United States
Environmental Protection Agency

Office of Chemical Safety and
Pollution Prevention

Final Risk Evaluation for Perchloroethylene

Supplemental File:

Releases and Occupational Exposure Assessment

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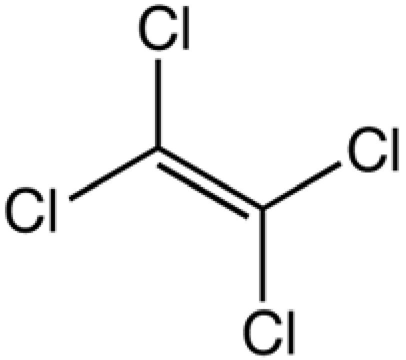

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ABBREVIATIONS

AC	Acute Concentration
ACGIH	Association Advancing Occupational and Environmental Health
ACP	AC Products
ADC	Average Daily Concentration
AFPM	American Fuel and Petrochemical Manufacturers
AIHA	American Industrial Hygiene Association
AISE	Association for Soaps, Detergents and Maintenance Products
AL	Alabama
AR	Arizona
ATSDR	Agency for Toxic Substances and Disease Registry
BAT	Best Available Technology Economically Achievable
BLS	Bureau of Labor Statistics
BPT	Best Practicable Control Technology Currently Available
CA	California
CARB	California Air Resources Board
CBI	Confidential Business Information
CDC	Center for Disease Control
CDR	Chemical Data Reporting
CFC	Chlorofluorocarbon
C_{FF}	Concentration (Far-Field)
C_{NF}	Concentration (Near-Field)
CO	Colorado
CT	Connecticut
CTFE	Chlorotrifluoroethylene
DEP	Department of Environmental Protection
DEQ	Department of Environmental Quality
DIY	Do It Yourself
DLI	Dry Cleaning and Laundry Institute
DMR	Discharge Monitoring Report
ECHO	Enforcement and Compliance History Online
EDC	Ethylene Dichloride
EG	Effluent Guidelines
EPA	Environmental Protection Agency
ERG	Eastern Research Group
ESD	Emission Scenario Document
EU	European Union
FL	Florida
G	Evaporation rate of PCE
GS	Generic Scenario
HCFC	Hydrochlorofluorocarbon
HERO	Health and Environmental Research Online
HF	Hydrofluoric Acid
HHE	Health Hazard Evaluation
HSIA	Halogenated Solvents Industry Alliance
IL	Illinois

IN	Indiana
ISOR	Initial Statement of Reasons
KS	Kansas
KY	Kentucky
LA	Louisiana
LADC	Lifetime Average Daily Concentration
lb	Pound
LEV	Local Exhaust Ventilation
LOD	Limit of Detection
LPG	Liquified Petroleum Gas
MI	Missouri
MN	Minnesota
MP&M	Metal Products and Machinery
NAICS	North American Industry Classification System
NCA	National Cleaner’s Association
NEI	National Emissions Inventory
NESHAP	National Emission Standards for Hazardous Air Pollutants
NEWMOA	Northeast Waste Management Officials’ Association
NIOSH	National Institute for Occupational Safety and Health
NJ	New Jersey
NKRA	Not Known or Reasonably Ascertainable
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standards
NV	Nevada
NY	New York
OAQPS	Office of Air Quality Planning and Standards
OARS	Occupational Alliance for Risk Science
OCPSF	Organic Chemicals, Plastics and Synthetic Fibers
OECD	Organization for Economic Co-operation and Development
OEL	Occupational Exposure Limit
OES	Occupational Employment Statistics
OH	Ohio
OK	Oklahoma
ONU	Occupational Non-User
OPPT	Office of Pollution Prevention and Toxics
OSHA	Occupational Safety and Health Administration
OTVD	Open-Top Vapor Degreaser
PA	Pennsylvania
PBZ	Personal Breathing Zone
PCE	Perchloroethylene
PEL	Permissible Exposure Limit
PERC	Perchloroethylene
PF	Protection Factor
POTW	Publicly-Owned Treatment Works
PPE	Personal Protective Equipment
PSES	Pretreatment Standards for Existing Sources
PSNS	Pretreatment Standards for New Sources

QC	Quality Control
Q_{FF}	Ventilation rate (Far-Field)
Q_{NF}	Ventilation rate (Near-Field)
RAR	Risk Assessment Report
RCRA	Resource Conservation and Recovery Act
RDF	Refuse-Derived Fuel
REL	Recommended Exposure Limit
RFI	Reporting Forms and Instructions
SC	South Carolina
SDS	Safety Data Sheet
SIC	Standard Industrial Classification
SOC	Standard Occupational Classification
SpERC	Specific Environmental Release Category
SUSB	Statistics of U.S. Businesses
TCE	Trichloroethylene
TLV	Threshold Limit Value
TRI	Toxic Release Inventory
TSCA	Toxic Substances Control Act
TSDF	Treatment, Storage, and Disposal Facility
TTO	Total Toxic Organics
TWA	Time-Weighted Average
TX	Texas
US	United States
USA	United States of America
UT	Utah
V_{FF}	Volume (Far-Field)
V_{NF}	Volume (Near-Field)
VOC	Volatile Organic Compound
VT	Vermont
WA	Washington
WEEL	Workplace Environmental Exposure Level
WI	Wisconsin
WV	West Virginia
WWT	Wastewater Treatment
yr	Year

EXECUTIVE SUMMARY

TSCA § 6(b)(4) requires the United States Environmental Protection Agency (EPA) to establish a risk evaluation process. In performing risk evaluations for existing chemicals, EPA is directed 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." In December of 2016, EPA published a list of 10 chemical substances that are the subject of the Agency's initial chemical risk evaluations (81 FR 91927), as required by TSCA § 6(b)(2)(A). Perchloroethylene (PCE) was one of these chemicals.

PCE, also known as ethene, 1,1,2,2-tetrachloro, tetrachloroethylene, and PERC, is a colorless volatile liquid with a mildly sweet odor that is used primarily as a reactant, a dry cleaning solvent, a vapor degreasing solvent, and aerosol degreasing solvent and is subject to federal and state regulations and reporting requirements. PCE is a Toxics Release Inventory (TRI)-reportable substance effective January 1, 1987.

