PCE, the decrease in risk was 0.27% per mile. The effect of mean distance on DLBCL incidence from all of the release sites was strongest for African Americans. Quantity of chemicals released was not included in the analysis.

G.2 Animal Studies

In a 2-year inhalation study by (NTP, 1986a), F344/N rats were exposed to PCE vapors at 0, 200, or 400 ppm for 6 hours/day, 5 days/week for 103 weeks. The incidence of mononuclear cell leukemia (MCL) showed a positive trend in males (control: 28/50, 200 ppm: 37/50, 400 ppm: 37/50) and females (control: 18/50, 200 ppm: 30/50, 400 ppm: 29/50), with a dose-related increase in severity of MCL in both sexes. In addition, the time to onset was decreased in exposed females, compared to controls. When only advanced (stage 3) MCL was considered, the incidence was statistically significantly increased in male and female rats exposed to 400 ppm (males - control: 20/50, 200 ppm: 24/50, 400 ppm: 27/50; females - control: 10/50, 200 ppm: 18/50, 400 ppm: 21/50). The incidence of testicular interstitial cell tumors was increased in exposed male rats, with a statistically significant positive trend (control: 35/50, 200 ppm: 39/49, 400 ppm: 41/50). Renal tubular cell hyperplasia was observed in exposed male rats (control: 0/49, 200 ppm: 3/49, 400 ppm: 5/50) and in one treated female rat (1/50 at 400 ppm only), and renal tubular adenomas and adenocarcinomas were observed in males (combined incidence - control: 1/49, 200 ppm: 3/49, 400 ppm: 4/50) but not females. Although the increase in kidney tumors was not statistically significant, renal tubular carcinomas are considered rare in this strain of rat and (U.S. EPA, 2012c) concluded that a dose-response relationship is apparent when the combined incidence of proliferative and neoplastic lesions was considered in combination with tumor severity. There was an increase in brain gliomas observed in males (control: 1/50, 200 ppm: 0/50, 400 ppm: 4/50). While the increase did not achieve statistical significance, it was considered to be biologically significant because the incidence of this rare tumor above the historical control range. The significance of the brain glioma findings is supported by the earlier occurrence of brain tumors in exposed animals (week 88 in males, week 75 in females), compared to controls (week 99 in males, week 104 in females) (U.S. EPA, 2012c).

In the same study by (NTP, 1986a), B6C3F1 mice were exposed to concentrations of PCE of 100 or 200 ppm for 6 hours/day, 5 days/week for 103 weeks. Statistically significant dose-related increases were observed in the incidence of hepatocellular carcinoma (males - control: 7/49, 100 ppm: 25/49, 200 ppm: 26/50; females - control: 1/48, 100 ppm: 13/50, 200 ppm: 36/50) and combined incidence of hepatocellular adenomas or carcinomas in male and female mice (males - control: 17/49, 100 ppm: 31/49, 200 ppm: 41/50; females - control: 4/48, 100 ppm: 17/50, 200 ppm: 38/50). The incidences of hepatocellular carcinoma and hepatocellular adenomas or carcinomas combined were significantly increased, compared to controls, at both 100 and 200 ppm in males and females. In several instances, hepatocellular carcinomas metastasized to the lungs in males (control: 2/49, 100 ppm: 7/49, 200 ppm: 1/50) and females (control: 0/48, 100 ppm: 2/50, 200 ppm: 7/50).

In a 2-year inhalation study conducted by (Jisa, 1993), F344/DuCrj rats were exposed to PCE vapors at 0, 50, 200, or 600 ppm. A statistically significant dose-related increase (statistical analysis by statistical analysis by statistical analysis by statistical analysis by U.S. EPA, 2012c) was observed in the incidence of MCL in males (control: 11/50, 50 ppm: 14/50, 200 ppm: 22/50, 600 ppm: 27/50) and females (control: 10/50, 50 ppm: 17/50, 200 ppm: 16/50, 600 ppm: 19/50). The increase in MCL incidence achieved statistical significance in males exposed to 600 ppm, compared to control males. The time to first occurrence of MCL was decreased in exposed female rats (weeks 66-74 in exposed groups) compared to control female rats (week 100). Also, there was a dose-related increase in the overall number of unscheduled deaths attributed to MCL in males and females.

(Jisa, 1993) also exposed Crj:BDF1 mice to PCE at 0, 10, 50, or 250 ppm for 6 hours/day, 5 days/week for 104 weeks. Dose-related increases in the incidences of hepatocellular adenomas (males - control: 7/50, 10 ppm: 13/50, 50 ppm: 8/50, 250 ppm: 26/50; females - control: 3/50, 10 ppm: 3/47, 50 ppm: 7/49, 250 ppm: 26/49), hepatocellular carcinomas (males - control: 7/50, 10 ppm: 8/50, 50 ppm: 12/50, 250 ppm: 25/50; females - control: 0/50, 10 ppm: 0/47, 50 ppm: 0/49, 250 ppm: 14/49), and combined hepatocellular adenomas or carcinomas were observed in males and females (males - control: 13/50, 10 ppm: 21/50, 50 ppm: 19/50, 250 ppm: 40/50; females - control: 3/50, 10 ppm: 3/47, 50 ppm: 7/49, 250 ppm: 33/49). The incidences of hepatocellular adenoma, hepatocellular carcinoma, and combined hepatocellular adenoma or carcinoma were statistically significantly increased at 250 ppm, relative to controls, in both sexes. A small increase in liver and spleen hemangiosarcomas (reported as malignant hemangioendotheliomas) was also observed in treated male mice (liver - control: 1/50, 10 ppm: 1/50, 50 ppm: 5/50, 250 ppm: 5/50; spleen - control: 1/50, 10 ppm: 1/50, 50 ppm: 3/50, 250 pm: 5/50). The combined incidence of hemangiosarcomas or hemangiomas (reported as malignant or benign hemangioendotheliomas, respectively) occurring in the liver, spleen, fat, subcutaneous skin, and heart was statistically significantly increased in male mice (combined incidence - control: 4/50, 10 ppm: 2/50, 50 ppm: 7/50, 250 ppm: 11/50) (analysis by (U.S. EPA, 2012c)). In addition, there was a statistically significant positive dose-related trend in the incidence of adenoma of the Harderian gland in male mice (control: 2/50, 10 ppm: 2/50, 50 ppm: 2/50, 250 ppm: 8/50).

In a lifetime bioassay by (Nci, 1977), Osborne-Mendel rats were administered PCE for 78 weeks via gavage in corn oil for 5 days/week, followed by a 32-week observation period. Dose adjustments were made throughout the exposure period depending upon the tolerance of treated animals to the existing dose level. Administered doses were 500-700 mg/kg-day in the low dose and 1,000-1,400 mg/kg-day in the high-dose males, with 7 dose-free weeks occurring intermittently during the last 33 weeks of exposure. Time-weighted average (TWA) doses during the 78-week treatment period were approximately 470 mg/kg-day at the low dose and approximately 950 mg/kg-day at the high dose. Rats showed no significant treatment-related increases in neoplastic lesions, compared to controls, and there were no significant positive dose-related trends. A high rate of early death was observed in treated rats. At the high dose, mortality was 50% in males by week 44 and in females by week 66. Respiratory

disease and pneumonia were observed in both treated and control rats, while toxic nephropathy occurred only in treated animals (males - low dose: 43/49, high dose: 47/50; females - low dose: 29/50, high dose: 39/50). Due to the high rate of early death in treated rats, (Nci, 1977) determined that the carcinogenicity of PCE in rats could not be evaluated from the results of this study.