Focus of this Risk Evaluation

During scoping and problem formulation, EPA considered all known TSCA uses for PCE. PCE has been manufactured and imported in the U.S. in large volumes with the most recently available data from the 2016 Chemical Data Reporting (CDR) indicating approximately 324 million pounds were either manufactured or imported in the U.S. in 2015 (U.S. EPA, 2016d). The largest use of PCE are as a reactant/intermediate in the production of fluorinated compounds, such as hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs). The second largest use of PCE is as a dry cleaning solvent; however, in recent years, there appears to be a trend towards alternatives to PCE in the dry cleaning industry. The third most prevalent use of PCE is as a degreasing solvent for vapor degreasing machines, cold cleaning machines, and aerosol degreasing products (e.g., brake cleaners) that are used to clean contaminated metal parts or other fabricated materials.

Exposures to workers, consumers, general populations, and ecological species may occur from industrial, commercial, and consumer uses of PCE and releases to air, water or land. Workers and occupational non-users may be exposed to PCE during conditions of use such as manufacturing, import, processing, distribution, repackaging, dry cleaning, degreasing, recycling, disposal, and other miscellaneous uses of PCE. Consumers and bystanders may also be exposed to PCE via inhalation of PCE that volatizes during use of consumer products or dermal contact with products containing PCE. Exposures to the general population and ecological species may occur from industrial releases related to the manufacture, import, processing, distribution, and use of PCE.

Risk Evaluation Approach

EPA evaluated acute and chronic exposures to workers and occupational non-users in association with PCE conditions of use. EPA used inhalation monitoring data from literature sources where available and exposure models where monitoring data were not available or were deemed insufficient for capturing actual exposure within the condition of use. EPA also used modeling approaches to estimate dermal exposures. EPA evaluated releases to water from the conditions of use assessed in this risk evaluation. EPA used release data from literature sources where available and used modeling approaches where release data were not available.

Uncertainties of this Risk Evaluation

There are a number of uncertainties associated with the monitoring and modeling approaches used to assess PCE exposures and releases. For example, the sites used to collect exposure monitoring and release data were not selected randomly, and the data reported therein may not be representative of all sites pertaining to the exposure and release scenarios. Further, of necessity, modeling approaches employed knowledge-based assumptions that may not apply to all use scenarios. Because site-specific differences in use practices and engineering controls exist, but are largely unknown, this represents another source of variability that EPA could not quantify in the assessment.

Human and Ecological Populations Considered in this Risk Evaluation

EPA assessed risks for acute and chronic exposure scenarios in workers (those directly handling PCE) and occupational non-users (workers not directly involved with the use of PCE) for PCE in the uses outlined under *Focus of this Risk Evaluation*. EPA assumed that workers and occupational non-users would be individuals of both sexes (age 16 years and older, including pregnant workers) based upon occupational work permits, although exposures to younger workers in occupational settings cannot be ruled out. An objective of the monitored and modeled inhalation data was to provide separate exposure level estimates for workers and occupational non-users.

EPA assessed releases to water to estimate exposures to aquatic species. The water release estimates developed by EPA are used to estimate the presence of PCE in the environment and biota and evaluate the environmental hazards. The release estimates were used to model exposure to aquatic species where environmental monitoring data were not available.

1 INTRODUCTION

1.1 Overview

TSCA § 6(b)(4) requires the United States Environmental Protection Agency (EPA) to establish a risk evaluation process. In performing risk evaluations for existing chemicals, EPA is directed 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." In December of 2016, EPA published a list of 10 chemical substances that are the subject of the Agency's initial chemical risk evaluations (81 FR 91927), as required by TSCA § 6(b)(2)(A). Perchloroethylene (PCE) was one of these chemicals.

PCE, also known as ethene, 1,1,2,2-tetrachloro, tetrachloroethylene, and PERC, is a colorless volatile liquid with a mildly sweet odor that is used primarily as a reactant, a dry cleaning solvent, a vapor degreasing solvent, and aerosol degreasing solvent and is subject to federal and state regulations and reporting requirements. PCE is a TRI-reportable substance effective January 1, 1987.

1.2 Scope

Workplace exposures and releases to water have been assessed for the following industrial and commercial conditions of use of PCE:

1. Manufacturing;
2. Repackaging;
3. Processing as a Reactant;
4. Incorporation into Formulation, Mixture, or Reactant Product;
5. Batch Open-Top Vapor Degreasing;
6. Batch Closed-Loop Vapor Degreasing;
7. Conveyorized Vapor Degreasing;
8. Web Degreasing;
9. Cold Cleaning;
10. Aerosol Degreasing and Aerosol Lubricants;
11. Dry Cleaning and Spot Cleaning;
12. Adhesives, Sealants, Paints, and Coatings;
13. Maskant for Chemical Milling;
14. Industrial Processing Aid;
15. Metalworking Fluids;
16. Wipe Cleaning and Metal/Stone Polishes;
17. Other Spot Cleaning/Spot Removers (Including Carpet Cleaning);
18. Other Industrial Uses;
19. Other Commercial Uses; and
20. Waste Handling, Disposal, Treatment, and Recycling.

For work place exposures, EPA considered exposures to both workers who directly handle PCE and occupational non-users (ONUs) who do not directly handle PCE but may be exposed to vapors or mists that enter their breathing zone while working in locations in close proximity to where PCE is being used.

For purposes of this report, “releases to water” include both direct discharges to surface water and indirect discharges to publicly-owned treatment works (POTW) or non-POTW wastewater treatment (WWT). It should be noted that for purposes of risk evaluation, discharges to POTW and non-POTW WWT are not evaluated the same as discharges to surface water. EPA considers removal efficiencies of POTWs and WWT plants and environmental fate and transport properties when evaluating risks from indirect discharges. The purpose of this report is only to quantify direct and indirect discharges; therefore, these factors are not discussed. The details on how these factors were considered when determining risk are described in the *Risk Evaluation for Perchloroethylene (Ethene, 1,1,2,2-Tetrachloro)*.