(Nci, 1977) also exposed B6C3F1 mice to PCE by gavage in corn oil for 78 weeks (5 days/week), followed by a 12-week observation period. Male mice were administered 450 or 900 mg/kg-day for the first 11 weeks, after which the doses were increased to 550 or 1,100 mg/kg-day, respectively, for the next 67 weeks. Female mice received 300 or 600 mg/kg-day during the first 11 weeks, and doses were increased to 400 or 800 mg/kg-day, respectively, for the subsequent 67 weeks. The TWA doses (5 days/week for 78 weeks) were 536 and 1,072 mg/kg-day for males and 386 and 772 mg/kg-day for females. The incidence of hepatocellular carcinoma was statistically significantly increased in treated male and female mice of both dose groups, compared with controls (males - untreated control: 2/17, vehicle control: 2/20, 536 mg/kg-day: 32/49, 1,072 mg/kg-day: 27/48; females - untreated control: 2/20, vehicle control: 0/20, 386 mg/kg-day: 19/48, 772 mg/kg-day: 19/48); the time to first tumor was also decreased in treated mice (weeks 27-40 in males, weeks 41-50 in females) compared to controls (weeks 90-91 in males, week 91 in females). Metastasis of hepatocellular carcinomas to the lung was observed in 3/49 low-dose males, 1/49 low-dose females, and 1/48 high-dose females.

Appendix H Evidence Synthesis and Integration of Immunological and Hematological Endpoints

Table_Apx H-1. Synthesis of Epidemiological Study Evidence on Immunological and Hematological Effects

Endpoint; sex	Results (OR/RR/ SIR[d] and 95[th] CI in parentheses if identified)	Important study characteristics	Study Confidence Rating	Reference	Type of immunotoxicity[a]
Multiple immune measures; males [a]	Increased IgE, total WBC, total lymphocytic counts, T lymphocytes (CD4+, CD8+), natural killer (CD3+ CD16CD56+) cells, B (CD19+) lymphocytes No difference in eosinophils, monocytes, platelets, CD3+ lymphocyte subpopulations, interferon-gamma	Exposure measure: PCE in air	High	Emara et al. (2010)	Immune measures Allergy Hematology
Multiple immune measures; females	Increased saliva IgA, serum complement C3 and C4 compared with unexposed administrators; decreased T-lymphocytes, higher phagocytic activity and higher C3 levels compared with the regional reference controls	Exposed group: Dry cleaning workers Control groups: administrators from same plant and regional reference values		Andrys et al. (1997)	Immune measures
Multiple immune measures; female/male neonates	Decreased percent IFN-y type 1 T cells; decreased Th1 cytokines IFN-y, tumor necrosis factor-alpha, IL-2; no effects on IL-4	Exposure measure: four weeks of monitoring in children's bedrooms <75%ile compared with > 75%ile		Lehmann et al. (2002)	Immune measures
Multiple immune measures; female/male 3-yr olds	No differences in either reduced IFN-y+CD8+Tcells or in enhanced IL4+CD3+Tcells between < 75[th] percentile and > 75[th] percentile PCE exposures, as measured in the children's bedrooms. ORs for egg white and milk sensitization were 0.6 and 1.8, respectively.	Exposure measure: four weeks of monitoring in children's bedrooms <75%ile compared with > 75%ile		Lehmann et al. (2001)	Immune measures

Sjorgen's syndrome; males/females	OR: 2.64 (1.20-5.77) semiquantitative/job matrix measure 4.07 (0.74 – 22.45) for cumulative exposure	Exposure measure: semi-quantitative exposure informed by job duties; Controls:	Medium	Chaigne et al. (2015)	Autoimmunity
Connective tissue diseases; sex not stated [b]	Higher frequency of systemic sclerosis associated with self-reported PCE exposure and among dry cleaning employees ($p < 0.001$ for both exposure measures); not observed for other connective tissue diseases	Case-control study; Exposure measure: self-reported PCE exposure and employment in dry cleaning both used as exposure measures	N/A	Goldman (1996)	Autoimmunity
Rheumatoid arthritis (RA); males/females	No increase in SIR for hospitalizations SIR: 1.0 (females) SIR: 0.8 (males)	SIRs calculated for first hospitalizations for RA; Exposure measure: dry-cleaning and laundry work; three census cohorts (1960, 1970, 1980)	N/A	Li et al. (2008)	Autoimmunity
RA and related diseases; males/females [c]	RR for RA: Females: 1.5 (95% CI: 0.7-3.2) Males: 0.8 (0.1-5.0); increased RRs not reported for other related diseases	RRs calculated for hospitalizations for RA; Exposure measure: launderers/dry cleaners in the same occupation in 1960 and 1970 censuses	N/A	Lundberg et al. (1994)	Autoimmunity
Undifferentiated connective tissue disease (UCTD); females	OR: 1.38 (0.68-2.78) for UTCD, adjusted for age and year of birth OR: 0.0 for PCE exposure measures	Exposure measure: working in dry cleaning; PCE exposure measures	N/A	Lacey et al. (1999)	Autoimmunity
Systemic sclerosis; females	OR: 1.4 (0.9-2.2) for dry cleaners; OR: 1.4 (0.6-3.4) self-reported PCE exposure; OR: 1.1 (0.4-2.9) expert identified exposures	Exposure measure: dry-cleaning workers, self-reported PCE exposure, expert-identified PCE exposure	N/A	Garabrant et al. (2003)	Autoimmunity
Anti-neutrophil cytoplasmic antibody	OR: 2.0 (0.6-6.9)	Case-control study	N/A	Beaudreuil et al. (2005)	Autoimmunity

(ANCA) related disease; males/females		Exposure measure: semi-quantitative PCE exposure score			
Systemic sclerosis	OR: 2.03 (0.44-9.27) with PCE exposure	Meta-analysis of 14 case-control studies (6 with TCE and/or PCE exposure analysis). PCE studies included 714 cases and 2479 controls. Proportion of subjects exposed to solvents occupationally	Medium	Zhao et al. (2016)	Autoimmunity
Acute asthma symptoms; males/females	OR: 1.13 (0.64-2.01) for bothersome asthma for *geometric mean* breath concentrations of PCE [no covariates in the model] OR: breath - 1.07 (0.51-2.25); ambient – 1.94 (0.80, 4.70) (model that controlled for respiratory infection and temperature)	24 pediatric subjects; Exposure measure: Exhaled breath and ambient concentrations of PCE	N/A	Delfino et al. (2003b)	Allergy
Acute asthma symptoms; peak expiratory flow (PEF); males/females	No significant associations with PEF; OR: 1.37 (1.09-1.71) for asthma symptom score > 1 and PCE in a single pollutant model (not controlling for other chemicals) but the association was reduced after adjustment for SO_2 or NO_2.	Hispanic schoolchildren with asthma (aged 10-15 years) Exposure measure:	N/A	Delfino et al. (2003a)	Allergy

[a] Most closely associated with measurements of the identified immunotoxicity endpoints; endpoints could also be associated with other immunotoxicity endpoints.
[b] Systemic lupus erythematosus, rheumatoid arthritis, dermatomyositis/polymyositis, mixed connective tissue disease, Sjogren's syndrome
c Mb Betherew, systemic lupus erythematodes, vasculitis, systemic sclerosis, myositis, rheumatoid arthritis.
d OR = odds ratio; RR = relative risk; SIR = standardized incidence ratio

Table_Apx H-2. Synthesis of In Vivo Animal Evidence on Immunological and Hematological Effects

Animal Evidence							
Species	**Exposure Route**	**Doses/ Concentration**	**Duration**	**NOAEL[a]**	**Effect**	**Study Confidence Rating**	**Reference**
Mouse (MRL/MpL); female [strain is susceptible to autoimmune diseases]	Drinking water	0.5 mg/ml (~ 100 ppm in air; 96 mg/kg-bw orally)	12, 18 or 24 wks	LOAEL = 0.5 mg/ml	Increased serum anti-nuclear, anti-dsDNA and anti-scleroderma 70 antibodies at 18 and 24 wks; increased malondialdehyde (MDA)-protein adducts and their antibodies (starting at 12 weeks); Splenocytes from 18 and 24 weeks stimulated with MDS-mouse serum albumin resulted in increased Th17 cell proliferation and increased IL-17 production compared with controls; decreased antioxidants GSH (all weeks) and SOD (18 and 24 wks)	High	Wang et al. (2017) Autoimmunity (and oxidative stress)
Mouse (CD1); female	Inhalation	25 and 50 ppm	3-hr exposure	25 ppm	Increased deaths from *Streptococcus zooepidemicus* challenge; decreased bacteriocidal activity of alveolar macrophages to *Klebsiella pneumonia*		Aranyi et al. (1986) Immuno-suppression
		25 ppm	3 hr/day, 5 day/wk exposure	25 ppm	No effects		

Mouse (ICR; Balbc); female	Inhalation (vapor)	0, 100, 300, 1000 ppm	6 hrs/day, 5 d/wk for 4 wks	1000 ppm	No antibody- forming cell response to sheep red blood cells (sRBCs); No phagocytic activity of pulmonary alveolar macrophages; no differences in spleen or thymus weight or histology, WBC differential cell distribution in bronchoalveolar lavage fluid or numbers of spleen cells.	High	Boverhof et al. (2013) Immuno-suppression
Rat (SD), Mouse (B6C3F1); male	Intraperitoneal	Rat: 0.05, 0.5, 5 mmol/kg Mouse: 0.1, 1.0, 10 mmol/kg	3 days	5 mmol/kg (rat) 10 mmol/kg (mouse)	No changes in splenocyte or liver immune cell viability, T or B lymphocyte proliferation (except slight, non-statistically significant change at the highest concentration (rat); no change in NK, natural cytotoxicity or natural P815 killer activity in liver immune cells; no change in NK or natural cytotoxic activity in splenocytes [a]	N/A	Schlichting et al. (1992) Immuno-suppression, other
Rat (Wistar); male	Oral gavage (corn oil)	0, 125, 250, 500, 1000, 2000 mg/kg-bw	5 days	1000 mg/kg-bw/day	Atrophy of: spleen ($p < 0.001$) (71% of controls) thymus ($p < 0.01$) (58% of controls)	N/A	Hanioka et al. (1995) Non-specific immunotoxicity
Rat (F344); female	Oral gavage (corn oil)	1000 mg/kg-bw	1 or 14 days	1000 mg/kg-bw	No effects on thymus or spleen wts	N/A	Berman et al. (1995) Non-specific immunotoxicity
Mouse (albino Swiss); male	Oral gavage (sesame oil)	300 mg/kg-bw	15 days	LOAEL = 300 mg/kg-bw	Increased WBC counts (by 42%; $p < 0.001$), decreased RBC (21%; $p< 0.01$), platelet counts (32%; $p < 0.001$), hemoglobin (17%; $p < 0.01$), hematocrit (23%; $p < 0.001$)[b]	N/A	Ebrahim et al. (2001) Non-specific immunotoxicity Hematology measures

Mouse (BDF1); female	Inhalation	6 hrs/day, 5 d/wk	7.5 wks (135 ppm); 11.5 wks (270 ppm)		Decreased leukocytes (neutrophils, lymphocytes and macrophages); increased reticulocytes (some return to normal after cessation of exposure); slight decrease in erythroid burst-forming units and erythroid colony forming units; no change in bone marrow pluripotent stem cells (not fully back to normal after exposure)	N/A	Seidel et al. (1992) Non-specific immunotoxicity; hematology measures

[a] This study found that similar measures were affected after *in vitro* exposure

[b] Changes were reverted back to near normal after administration of vitamin E, taurine or 2-deoxy-D-glucose

Table_Apx H-3. Evidence Integration Summary Judgment on Immunological and Hematological Effects

Summary of Human and Animal Studies					Inferences across evidence streams
Evidence from Studies of Exposed Humans					
Studies, outcomes, and confidence	**Factors that increase strength or certainty**	**Factors that decrease strength or certainty**	**Key findings and interpretation**	**Evidence stream summary**	
Autoimmunity (7 studies of various diseases) – 2 studies had statistically significant (s.s.) associations with PCE exposure or dry-cleaning work 5 studies had ORs or RRs > 1.0 for one or both sexes, depending on exposure measure used (but not s.s.) 1 study had no association with disease (SIR for hospitalization) *Allergy (asthma)* – *1* 2 studies showed mixed results *Immune measures (supportive of allergy, possibly autoimmunity, not likely immunosuppression)* • 3 of 4 studies show some associations *Hematology* 1 study - identified changes in multiple parameters	*Autoimmunity* • Majority of RR, ORs etc. greater than 1 • Robust study of RA more positive than the less robust study • Possible support from studies on immune measures *Allergy (asthma)* • Some support from studies on immune measures *Hematology* • Mult. measured parameters affected	*Autoimmunity* <u>Imprecision</u> Just 2 of 7 studies had s.s. associations Some more robust exposure measures (*e.g.*, expert review of exposure; PCE exposure) had less association with disease than other measures (*e.g.*, no expert review; dry-cleaning work) *Allergy (asthma)* • 1 study – assoc. lessened after accounting for other pollutants *Hematology* • Only 1 study available	*Autoimmunity* • Multiple studies with RR, ORs etc. > 1 with some imprecision in the estimates (*i.e.*, not s.s. for some) *Allergy (asthma)* • Two studies suggest possible effects but inconsistency makes a firm conclusion difficult *Hematology* • Although only one study measured these effects, multiple measured parameters were changed	• Results across human epidemiological studies suggest that PCE may be associated with autoimmune diseases (s.s. shown for 2 studies) • Some imprecision in the estimates limits the strength of the evidence • Possible association with allergy (asthma symptoms and bothersome asthma) • No information on immunosuppression • Evidence of hematological changes	• Information from multiple human studies (with some imprecise estimates) and one animal study support autoimmunity as a likely endpoint for PCE • Studies on allergy (asthma) in humans are less clear but suggest a possible association • Studies on immuno-suppression are mixed in animals and generally lacking in humans • Changes in immune measures support immunotoxicity more generally