The assessed conditions of use were described in Table 2-3 of the *Problem Formulation of the Risk Evaluation for Perchloroethylene (Ethene, 1,1,2,2-Tetrachloro)* (Problem Formulation Document) (U.S. EPA, 2018b); however, due to expected similarities in both processes and exposures/releases several of the subcategories of use in Table 2-3 were grouped and assessed together during the risk evaluation process. A crosswalk of the conditions of use in Table 2-3 to the conditions of use assessed in this report is provided in Table 1-1.

Table 1-1. Crosswalk of Subcategories of Use Listed in the Problem Formulation Document to Conditions of Use Assessed in the Risk Evaluation

Life Cycle Stage	Category[a]	Subcategory[b]	Assessed Condition of Use
Manufacture	Domestic Manufacture	Domestic Manufacture	Section 2.1 – Manufacturing
	Import	Import	Section 2.2 – Repackaging[a]
Processing	Processing as a Reactant/Intermediate	Intermediate in industrial gas manufacturing	Section 2.3 – Processing as a Reactant
		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 – Incorporation into Formulation, Mixture, or Reactant Product
		Adhesive and sealant products	
		Paint and coating products	

Life Cycle Stage	Category[a]	Subcategory[b]	Assessed Condition of Use
		Other chemical products and preparations	
	Incorporated into articles	Plastic and rubber products	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; therefore, no exposure scenario was developed for incorporation into articles. Use of PCE as a degreasing solvent at plastic manufacture sites is assessed with other degreasing scenarios in Sections 2.5 to 2.9
	Repackaging	Solvent for cleaning or degreasing	Section 2.2 – Repackaging
		Intermediate	
	Recycling	Recycling	Section 2.21 – Waste Handling, Disposal, Treatment, and Recycling
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."
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.
		Batch vapor degreaser (e.g., open-top, closed-loop)	Section 2.5 – Batch Open-Top Vapor Degreasing; Section 2.6 – Batch Closed-Loop Vapor Degreasing
		In-line vapor degreaser (e.g.,	Section 2.7 – Conveyorized Vapor Degreasing; Section 2.8 – Web Degreasing

Life Cycle Stage	Category[a]	Subcategory[b]	Assessed Condition of Use
		conveyorized, web cleaner)	
		Cold cleaner	Section 2.9 – Cold Cleaning
		Aerosol spray degreaser/cleaner	Section 2.10 – Aerosol Degreasing and Aerosol Lubricants
		Dry cleaning solvent	Section 2.11 – Dry Cleaning and Spot Cleaning
		Spot cleaner	
	Lubricants and greases	Lubricants and greases (e.g., penetrating lubricants, cutting tool coolants, aerosol lubricants)	Section 2.10 – Aerosol Degreasing and Aerosol Lubricants; Section 2.15 – Metalworking Fluids
	Adhesive and sealant chemicals	Solvent-based adhesives and sealants	Section 2.12 – Adhesive, Sealants, Paints, and Coatings
	Paints and coatings including paint and coating removers	Solvent-based paints and coatings, including for chemical milling	Section 2.12 – Adhesive, Sealants, Paints, and Coatings; Section 2.13 – Maskant for Chemical Milling
	Processing aids, not otherwise listed	Pesticide, fertilizer and other agricultural chemical manufacturing	Section 2.14 – Industrial Processing Aid
	Processing aids, specific to petroleum production	Catalyst regeneration in petrochemical manufacturing	Section 2.14 – Industrial Processing Aid
	Other uses	Textile processing	Section 2.17 – Other Spot Cleaning/Spot Removers (Including Carpet Cleaning); Section 2.18 – Other Industrial Uses
		Wood furniture manufacturing	Section 2.18 – Other Industrial Uses
		Laboratory chemicals	Section 2.20 – Laboratory Chemicals
		Foundry applications	Section 2.18 – Other Industrial Uses

Life Cycle Stage	Category[a]	Subcategory[b]	Assessed Condition of Use
		Other DoD Uses	Section 2.18 – Other Industrial Uses
Commercial/consumer use	Cleaning and furniture care products	Cleaners and degreasers (other)	Section 2.16 – Wipe Cleaning and Metal/Stone Polishes; Section 2.17 – Other Spot Cleaning/Spot Removers (Including Carpet Cleaning); Section 2.19 – Other Commercial Uses
		Dry cleaning solvent	Section 2.11 – Dry Cleaning and Spot Cleaning
		Spot cleaner	
		Automotive care products (e.g., engine degreaser and brake cleaner)	Section 2.10 – Aerosol Degreasing and Aerosol Lubricants
		Aerosol cleaner	
		Non-aerosol cleaner	Section 2.16 – Wipe Cleaning and Metal/Stone Polishes
	Lubricants and greases	Lubricants and greases (e.g., penetrating lubricants, cutting tool coolants, aerosol lubricants)	Section 2.10 – Aerosol Degreasing and Aerosol Lubricants; Section 2.15 – Metalworking Fluids
	Adhesives and sealant chemicals	Adhesives for arts and crafts	Not assessed in occupational settings – consumer use only
		Light repair adhesives	Section 2.12 – Adhesive, Sealants, Paints, and Coatings
	Paints and coatings	Solvent-based paints and coatings	Section 2.12 – Adhesive, Sealants, Paints, and Coatings
	Other Uses	Carpet cleaning	Section 2.17 – Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)
		Laboratory chemicals	Section 2.20 – Laboratory Chemicals
		Metal (e.g., stainless steel) and stone polishes	Section 2.16 – Wipe Cleaning and Metal/Stone Polishes

Life Cycle Stage	Category[a]	Subcategory[b]	Assessed Condition of Use
		Inks and ink removal products	Section 2.19 – Other Commercial Uses
		Welding	Section 2.10 – Aerosol Degreasing and Aerosol Lubricants[b]
		Photographic film	Section 2.19 – Other Commercial Uses
		Mold cleaning, release and protectant products	Section 2.19 – Other Commercial Uses
Disposal	Disposal	Industrial pre-treatment	Section 2.21 – Waste Handling, Disposal, Treatment, and Recycling[c]
		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	

[a] 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 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.

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

[c] 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.

1.3 Components of the Occupational Exposure and Environmental Release Assessment

The occupational exposure and environmental release assessment of each condition of use comprises the following components:

- **Estimates of Number of Facilities:** An estimate of the number of sites that use PCE for the given condition of use.
- **Process Description:** A description of the condition of use, including the role of the chemical in the use; process vessels, equipment, and tools used during the condition of use.
- **Worker Activities:** A descriptions of the worker activities, including an assessment for potential points of worker and occupational non-user (ONU) exposure.
- **Number of Workers and Occupational Non-Users:** An estimate of the number of workers and occupational non-users potentially exposed to the chemical for the given condition of use.
- **Occupational Inhalation Exposure Results:** Central tendency and high-end estimates of inhalation exposure to workers and occupational non-users. See Section 1.4.5 for a discussion of EPA's statistical analysis approach for assessing inhalation exposure.
- **Water Release Sources:** A description of each of the potential sources of water releases in the process for the given condition of use.
- **Water Release Assessment Results:** Estimates of chemical released into water (surface water, POTW, or non-POTW WWT).

In addition to the above components for each condition of use, a separate dermal exposure section is included that provides estimates of the dermal exposures for all the assessed conditions of use.

1.4 General Approach and Methodology for Occupational Exposures and Environmental Releases

1.4.1 Estimates of Number of Facilities

Where available, EPA used 2016 CDR (U.S. EPA, 2016d), 2016 TRI (U.S. EPA, 2017d), 2016 Discharge Monitoring Report (DMR) (U.S. EPA, 2016b) and 2014 National Emissions Inventory (NEI) (U.S. EPA, 2016a) 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:

1. Information on known uses of the chemical and market data identifying the most prevalent conditions of use of the chemical.
2. 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.

1.4.2 Process Description

EPA performed a literature search to find descriptions of processes involved in each condition of use. Where process descriptions were unclear or not available, EPA referenced relevant Emission Scenario Documents (ESD) or Generic Scenarios (GS). Process descriptions for each condition of use can be found in Section 2.

1.4.3 Worker Activities

EPA performed a literature search to identify worker activities that could potentially result in occupational exposures. Where worker activities were unclear or not available, EPA referenced relevant ESD's or GS's. Worker activities for each condition of use can be found in Section 2.

1.4.4 Number of Workers and Occupational Non-Users

Where available, EPA used CDR data to provide a basis to estimate the number of workers and ONUs. EPA supplemented the available CDR data with U.S. economic data using the following method:

1. Identify the North American Industry Classification System (NAICS) codes for the industry sectors associated with these uses.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics (OES) data (BLS Data).
3. Refine the OES estimates where they are not sufficiently granular by using the U.S. Census' Statistics of US Businesses (SUSB) (SUSB Data) data on total employment by 6-digit NAICS.

4. Use market penetration data to estimate the percentage of employees likely to be using PCE instead of other chemicals.
5. Where market penetration data are not available, use the estimated workers/ONUs per site in the 6-digit NAICS code and multiply by the number of sites estimated from CDR, TRI, DMR and/or NEI. In DMR data, sites report Standard Industrial Classification (SIC) codes rather than NAICS codes; therefore, EPA mapped each reported SIC code to a NAICS code for use in this analysis.
6. Combine the data generated in Steps 1 through 5 to produce an estimate of the number of employees using PCE in each industry/occupation combination, and sum these to arrive at a total estimate of the number of employees with exposure within the condition of use.

1.4.5 Inhalation Exposure Assessment Approach and Methodology

1.4.5.1 General Approach

EPA provided occupational exposure results representative of *central tendency* conditions *and high-end* conditions. A central tendency is assumed to be representative of occupational exposures in the center of the distribution for a given condition of use. For risk evaluation, EPA used the 50th percentile (median), mean (arithmetic or geometric), mode, or midpoint values of a distribution as representative of the central tendency scenario. EPA's preference is to provide the 50th percentile of the distribution. However, if the full distribution is not known, EPA may assume that the mean, mode, or midpoint of the distribution represents the central tendency depending on the statistics available for the distribution.

A high-end is assumed to be representative of occupational exposures that occur at probabilities above the 90th percentile but below the exposure of the individual with the highest exposure (U.S. EPA, 1992). For risk evaluation, EPA provided high-end results at the 95th percentile. 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 occupational exposures, EPA used measured or estimated air concentrations to calculate exposure concentration metrics required for risk assessment, such as average daily concentration (ADC) and lifetime average daily concentration (LADC). These calculations require additional parameter inputs, such as years of exposure, exposure duration and frequency, and lifetime years. EPA estimated exposure concentrations from monitoring data, modeling, or occupational exposure limits.

For the final exposure result metrics, each of the input parameters (e.g., air concentrations, working years, exposure frequency, lifetime years) may be a point estimate (i.e., a single descriptor or statistic, such as central tendency or high-end) or a full distribution. EPA considered three general approaches for estimating the final exposure result metrics:

- Deterministic calculations: EPA used combinations of point estimates of each parameter to estimate a central tendency and high-end for each final exposure metric result. EPA documented the method and rationale for selecting parametric combinations to be representative of central tendency and high-end in Appendix B.
- Probabilistic (stochastic) calculations: EPA used Monte Carlo simulations using the full distribution of each parameter to calculate a full distribution of the final exposure metric results

and selecting the 50th and 95th percentiles of this resulting distribution as the central tendency and high-end, respectively.

- Combination of deterministic and probabilistic calculations: EPA had full distributions for some parameters but point estimates of the remaining parameters. For example, EPA used Monte Carlo modeling to estimate exposure concentrations, but only had point estimates of exposure duration and frequency, and lifetime years. In this case, EPA documented the approach and rationale for combining point estimates with distribution results for estimating central tendency and high-end results in Appendix B.