Evidence from In vivo Animal Studies					
Studies, outcomes, and confidence	**Factors that increase strength or certainty**	**Factors that decrease strength or certainty**	**Key findings and interpretation**	**Evidence stream summary**	
Autoimmunity One study – multiple changes in female mice *Immunosuppression* • Studies of various measures, with just one of three showing changes *Immune measures (supportive of autoimmunity)* • Oxidative stress seen in one study is supportive of the autoimmunity changes; general immunotoxicity in other studies, sometimes only at high doses	*Autoimmunity* • Multiple effects observed in a single study	*Autoimmunity* • Only one study evaluated these endpoints	*Autoimmunity* • Robust findings in single study suggest autoimmunity is possible; other studies on immune measures may be supportive depending on autoimmunity mechanism *Immunosuppression* • Only one of 3 studies were positive, although the positive study used relevant apical endpoints	• Evidence is limited but supportive for autoimmunity • Evidence is less clear for immuno-suppression • General immune markers positive for immunotoxicity	

Appendix I PBPK Model Input Parameters

Presents input parameters for the PBPK model from (2011a). Sources are provided in footnotes below the table.

Table_Apx I-1. PCE PBPK Model Baseline Parameters

Parameter	Description (units)	Formula	Baseline value or parameter	Description	Mouse F / M	Rat F / M	Human F / M	Scaling parameter	Sources(s)
QC	Cardiac Output (L/h)	$QC=QCC_0\times\exp(lnQCC)\times BW^{0.75}$	QCC_0	Cardiac Output allometrically scaled	11.6	13.3	16 / 16	lnQCC	a, b
QP	Alveolar ventilation (L/h)	$QP=QC\times VPR_0\times\exp(lnVPR)$	VPR_0	Ventilation-perfusion ratio	2.5	1.9	0.96 / 0.96	lnVPRC	a, b, Optimized
QFat	Blood flow to fat (L/h)	$QFat=QC\times QFatC_0\times QFatC$	$QFatC_0$	Fraction of blood flow to fat	0.07	0.07	0.085 / 0.05	QFatC	a, b
QGut	Blood flow to gut (L/h)	$QGut=QC\times QGutC_0\times QGutC$	$QGutC_0$	Fraction of blood flow to gut	0.141	0.153	0.21 / 0.19	QGutC	a, b
QLiv	Hepatic artery blood flow (L/h)	$QLiv=QC\times QLivC_0\times QLivC$	$QGutC_0$	Fraction of blood flow to hepatic artery	0.02	0.021	0.065 / 0.065	QLivC	a, b
QSlw	Blood flow to slowly perfused tissues (L/h)	$QSlw=QC\times QSlwC_0\times QSlwC$	$QSlwC_0$	Fraction of blood flow to slowly perfused tissues	0.217	0.336	0.17 / 0.22	QSlwC	a, b
QKid	Blood flow to kidney (L/h)	$QKid=QC\times QKidC_0\times QKidC$	$QKidC_0$	Fraction of blood flow to kidney	0.091	0.141	0.17 / 0.19	QKidC	a, b
QRap	Blood flow to rapidly perfused tissues (L/h)	$QRap=QC-(QFat+QGut+QLiv+QSlw+QKid)$	–	–	–	–	–	–	
DResp	Diffusion clearance rate (L/h)	$DResp=QP\times\exp(lnDRespC)$	–	–	–	–	–	lnDRespC	c
FracPlas	Fraction of blood that is plasma	$FracPlas=FracPlas_0\times FracPlasC$	$FracPlas_0$	Fraction of blood that is plasma	0.52	0.53	0.615 / 0.567	FracPlasC	b, c, d
VFat	Volume of fat (L)	$VFat=BW\times VFatC_0\times VFatC$	$VFatC_0$	Fraction of body weight that is fat	0.07	0.07	0.317 / 0.199	VFatC	a, b

Parameter	Description (units)	Formula	Baseline value or parameter	Description	Mouse F / M	Rat F / M	Human F / M	Scaling parameter	Sources(s)
VGut	Volume of gut (L)	VGut=BW×VGutC_0× VGutC	VGutC_0	Fraction of body weight that is gut	0.049	0.032	0.022 / 0.02	VGutC	a, b
VLiv	Volume of liver (L)	VLiv=BW×VLivC_0× VLivC	VLivC_0	Fraction of body weight that is liver	0.055	0.034	0.023 / 0.025	VLivC	a, b
VRap	Volume of rapidly perfused tissues (L)	VRap=BW×VRapC_0× VRapC	VRapC_0	Fraction of body weight that is rapidly perfused	0.1	0.088	0.093 / 0.088	VRapC	a, b
VRespLum	Volume of respiratory tract lumen (L)	VRespLum=BW× VRespLumC_0× VRespLumC	VRespLumC_0	Respiratory lumen volume as fraction body weight	0.004667	0.004667	0.002386 / 0.002386	VRespLumC	e
VResp	Volume of respiratory tract tissue (L)	VResp=BW×VRespC_0× VRespC	VRespC_0	Fraction of body weight that is respiratory tract	0.0007	0.0005	0.00018 / 0.00018	VRespC	a, b, e
VKid	Volume of kidney (L)	VKid=BW×VKidC_0× VKidC	VKidC_0	Fraction of body weight that is kidney	0.017	0.007	0.0046 / 0.0043	VKidC	a, b,
VBld	Volume of blood (L)	VBld=BW×VBldC_0× VBldC	VBldC_0	Fraction of body weight that is blood	0.049	0.074	0.068 / 0.077	VBldC	a, b,
VSlw	Volume of slowly perfused tissue (L)	VSlw=BW×VperfC_0− (VFat+VGut+VLiv+ VRap+VResp+VKid+ VBld)	VperfC_0	Fraction of body weight that is blood perfused	0.8897	0.8995	0.85778 / 0.8560	–	
PB	Perc blood-air PC	PB=PB_0×PBC	PB_0	Perc blood-air PC	18.6	15.1	14.7	PBC	f
PFat	Perc fat-blood PC	PFat=(PFatC_0/PB)×PFatC	PFatC_0	Perc fat-air PC	1510.8	1489.3	1450.0	PFatC	f
PGut	Perc gut-blood PC	PGut=(PGutC_0/PB)× exp(lnPGutC)	PGutC_0	Perc gut-air PC	62.1	40.6	59.9	lnPGutC	f
PLiv	Perc liver-blood PC	PLiv=(PLivC_0/PB)× exp(lnPLivC)	PLivC_0	Perc liver-air PC	48.8	50.3	61.1	lnPLivC	f
PRap	Perc rapidly perfused-blood PC	PRap=(PRapC_0/PB)× exp(lnPRapC)	PRapC_0	Perc rapidly perfused-air PC	62.1	40.4	59.9	lnPRapC	f
PResp	Perc respiratory tract tissue-blood PC	PResp=(PrespC_0/PB)× exp(lnPRespC)	PRespC_0	Perc respiratory tract-air PC	79.1	32.7	58.6	lnPRespC	f
PKid	Perc kidney-blood PC	PKid=(PKidC_0/PB)× exp(lnPKidC)	PKidC_0	Perc kidney-air PC	79.1	32.7	58.6	lnPKidC	f

Parameter	Description (units)	Formula	Baseline value or parameter	Description	Mouse F / M	Rat F / M	Human F / M	Scaling parameter	Sources(s)
PSlw	Perc slowly perfused-blood PC	$PSlw=(PSlwC_0/PB)\times exp(lnPSlwC)$	$PSlwC_0$	Perc slowly perfused-air PC	79.1	21.6	70.5	lnPSlwC	f
TCAPlas	TCA blood-plasma concentration ratio	$TCAPlas=FracPlas+(1-FracPlas)\times PRBCPlasTCA_0\times exp(lnPRBCPlasTCAC)$	$PRBCPlasTCA_0$	TCA red blood cell-plasma partition coefficient	0.5	0.5	0.5 / 0.5	lnPRBCPlasTCAC	c, g
PBodTCA	Free TCA body-plasma PC	$PBodTCA=TCAPlas\times PBodTCAC_0\times exp(lnPBodTCAC)$	$PBodTCAC_0$	Free TCA body-blood PC	0.88	0.88	0.52	lnPBodTCAC	c, h
PLivTCA	Free TCA liver-plasma PC	$PLivTCA=TCAPlas\times PLivTCAC_0\times exp(lnPLivTCAC)$	$PLivTCAC_0$	Free TCA liver-blood PC	1.18	1.18	0.66	lnPLivTCAC	c, h
kDissoc	Protein TCA dissociation constant (microM)	$kDissoc=kDissoc_0\times exp(lnkDissocC)$	$kDissoc_0$	Protein TCA dissociation constant (microM)	107	275	182	lnkDissocC	c, i
BMax	Protein concentration (microM)	$BMax=BMaxkD_0\times kDissoc\times exp(lnBMaxkDC)$	$BMaxkD_0$	BMax/kDissoc ratio	0.88	1.22	4.62	lnBMaxkDC	c, i
kTSD	Perc oil gavage stomach-duodenum transfer coefficient (/hr)	$kTSD=exp(lnkTSD)$	1.4	–	–	–	–	lnkTSD	Optimized in mouse and rat
kAS	Perc oil gavage stomach-absorption coefficient (/hr)	$kAS=exp(lnkAS)$	1.4	–	–	–	–	lnkAS	Optimized in mouse and rat
kAD	Perc oil gavage duodenum-absorption coefficient (/hr)	$kAD=exp(lnkAD)$	0.75	–	–	–	–	lnkAD	Optimized in mouse and rat
kTSDAq	Perc aqueous gavage stomach-duodenum transfer coefficient (/hr)	$kTSDAq=exp(lnkTSDAq)$	1.4	–	–	–	–	lnkTSDAq	Optimized in mouse and rat

Parameter	Description (units)	Formula	Baseline value or parameter	Description	Mouse F / M	Rat F / M	Human F / M	Scaling parameter	Sources(s)
kASAq	Perc aqueous gavage stomach-absorption coefficient (/hr)	kASAq=exp(lnkASAq)	1.4	–	–	–	–	lnkASAq	Optimized in mouse and rat
kADAq	Perc aqueous gavage duodenum-absorption coefficient (/hr)	kADAq=exp(lnkADAq)	0.75	–	–	–	–	lnkADAq	Optimized in mouse and rat
kASTCA	TCA stomach absorption coefficient (/hr)	kASTCA=exp(lnkASTCA)	0.75	–	–	–	–	lnkASTCA	–
KM	KM for first perc hepatic oxidation pathway (mg/L blood)	$KM=KM_0 \times exp(lnKMC)$	KM_0	KM for perc hepatic oxidation (mg/L blood)	88.6	69.7	55.8	lnKMC	See text; Optimized
VMax	VMax for first perc hepatic oxidation pathway (mg/hr)	$VMax=KM \times ClC_0 \times VLiv \times exp(lnClC)$	ClC_0	VMax/KM per kg liver for perc hepatic oxidation (L blood/hr/kg liver)	1.57	0.36	0.202	lnClC	See text; Optimized
KM2	KM for second perc hepatic oxidation pathway (mg/L blood)	KM2=KM×exp(lnKM2C)	-					lnKM2C (ln of ratio to first pathway KM)	See text; Optimized
VMax2	VMax for second perc hepatic oxidation pathway (mg/hr)	VMax2=KM2× (VMax/KM) exp(lnCl2OxC)	-	Scaled to first pathway Clearance				lnClC2OxC (ln of ratio to first pathway clearance)	See text; Optimized
FracOther	Fraction of perc oxidation not to TCA	FracOther= exp(lnFracOtherC)/ (1+exp(lnFracOtherC))	0.1	–	–	–	–	lnFracOtherC	See text
KMKid	KM for perc renal oxidation (mg/L blood)	$KMKid=KM \times KMKidLiv_0 \times exp(lnKMKidLivC)$	$KMKidLiv_0$	Ratio of kidney to liver oxidation KM in blood	0.616	1.53	1.04	lnKMKidLivC	See text; Optimized in humans

Parameter	Description (units)	Formula	Baseline value or parameter	Description	Mouse F / M	Rat F / M	Human F / M	Scaling parameter	Sources(s)
VMaxKid	VMax for perc renal oxidation (mg/hr)	VMaxKid=(VMax/KM)×(VKid/VLiv)×KMKid×ClKidLiv$_0$×exp(lnClKidLivC)	ClKidLiv$_0$	Ratio of kidney to liver oxidation Vmax/KM per kg tissue (mg/hr/kg per mg/hr/kg)	0.0211	0.0085	0.0125	lnClKidLivC	See text; Optimized in humans
FracKidTCA	Fraction of renal TCA production going directly to urine	FracKidTCA= exp(lnFracKidTCAC)/(1+exp(lnFracKidTCAC))	0.5	–	–	–	–	lnFracKidTCAC	See text
KMClara	KM for perc lung oxidation (mg/L air)	KMClara=KM×PLiv×KMRespLiv$_0$×exp(lnKMRespLivC)/(PB×PResp)	KMRespLiv$_0$	Ratio of lung to liver KM in tissue (mg/L per mg/L)	1	1	1	lnKMRespLivC	See text
VMaxClara	VMax for perc lung oxidation (mg/hr)	VMaxClara=VMax×VMaxLungLiv$_0$×exp(lnVMaxLungLivC)	VMaxLungLiv$_0$	Ratio of lung to liver total Vmax (mg/hr per mg/hr)	0.07	0.0144	0.0138 / 0.0128	lnVMaxLungLivC	See text
VMaxTCVG	VMax for perc hepatic GSH conjugation (mg/hr)	VMaxTCVG= VMaxTCVG$_0$×VLiv×exp(lnVMaxTCVGC)	VMaxTCVG$_0$	VMax per kg liver for perc GSH conjugation (L blood/hr/kg liver)	35.3	93.9	0.665	lnVMaxTCVGC	See text; Optimized
KMTCVG	KM for perc hepatic GSH conjugation (mg/L blood)	KM=VMaxTCVG/(ClTCVG$_0$×exp(lnClTCVGC)	ClTCVG$_0$	VMax/KM for perc hepatic GSH conjugation (L blood/hr)	0.656	2.218	0.0196	lnClTCVGC	See text; Optimized
VMaxKidTCVG	VMax for perc renal GSH conjugation (mg/hr)	VMaxKidTCVG= (VMaxTCVG/VLiv×VKid×VMaxKidLivTCVG$_0$×exp(lnVMaxKidLivTCVGC)	VMaxKidLivTCVG$_0$	Ratio of kidney to liver GSH conjugation Vmax per kg tissue (mg/hr/kg per mg/hr/kg)	0.15	0.15	0.15	lnVMaxKidLivTCVGC	See text;
KMKidTCVG	KM for perc renal GSH conjugation (mg/L blood)	KMKid=VMaxKidTCVG/(VMaxTCVG/KMTCVG/VLiv×VKid×ClKidLivTCVG$_0$×exp(lnClKidLivTCVGC)	ClKidLivTCVG$_0$	Ratio of kidney to liver GSH conjugation Vmax/KM per kg tissue (L/hr/kg per L/hr/kg)	0.24	0.098	0.14	lnClKidLivTCVGC	See text;