EPA follows the following hierarchy in selecting data and approaches for assessing inhalation exposures:

1. Monitoring data:
   a. Personal and directly applicable
   b. Area and directly applicable
   c. Personal and potentially applicable or similar
   d. Area and potentially applicable or similar
2. Modeling approaches:
   a. Surrogate monitoring data
   b. Fundamental modeling approaches
   c. Statistical regression modeling approaches
3. Occupational exposure limits:
   a. Company-specific OELs (for site-specific exposure assessments, e.g., there is only one manufacturer who provides to EPA their internal OEL but does not provide monitoring data)
   b. OSHA PEL
   c. Voluntary limits (ACGIH TLV, NIOSH REL, Occupational Alliance for Risk Science (OARS) workplace environmental exposure level (WEEL) [formerly by AIHA])

1.4.5.2 Approach for this Risk Evaluation

EPA reviewed workplace inhalation monitoring data collected by government agencies such as OSHA and NIOSH, monitoring data found in published literature (i.e., personal exposure monitoring data and area monitoring data), and monitoring data submitted via public comments. Studies were evaluated using the evaluation strategies laid out in the *Application of Systematic Review in TSCA Risk Evaluations* (U.S. EPA, 2018a).

Exposures are calculated from the datasets provided in the sources depending on the size of the dataset. For datasets with six or more data points, central tendency and high-end exposures were estimated using the 50th percentile and 95th percentile. For datasets with three to five data points, central tendency exposure was calculated using the 50th percentile and the maximum was presented as the high-end exposure estimate. For datasets with two data points, the midpoint was presented as a midpoint value and the higher of the two values was presented as a higher value. Finally, data sets with only one data point presented the single exposure value. 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) which recommends 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. Specific details related to each condition of use can be found in Section 2. For each condition of use, these values were used to calculate acute and chronic (non-cancer and cancer) exposures. Equations and sample calculations for chronic exposures can be found in Appendix B and Appendix C, respectively.

EPA used exposure monitoring data or exposure models to estimate inhalation exposures for all conditions of use. Specific details related to the use of monitoring data for each condition of use can be found in Section 2. Descriptions of the development and parameters used in the exposure models used for this assessment can be found in Appendix E through Appendix I.

1.4.5.3 Approach to Monitoring Data Obtained from OSHA's Chemical Exposure Health Data (CEHD)

A key source of monitoring data is samples collected by OSHA during facility inspections. OSHA inspection data are compiled in an agency information system (OIS) for internal use. Air sampling data records from inspections are entered into the OSHA Chemical Exposure Health Database (CEHD) that can be accessed on the agency website (https://www.osha.gov/opengov/healthsamples.html). The database includes personal breathing zone (PBZ) monitoring data, area monitoring data, bulk samples, wipe samples, and serum samples. The collected samples are used for comparing to OSHA's Permissible Exposure Limits (PEL). OSHA's CEHD website indicates that they do not: perform routine inspections at every business that uses toxic/hazardous chemicals, completely characterize all exposures for all employees every day, or always obtain a sample for an entire shift. Rather, OSHA performs targeted inspections of certain industries based on National and regional emphasis programs, often attempts to evaluate worst case chemical exposure scenarios, and develop "snapshots" of chemical exposures and assess their significance (e.g., comparing measured concentrations to PELs).

EPA takes the following approach to analyzing OSHA CEHD:

1. Download all data for PCE from all available years in the CEHD (generally 1984-present).
2. Organize data by site (group data collected at the same site together).
3. Remove data in which all measurements taken at the site were recorded as "0" or below the limit of detection as EPA cannot be certain the chemical of interest was at the site at the time of the inspection (Note: sites where bulk samples were collected that indicate PCE was present were not removed from the data set).
4. Remove serum samples, bulk samples, wipe samples, and blanks. These data are not used in EPA's assessment.
5. Assign each data point to an OES. Review NAICS codes, SIC codes, and as needed, company information available online, to map each sample to an OES. In some instances, EPA was not able to determine the OES from the information in the CEHD; in such cases, EPA did not use the data in the assessment. EPA also removed data determined to be for non-TSCA uses or otherwise out of scope.
6. Combine samples from the same worker. In some instances, OSHA inspectors will collect multiple samples from the same worker on the same day (these are indicated by sample ID numbers). In these cases, EPA combined results from each sample to construct a exposure concentration based on the totality of exposures from each sample.
7. Occasionally, one or all the samples associated with a single sample number measured below the limit of detection. Because the samples were often on different time scales (e.g., one hour vs four hours), EPA did not include these data in the statistical analysis to estimate values below the LOD as described in Section 1.4.5.2. Sample results from different time scales may vary greatly as short activities my cause a

large, short-term exposure that when averaged over a full-shift are comparable to other full-shift data. Therefore, including data of different time scales in the analysis may give the appearance of highly skewed data when in fact the full-shift data is not skewed. Therefore, EPA performed the statistical analysis (as needed) using all the non-OSHA CEHD data for each OES and applied the approach determined by the analysis to the non-detects in the OSHA CEHD data. Where all the exposure data for an OES came from CEHD, EPA used only the 8-hr TWAs that did not include samples that measured below the LOD to perform the statistical analysis.

8. Calculate 8-hr TWA results from combined samples. Where the total sample time was less than eight hours, EPA calculated an 8-hr TWA by assuming exposures were zero for the remainder of the shift.

It should be noted that the OSHA CEHD does not provide job titles or worker activities associated with the samples; therefore, EPA assumed all data were collected on workers and not ONUs.

1.4.6 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 (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 2.22 and equations and sample calculations for estimate dermal exposures can be found in Appendix K.

1.4.7 Consideration of Engineering Controls and Personal Protective Equipment

OSHA and NIOSH recommend 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 ensure no leaks) to reduce exposure potential. Administrative controls are policies and procedures instituted and overseen by the employer to limit worker exposures. Under §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 § 1910.134(a)(1). The PPE (*e.g.*, respirators, gloves) could be used as the last means of control, when the other control measures cannot reduce workplace exposure to an acceptable level.

OSHA's Respiratory Protection Standard (29 CFR § 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 § 1910.134(d)(3)(i)(A) (see below in Table 1-2) 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 1-2. 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.

Table 1-2. 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 § 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. The survey was sent to a sample of 40,002 establishments designed to represent all private sector establishments. The survey had a 75.5% response rate (Niosh, 2003). A voluntary survey may not be representative of all private industry respirator use patterns as some establishments with low or no respirator use may choose to not respond to the survey. Therefore, results of the survey may potentially be biased towards higher respirator use.