Parameter	Description (units)	Formula	Baseline value or parameter	Description	Mouse F / M	Rat F / M	Human F / M	Scaling parameter	Sources(s)
kUrnTCA	Rate constant for TCA excretion to urine (/hr)	kUrnTCA=GFR_BW exp(lnkUrnTCAC)× exp(lnkTotTCAC)× BW/VPlas	GFR_BW	Glomerular filtration rate per kg body weight (L/hr/kg)	0.6	0.522	0.108	lnkUrnTCAC	c, j
								lnkTotTCAC (ln of overall rescaling of kUrnTCA and kMetTCA)	
kMetTCA	Rate constant for other TCA clearance (/hr)	kMetTCA=$BW^{-¼}$ × exp(lnkMetTCAC) × exp(lnkTotTCAC)	–	–	–	–	–	lnkMetTCAC	c
FracNATUrn	Fraction of GSH conjugation to urinary NAcTCVC	FracNATUrn= exp(lnFracNATUrnC)/(1+ exp(lnFracNATUrnC))	–	–	–	–	–	lnFracNATUrnC	Optimized in rat and human
FracDCAUrn	Fraction of GSH conjugation to urinary DCA	FracDCAUrn=(1 – FracNATUrn) × exp(lnFracDCAUrnC)/(1+ exp(lnFracDCAUrnC))	–	–	–	–	–	lnFracDCAUrnC	Optimized in rat and human
kNAT	Rate constant for urinary excretion of DCA (/hr)	kNAT=$BW^{-¼}$ × exp(lnkNATC)	–	–	–	–	–	lnkNATC	Optimized in rat and human
kDCA	Rate constant for urinary excretion of NAcTCVC (/hr)	kDCA=$BW^{-¼}$ × exp(lnkDCAC)	–	–	–	–	–	lnkDCAC	Optimized in rat

a: (Brown et al., 1997)
b: (ICRP, 2002)
c: Posterior mean from (Chiu et al., 2009)
d: Measurements in control F344 rats and B6C3F1 mice at 19 weeks of age from (Hejtmancik et al., 2002)
e: (Sarangapani et al., 2003)
f: In mice, blood-air from (Reitz et al., 1996; Gearhart et al., 1993; Gargas et al., 1989); liver, kidney, and muscle (slowly perfused) from (Gearhart et al., 1993); gut, rapidly perfused used geometric mean of kidney and liver; respiratory tract used kidney. In rats, blood-air, fat, liver, muscle (slowly perfused) from (Mahle et al., 2007; Gargas et al., 1989; Koizumi, 1989); kidney and brain (rapidly perfused) used (Mahle et al., 2007); gut used geometric mean of kidney and liver; respiratory tract used kidney. In humans, blood-air from (Mahle et al., 2007; Fisher et al., 1997; Gearhart et al., 1993; Gargas et al., 1989; Koizumi, 1989; Sato and Nakajima, 1979); kidney, liver, and muscle (slowly perfused) used (Gearhart et al., 1993); gut and rapidly perfused used geometric mean of kidney and liver; and respiratory tract used kidney.
g: Baseline corresponds to Blood/Plasma concentration ratio of 0.76 measured in rats from (Schultz et al., 1999).

h: (Fisher et al., 1998; Abbas and Fisher, 1997)
i: Geometric mean of (Lumpkin et al., 2003; Yu et al., 2000; Schultz et al., 1999; Templin et al., 1995; Templin et al., 1993)
j: Clearance based on glomerular filtration rates across species from (Lin, 1995)

Appendix J Genotoxicity Data on PCE and Relevant Metabolite

Table_Apx J-1 and Table_Apx J-2 below present all identified genotoxicity data on PCE. Table_Apx J-3 presents data on conjugative metabolites of PCE, which may contribute to the MOA for cancer (Section 3.2.3.3). Unacceptable studies were included for reference (indicated in red) but were not considered for their contribution to the weight of the scientific evidence for PCE genotoxicity.

Table_Apx J-1. Genotoxicity of tetrachloroethylene—bacterial, yeast, fungal, and invertebrate systems[a]

Test system/endpoint	Doses (LED or HID)[b]	Results[c]		Reference	Data Quality
		With activation	Without activation		
SOS chromotest, *E. coli* PQ37	8,150	–	–	Mersch-Sundermann et al. (1994)	Not evaluated – foreign language
SOS chromotest, *E. coli* PQ37	NA	–	–	von der Hude et al. (1988)	Unacceptable
λ Prophage induction, *E. coli* WP2	10,000	–	–	DeMarini et al. (1994)	High
S. typhimurium BAL13, forward mutation *(ara* test)	76	–	–	Roldán-Arjona et al. (1991)	High
S. typhimurium TA100, reverse mutation	660	–	–	Bartsch et al. (1979)	Unacceptable
S. typhimurium TA100, reverse mutation	167	–	–	Haworth et al. (1983)	High
S. typhimurium TA100, reverse mutation	1,000	–	–	Connor et al. (1985)	Medium
S. typhimurium TA100, reverse mutation	166 (vapor)	–	–[d]	Shimada et al. (1985)	High
S. typhimurium TA100, reverse mutation	NA	–	–	Milman et al. (1988)	Unacceptable
S. typhimurium TA100, reverse mutation	332	+[e]	–	Vamvakas et al. (1989c)	High
S. typhimurium TA100, reverse mutation	1.3 (vapor)	–	–	DeMarini et al. (1994)	High
S. typhimurium TA1535, reverse mutation	50	NT	–	Kringstad et al. (1981)	Unacceptable
S. typhimurium TA1535, reverse mutation	167	–	–	Haworth et al. (1983)	High
S. typhimurium TA1535, reverse mutation	66 (vapor)	(+)	–[d]	Shimada et al. (1985)	High
S. typhimurium TA1535, reverse mutation	NA	–	–	Milman et al. (1988)	Unacceptable
S. typhimurium TA1537, reverse mutation	167	–	–	Haworth et al. (1983)	High