NIOSH and BLS estimated about 619,400 establishments used respirators for voluntary or required purposes (including emergency and non-emergency uses). About 281,800 establishments (45%) were estimated to have had respirator use for required purposes in the 12 months prior to the survey. The 281,800 establishments estimated to have had respirator use for required purposes were estimated to be approximately 4.5% of all private industry establishments in the U.S. at the time (Niosh, 2003).

The survey found that the establishments that required respirator use had the following respirator program characteristics (Niosh, 2003):

- 59% provided training to workers on respirator use.
- 34% had a written respiratory protection program.
- 47% performed an assessment of the employees' medical fitness to wear respirators.
- 24% included air sampling to determine respirator selection.

The survey report does not provide a result for respirator fit testing or identify if fit testing was included in one of the other program characteristics.

Of the establishments that had respirator use for a required purpose within the 12 months prior to the survey, NIOSH and BLS found (Niosh, 2003):

- Non-powered air purifying respirators are most common, 94% overall and varying from 89% to 100% across industry sectors.
- Powered air-purifying respirators represent a minority of respirator use, 15% overall and varying from 7% to 22% across industry sectors.
- Supplied air respirators represent a minority of respirator use, 17% overall and varying from 4% to 37% across industry sectors.

Of the establishments that used non-powered air-purifying respirators for a required purpose within the 12 months prior to the survey, NIOSH and BLS found (Niosh, 2003):

- A high majority use dust masks, 76% overall and varying from 56% to 88% across industry sectors.
- A varying fraction use half-mask respirators, 52% overall and varying from 26% to 66% across industry sectors.
- A varying fraction use full-facepiece respirators, 23% overall and varying from 4% to 33% across industry sectors.

Table 1-3 summarizes the number and percent of all private industry establishments and employees that used respirators for a required purpose within the 12 months prior to the survey and includes a breakdown by industry sector (Niosh, 2003).

Table 1-3. Number and Percent of Establishments and Employees Using Respirators Within 12 Months Prior to Survey

Industry	Establishments		Employees	
	Number	Percent of All Establishments	Number	Percent of All Employees
Total Private Industry	281,776	4.5	3,303,414	3.1
Agriculture, forestry, and fishing	13,186	9.4	101,778	5.8
Mining	3,493	11.7	53,984	9.9
Construction	64,172	9.6	590,987	8.9
Manufacturing	48,556	12.8	882,475	4.8
Transportation and public utilities	10,351	3.7	189,867	2.8
Wholesale Trade	31,238	5.2	182,922	2.6
Retail Trade	16,948	1.3	118,200	0.5
Finance, Insurance, and Real Estate	4,202	0.7	22,911	0.3
Services	89,629	4.0	1,160,289	3.2

OSHA’s hand protection standard (29 CFR § 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 1-4, 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.

Table 1-4. 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

1.4.8 Water Release Sources

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 release sources were unclear or not available, EPA referenced relevant ESD's or GS's. Water release sources for each condition of use can be found in Section 2.

1.4.9 Water Release Assessment Approach and Methodology

Where available, EPA used 2016 TRI (U.S. EPA, 2017d) and 2016 DMR (U.S. EPA, 2016b) 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 (25,000 pounds for manufacturers and processors of PCE and 10,000 pounds 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 (U.S. EPA, 2016b), 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.

Where releases are expected but TRI and DMR data were not available or where EPA determined TRI and DMR data did not capture the entirety of water releases for a condition of use, releases were estimated using release data from literature, relevant ESD's or GS's, existing EPA 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. Specific details related to the use of release data or models for each condition of use can be found in Section 2.

For each condition of use EPA estimated annual releases, average daily releases, and number of release days per year. 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 expected release days per year. 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.

1.5 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.

1.5.1 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 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 activity (U.S. EPA, 2020a, b). 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, b). 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 crosswalking 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 to 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 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.

1.5.2 Results and Uncertainties in the Mass Balance

Figure 1-1 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 most 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.

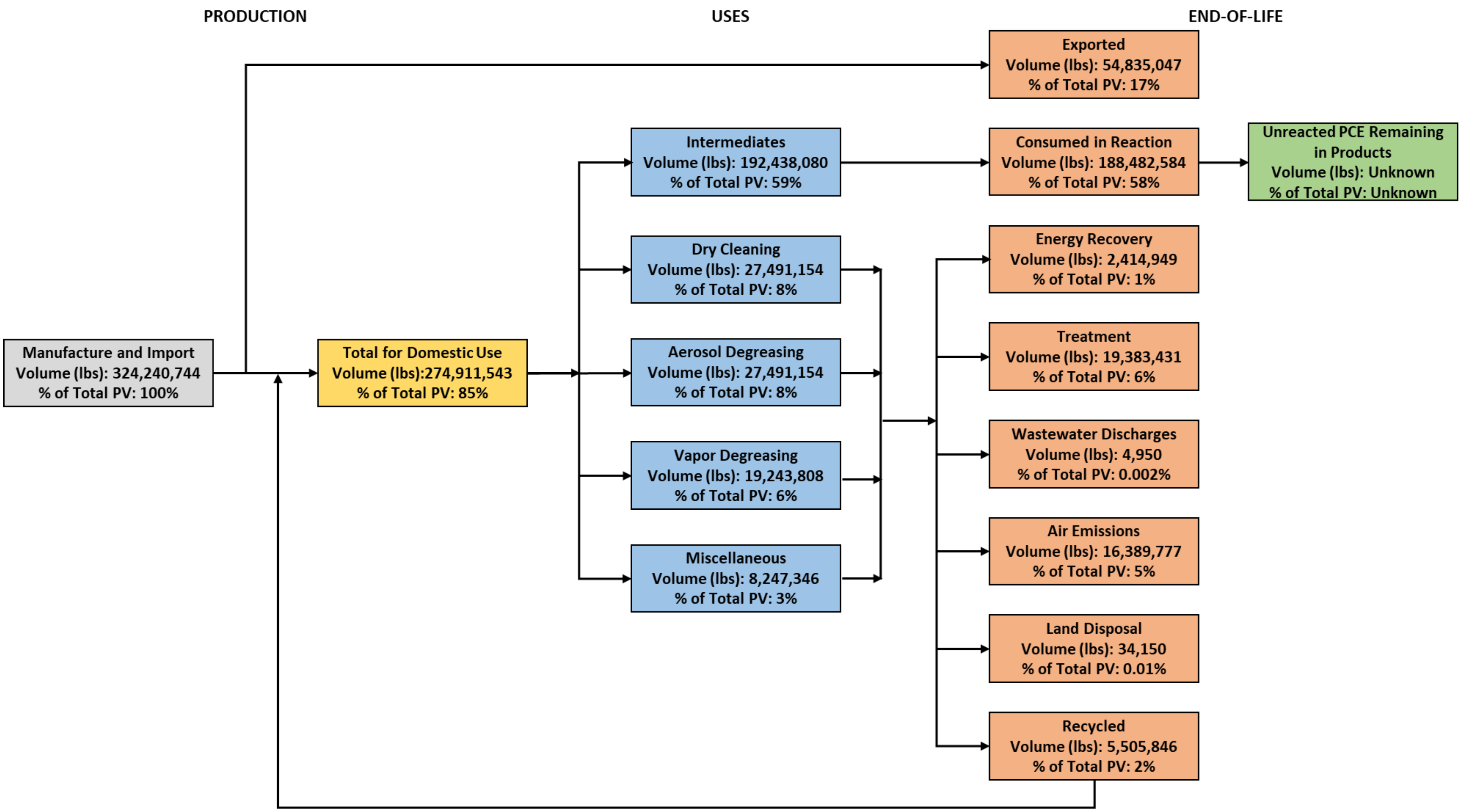

Figure 1-1. Mass Balance for Perchloroethylene

2 Engineering Assessment

The following sections contain process descriptions and the specific details (worker activities, analysis for determining number of workers, exposure assessment approach and results, release sources, media of release, and release assessment approach and results) for the assessment for each condition of use.

EPA assessed the conditions of use as stated in the *Problem Formulation of the Risk Evaluation for Perchloroethylene (Ethene, 1,1,2,2-Tetrachloro)* published by EPA in May 2018 (U.S. EPA, 2018b).

2.1 Manufacturing

2.1.1 Estimates of Number of Facilities

The 2016 CDR data show a total of 320,258,381 lb of PCE manufactured in the U.S. in 2015 (U.S. EPA, 2016d). In the 2016 CDR, there are four sites that domestically manufacture PCE and eight sites where the domestic manufacture/import activity field is either claimed as confidential business information (CBI) or withheld (U.S. EPA, 2016d). Of the eight sites, four reported 0 lb of PCE imported or manufactured for reporting year 2015 (U.S. EPA, 2016d). EPA assumed manufacture/import of PCE at these sites has ceased.

To determine whether the remaining four CDR sites were manufacturers or importers, EPA mapped the sites to 2016 TRI data using the facility names and addresses and found that two of the sites reported manufacturing PCE in TRI (U.S. EPA, 2017d). EPA assumed the other two sites for which the activity could not be determined through CDR or TRI may import or manufacture PCE. Therefore, there may be up to eight sites that domestically manufacture PCE. It should be noted that EPA only considered sites reporting to the 2016 CDR for the universe of manufacturing sites and supplemented the CDR data with TRI data to overcome CBI claims or withheld data in the 2016 CDR. Other sites in TRI may have reported "producing the chemical" for PCE; however, based on the process described in Section 1.4.1, EPA assessed a different condition of use at these sites and did not consider them for manufacturing to avoid double counting.

In the 2016 CDR, one site reported 131,453 lb of PCE manufactured in 2015 and another reported 77,380,652 lb manufactured in 2015 (U.S. EPA, 2016d). The remaining sites claimed their manufacturing volumes as CBI (U.S. EPA, 2016d). EPA estimated the average annual production rate at the other seven manufacturing sites by subtracting the known volume and averaging the remaining production volume across the seven sites. This resulted in an average annual production volume of 40,457,713 lb per site. Table 2-1 lists the PCE manufacturing facilities and their production volumes.

Table 2-1. List of Assessed Perchloroethylene Manufacturing Sites

Site	Basis for Manufacturing Determination	Assessed Production Volume (lb/site-yr)	Production Volume Basis
Axiall Corporation, Westlake, LA	2016 CDR	77,380,652	2015 reported production volume in CDR
Blue Cube Operations LLC - Plaquemine Site, Plaquemine, LA	2016 CDR	40,457,713	Average of unallocated 2015 National Production Volume
Geon Oxy Vinyl Laporte Plant, Laporte, TX[a]	2016 TRI	40,457,713	Average of unallocated 2015 National Production Volume
Greenchem, West Palm Beach, FL	Activity unknown; assumed manufacturer	40,457,713	Average of unallocated 2015 National Production Volume
Occidental Chemical Corp Geismar Plant, Geismar, LA	2016 TRI	40,457,713	Average of unallocated 2015 National Production Volume
Olin Blue Cube, Freeport, TX	2016 CDR	40,457,713	Average of unallocated 2015 National Production Volume
Solvents & Chemicals, Pearland, TX	2016 CDR	131,453	2015 reported production volume in CDR
Univar USA Inc, Redmond, WA	Activity unknown; assumed manufacturer	40,457,713	Average of unallocated 2015 National Production Volume

[a] The site name listed here is based on its 2016 CDR reported site name. In the 2016 TRI, the site is listed as “Oxy Vinyls LP La Porte VCM Plant”. EPA determined they are the same site as the address in each database is the same and in 1999 the site became a part of the newly formed Oxy Vinyls, LP which is a joint venture of the Occidental Petroleum Corporation and The Geon Company (Hydrocarbon Online, 1999).

2.1.2 Process Description

PCE was previously produced through chlorination of acetylene to tetrachloroethane, then dehydrochlorination to trichloroethylene (TCE), followed by chlorination of TCE to pentachloroethane and finally dehydrochlorination to PCE (Snedecor et al., 2004). The last U.S. plant using the acetylene process was shut down in 1978 (Snedecor et al., 2004). Currently, most PCE is manufactured using one of three methods: chlorination of ethylene dichloride (EDC); chlorination of hydrocarbons containing one to three carbons (C1 to C3) or their partially chlorinated derivatives; or oxychlorination of two-carbon (C2) chlorinated hydrocarbons (Atsdr, 2014; Snedecor et al., 2004; U.S. EPA, 1985).