Test system/endpoint	Doses (LED or HID)[b]	Results[c]		Reference	Data Quality
		With activation	Without activation		
S. typhimurium TA1537, reverse mutation	NA	–	–	Milman et al. (1988)	Unacceptable
S. typhimurium, gene mutation TA100, TA1535, TA1537, TA98	333 µg/plate	–	–	NTP (1986a)	High
S. typhimurium TA98, reverse mutation	167	–	–	Haworth et al. (1983)	High
S. typhimurium TA98, reverse mutation	1,000	–	–	Connor et al. (1985)	Medium
S. typhimurium TA98, reverse mutation	NA	–	–	Milman et al. (1988)	Unacceptable
S. typhimurium UTH8413, reverse mutation	1,000	–	–	Connor et al. (1985)	Medium
S. typhimurium UTH8414, reverse mutation	1,000	–	–	Connor et al. (1985)	Medium
S. typhimurium TA102, TA2638 *E. coli* WP2/pKM101, WP2 *uvr*A/pKM101, gene mutation	1,250 µg/plate	–	NT	Watanabe et al. (1998)	High
S. typhimurium, YG7108pin3ERb$_5$, gene mutation (strain is methyltransferase deficient and stably expresses complete electron transport chain including P450 reductase, cytochrome b5 and CYP2E1)	200 µg/plate	NT	-	Emmert et al. (2006)	High
E. coli K12, forward mutation	150	–	–	Greim et al. (1975)	Unacceptable
E. coli K12, reverse mutation *(arg*)*	150	–	–	Greim et al. (1975)	Unacceptable
E. coli K12, reverse mutation *(gal*)*	150	–	–	Greim et al. (1975)	Unacceptable
E. coli K12, reverse mutation *(nad*)*	150	–	–	Greim et al. (1975)	Unacceptable
S. cerevisiae D7, log-phase cultures, gene conversion	1,100	NT	+	Callen et al. (1980)	High
S. cerevisiae D7, gene conversion	9,960	–	–	Bronzetti et al. (1983)	High
S. cerevisiae D7, log-phase and stationary cultures, gene conversion	2,440	–	–	Koch et al. (1988)	Low
S. cerevisiae D7, log-phase cultures, mitotic recombination or other genetic alterations *(ade2)*	1,100	NT	+	Callen et al. (1980)	High

Test system/endpoint	Doses (LED or HID)[b]	Results[c]		Reference	Data Quality
		With activation	Without activation		
S. cerevisiae D7, mitotic recombination	9,960	–	–	Bronzetti et al. (1983)	High
S. cerevisiae D7, log-phase cultures, reverse mutation	810	NT	(+)	Callen et al. (1980)	High
S. cerevisiae D7, reverse mutation	9,960	–	–	Bronzetti et al. (1983)	High
S. cerevisiae D7, log-phase and stationary cultures, reverse mutation	2,440	–	–	Koch et al. (1988)	Low
S. cerevisiae D61.M, growing cells, aneuploidy	810	(+)	(+)	Koch et al. (1988)	Low
D. melanogaster, sex-linked recessive lethal mutation	4,000 ppm p.o. 1,000 ppm injection	NT	–	NTP (1986a)	Medium
D. melanogaster, sex-linked recessive lethal mutation	3,400 mg/m^3, 7 h	NT	–	Beliles et al. (1980)	High

[a]Table adapted from ATSDR (1997) and IARC monograph (1995) and modified/updated for newer references.
[b]LED, lowest effective dose; HID, highest ineffective dose; doses are in µg/mL for in vitro tests unless otherwise specified; NA = not available.
[c]Results: + = positive; (+) = weakly positive; – = negative; NT = not tested.
[d]PCE with stabilizers was positive with and without metabolic activation.
[e]Weak increase in activity with rat liver S9, rat kidney microsomes and glutathione (GSH): fourfold increase with rat kidney microsomes, GSH and GSH *S*-transferase.

Table_Apx J-2. Genotoxicity of perchloroethylene—mammalian systems (in vitro and in vivo)[a]

Test system/endpoint	Doses (LED or HID)[b]	Results[c]		Reference	Data Quality
		With activation	Without activation		
IN VITRO SYSTEMS					
Binding (covalent) to calf thymus DNA in vitro	2.5 µCi ^{14}C-PCE	+	Data not shown	Mazzullo et al. (1987)	High
Micronucleus induction (Chinese hamster lung cell line)	250 µg/mL	–	–	Matsushima et al. (1999)	Unacceptable
Gap Junction Intercellular Communication (rat liver cells)	0.1 mM	NT	+	Benane et al. (1996)	High
Unscheduled DNA synthesis, rat primary hepatocytes in vitro	166 (vapor)	NT	–[d]	Shimada et al. (1985)	High
Unscheduled DNA synthesis, Osborne Mendel rat primary hepatocytes in vitro	NA	NT	–	Milman et al. (1988)	Unacceptable
Unscheduled DNA synthesis, B6C3F$_1$ mouse primary hepatocytes in vitro	NA	NT	–	Milman et al. (1988)	Unacceptable

Test system/endpoint		Doses (LED or HID)[b]	Results[c]		Reference	Data Quality
			With activation	Without activation		
Gene mutation, mouse lymphoma L5178Y cells, tk locus		245	–	–	NTP (1986a)	High
Sister chromatid exchange, Chinese hamster ovary (CHO) cells in vitro		164	–	–	Galloway et al. (1987)	High
Chromosomal aberrations, Chinese hamster lung (CHL) cells in vitro		500	–	–	Sofuni et al. (1985)	Low
Chromosomal aberrations, Chinese hamster ovary (CHO) cells in vitro		136	–	–	Galloway et al. (1987)	High
Cell transformation, RLV/Fischer rat embryo F1706 cells in vitro		16	NT	+	Price et al. (1978)	Unacceptable
BALB/c-3T3 mouse cells, cell transformation in vitro		250	NT	–	Tu et al. (1985)	High
Rat and mouse hepatocyte, DNA damage (unscheduled DNA synthesis)		2.5mM	NT	–	Costa and Ivanetich (1984)	High
Human fibroblast cells, DNA damage (unscheduled DNA synthesis)		0.1 nL/mL	(+/–)	(+/–)	Beliles et al. (1980)	High
Human hepatoma (HepG2) cells, DNA damage (8OHdG)		2 mM	NT	-	Deferme et al. (2015)	High
Host mediated assay—*S. typhimurium* implanted in CD-1 mice		100 ppm (male mice;500 ppm (female mice)	+	NT	Beliles et al. (1980)	High
Chinese hamster ovary cells, sister chromatid exchange		164 µg/mL	–	–	NTP (1986a)	High
Chinese hamster ovary (CHO-K1) cells, increased frequency of micronuclei		~63 ppm	NT	+	Wang et al. (2001)	Medium
Cytochalasin B-blocked micronucleus assay using human lymphoblastoid cell lines with enhanced metabolic activity, increased frequency of micronuclei	AHH-1	5 mM	NT	+	Doherty et al. (1996)	High
	H2E1	1 mM	NT	+	Doherty et al. (1996)	High
	MCL-5	1 mM	NT	+	Doherty et al. (1996)	High
Human white blood cells, length of DNA migration Human lymphocytes, sister chromatid exchange		5×10^{-3} M	– –	– –	Hartmann and Speit (1995)	High
Human lymphocytes in vitro (unscheduled DNA synthesis)		1 mM	–	–	Perocco et al. (1983)	Medium
IN VIVO / EX VIVO SYSTEMS						

Test system/endpoint	Doses (LED or HID)[b]	Results[c]		Reference	Data Quality
		With activation	Without activation		
Gene conversion and reverse mutation in *S. cerevisiae* D7 recovered from liver, lungs, and kidneys of CD-1 mice	11,000 p.o. × 1	NT	–	Bronzetti et al. (1983)	High
Gene conversion and reverse mutation in *S. cerevisiae* D7 recovered from liver, lungs, and kidneys of CD-1 mice	2,000 p.o. × 12	–	NT	Bronzetti et al. (1983)	High
DNA single-strand breaks (alkaline unwinding) in liver and kidney of male NMRI mice in vivo	660 i.p. × 1	NT	+[e]	Walles (1986)	High
Sister chromatid exchange, human lymphocytes in vivo	1,500 mg/m^3 inhaled	NT	–	Ikeda et al. (1980)	Unacceptable
Chromosomal aberrations, human lymphocytes in vivo	92 ppm inhaled	NT	–	Ikeda et al. (1980)	Unacceptable
Binding (covalent) to DNA in male B6C3F$_1$ mouse liver in vivo	1,400 inhaled 6 h 600 ppm	NT	–	Schumann et al. (1980)	Unacceptable
Binding (covalent) to DNA in male B6C3F$_1$ mouse liver in vivo	500 p.o. × 1	NT	–	Schumann et al. (1980)	Unacceptable
Binding (covalent) to DNA in male BALB/c mouse and Wistar rat liver, kidney, lung, and stomach in vivo	1.4 i.p. × 1 22 h	NT	+	Mazzullo et al. (1987)	Medium
Binding (covalent) to RNA and protein in male BALB/c mouse and Wistar rat liver, kidney, lung, and stomach in vivo	1.4 i.p. × 1 22 h	NT	+	Mazzullo et al. (1987)	Medium
Human lymphocytes, sister chromatid exchange	10 ppm (geometric mean)	NT	–	Seiji et al. (1990)	Medium
Human lymphocytes, DNA damage (alkaline Comet assay)	NA	NT	+	Azimi et al. (2017)	Medium
Human lymphocytes, chromosomal aberrations (correlation of exposure level with frequency of acentric fragments)	3.8 ppm (TWA air concentration)	NT	+	Tucker et al. (2011)	Medium
Human lymphocytes, chromosomal aberrations	31.4 mg/m^3 (mean air concentration)	NT	-	Everatt et al. (2013)	Medium
Human lymphocytes, DNA damage (alkaline Comet assay)	31.4 mg/m^3 (mean air concentration)	NT	+	Everatt et al. (2013)	Medium
Human lymphocytes, micronucleus	31.4 mg/m^3 (mean air concentration)	NT	+	Everatt et al. (2013)	Medium

Test system/endpoint	Doses (LED or HID)[b]	Results[c]		Reference	Data Quality
		With activation	Without activation		
Mouse, reticulocytes, micronucleus	2,000 mg/kg	NT	–	Murakami and Horikawa (1995)	High
Mouse, hepatocytes, micronucleus Before partial hepatectomy After partial hepatectomy	1,000 mg/kg	NT	 – +	Murakami and Horikawa (1995)	High
Mouse, induction of DNA damage in hepatocytes (alkaline Comet assay)	1,000 mg/kg-day 2,000 mg/kg-day	NT	+/– +/–	Cederberg et al. (2010)	High
Mouse, induction of DNA damage in kidney (alkaline Comet assay)	1,000 mg/kg-day 2,000 mg/kg-day	NT	– –	Cederberg et al. (2010)	High
Rat bone marrow cells, chromosomal aberrations	100 and 500 ppm	NT	–	Beliles et al. (1980)	High
Enzyme-altered foci in male Osborne Mendel rat liver in vivo, promotion protocol, with or without N-nitrosodiethylamine as an initiator	1,000, 5 d/wk for 7 wk	NT	+	Milman et al. (1988)	High
Enzyme-altered foci in male Osborne Mendel rat liver in vivo, initiation protocol, phenobarbital as a promoter	1,000	NT	–	Milman et al. (1988)	High
DNA damage (8OHdG) in urine and leukocytes of dry cleaners (female only)	3.8 ± 5.3 ppm (TWA)	NT	–	Toraason et al. (2003)	Medium
DNA damage (8OHdG) in Fischer rats measured in urine, lymphocytes, and liver	100–1,000 mg/kg	NT	– (Substantial morbidity at all doses limits interpretation.)	Toraason et al. (1999)	High
Human lymphocytes in vivo (Chromosomal aberrations)	144 mg/m^3 (but contaminated with trichloroethylene)	NT	+	Fender (1993)	Not evaluated – foreign language
DNA single-strand breaks in male F-344 rats	1,000 mg/kg p.o.	NT	–	Potter et al. (1996)	High

[a]Table adapted from ATSDR (1997) and IARC monograph (1995) and modified/updated for newer references.
[b]LED, lowest effective dose; HID, highest ineffective dose; doses are in µg/mL for in vitro tests; mg/kg for in vivo tests unless otherwise specified; i.p. = intraperitoneal; p.o. = oral; NA = not available.
[c]Results: + = positive; (+) = weakly positive; (+/–) = mixed results; – = negative; NT = not tested.
[d]PCE with stabilizers was positive with and without metabolic activation.
[e]Negative in lung.

Table_Apx J-3. Genotoxicity of perchloroethylene - GSH-conjugation metabolites

Metabolite	Test system/endpoint	Doses (LED or HID)[a]	Results[b]		Reference	Data Quality
			With activation	Without activation		
Trichlorovinyl-cysteine (TCVC)	*S. typhimurium* TA100, reverse mutation	50 nmol/plate	NT	+	Dreessen et al. (2003)	Medium
	Cultured porcine LLC-PK1 (kidney) cells, unscheduled DNA synthesis, in vitro	5×10^{-6} M	NT	+	Vamvakas et al. (1989a)	High
	S. typhimurium TA100, reverse mutation	12.5 nmol/plate	NT	+	Irving and Elfarra (2013)	High
NAcTCVC	*S. typhimurium* TA100, increased mutation frequency	<50 nmol[c]	+	+	Vamvakas et al. (1987)	Unacceptable
Trichloroacetyl chloride	PRB, λ Prophage induction, *E. coli* WP2	10,000	–	–	DeMarini et al. (1994)	High
	SA0, *S. typhimurium* TA100, reverse mutation	2.6	+	+	DeMarini et al. (1994)	High
	S. typhimurium TA100, increased mutation frequency	5 µg/mL	–	–	Reichert et al. (1983)	High
Trichlorovinyl-glutathione (TCVG)	*S. typhimurium* TA100, reverse mutation	100 nmol/plate	+	–	Dreessen et al. (2003)	Medium
	S. typhimurium TA100, increased mutation frequency	25 nmol/plate (with) 250–500 nmol/plate (without)	+	(+)	Vamvakas et al. (1989c)	High
	Cultured porcine LLC-PK1 (kidney) cells, unscheduled DNA synthesis, in vitro	7.5×10^{-6} M	NT	+	Vamvakas et al. (1989b)	Medium

[a]LED, lowest effective dose; HID, highest ineffective dose; NA = not available.
[b]Results: + = positive; (+) = weakly positive; – = negative; NT = not tested.
[c]Lower-level concentrations that indicate mutagenicity are not specified in Vamvakas et al. (1987).