The chlorination of EDC involves a non-catalytic reaction of chlorine and EDC or other C2 chlorinated hydrocarbons to form PCE and TCE as co-products and hydrochloric acid (HCl) as a byproduct (Atsdr, 2014; Snedecor et al., 2004; U.S. EPA, 1985). The chlorination of C1-C3 hydrocarbons involves the reaction of chlorine with a hydrocarbon such as methane, ethane, propane, propylene or their chlorinated derivatives, at high temperatures (550–700°C), with or without a catalyst, to form PCE and carbon tetrachloride (CCl_4) as co-products and HCl as a byproduct (Atsdr, 2014; Snedecor et al., 2004; U.S. EPA, 1985). The oxychlorination of C2 chlorinated hydrocarbons involves the reaction of either chlorine or HCl and oxygen with EDC in the presence of a catalyst to produce PCE and TCE as co-products (Atsdr, 2014; Snedecor et al., 2004). In all three processes the product ratio of PCE to TCE/CCl_4 products are controlled by adjusting the reactant ratios (Snedecor et al., 2004).

2.1.3 Exposure Assessment

2.1.3.1 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 are therefore expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs for manufacturing 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.

2.1.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed to PCE at manufacturing sites using 2016 CDR (U.S. EPA, 2016d) data (where available), Bureau of Labor Statistics' OES data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). The method for estimating number of workers from the Bureau of Labor Statistics' OES data and U.S. Census' SUSB data is detailed in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census.

2016 CDR data for number of workers are available for six manufacturing sites. Of the six sites, four sites reported 100 to 500 workers, one site reported 50 to 100 workers, and one site reported 25 to 50 workers (U.S. EPA, 2016d). For the other two manufacturing sites, the number of workers in CDR is claimed CBI (U.S. EPA, 2016d).

EPA identified the NAICS code 325199, All Other Basic Organic Chemical Manufacturing, as the code expected to include sites manufacturing PCE. Based on data from the BLS for this NAICS code and related SOC codes, there are an average of 39 workers and 18 ONUs per site, or a total of 57 potentially exposed workers and ONUs, for sites under this NAICS code (U.S. BLS, 2016; U.S. Census Bureau, 2015). This is consistent with the one site reporting 50 to 100 workers and only slightly higher than the one site reporting 25 to 50 workers.

To determine the average number of workers, EPA used the average of the ranges reported in CDR for the six sites where data were available, and the average worker and ONUs estimates from the BLS analysis for the other two sites. 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; U.S. Census Bureau, 2015). This resulted in approximately 640 workers and 300 ONUs (see Table 2-2).

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

Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
2[a]	39	18	77	36	114
4[b]	204	96	816	384	1,200
1[c]	51	24	51	24	75
1[d]	25	12	25	12	38
Total[e]	120	57	970	460	1,400

[a] For the sites using values from the BLS analysis, the total number of workers and occupational non-users are calculated using the number of workers and occupational non-users per site and estimated from BLS and multiplying by the four sites. The number of workers and occupational non-users per site presented in the table round the values estimated from the BLS analysis to the nearest integer.
[b] Number of workers and occupational non-users per site estimated by taking the average of 100 and 499 (per 2016 CDR) and multiplying by 68% and 32%, respectively. Values are rounded to the nearest integer.
[c] Number of workers and occupational non-users per site estimated by taking the average of 50 and 99 (per 2016 CDR) and multiplying by 68% and 32%, respectively. Values are rounded to the nearest integer.
[d] Number of workers and occupational non-users per site estimated by taking the average of 25 and 49 (per 2016 CDR) and multiplying by 68% and 32%, respectively. Values are rounded to the nearest integer.
[e] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.1.3.3 Occupational Exposure Results

EPA assessed inhalation exposures during manufacturing using identified monitoring data. Table 2-3 summarizes 8-hr and 12-hr TWA samples obtained from data submitted by the Halogenated Solvents Industry Alliance (HSIA) via public comment for three companies (HSIA, 2018). A HSIA public comment on the draft risk evaluation of carbon tetrachloride identified the following job titles as ONUs: Administration II (Process Supervisor), Electrician, and Utilities Control Board Technician (EPA-HQ-OPPT-2019-0499-0022). As described in Section 2.1.2, carbon tetrachloride and PCE can be co-products of the same reaction; therefore, EPA assumed similar job titles in the HSIA exposure data for PCE were also ONUs.

Three additional studies with monitoring data for manufacturing were identified; however, the data from these studies were not used in the assessment. Two of these studies were from China and almost 30 years old and are unlikely to be representative of current conditions at U.S. manufacturing sites (Seiji et al., 1990; Seiji et al., 1989). The third study provides data collected in 1982 from a Dow Chemical site manufacturing PCE and carbon tetrachloride; however, this site was not identified as a current manufacturer of PCE (see Table 2-1) (Dow Chem Co, 1983c). Due to the age of the collected data (over 30 years old) and the fact the site is no longer identified as manufacturing PCE coupled with the availability of more recent monitoring data from current manufacturing sites, EPA did not include the data from the Dow Chemical site in this analysis.

HSIA (2018) provided monitoring data for PCE collected by three companies listed as “Company A”, “Company B”, and “Company C”. The data were collected between 2006 and 2018 with full-shift data collected over 8 to 12 hours during which workers engaged in a variety of activities including collecting catch samples; performing filter changes; line and equipment opening; loading and unloading; process sampling; and transferring of hazardous wastes (HSIA, 2018).

EPA assessed exposures for both 8-hr and 12-hr exposures separately. The high-ends for the 15-min, 30-min, 8-hr, and 12-hr TWAs 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 the half the LOD and the LOD, respectively. It should be noted that approximately 65% of the 8-hr TWA exposure data and 73% of the 12-hr 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 1.4.5.2. The geometric standard deviation for both 8-hr TWA data and 12-hr TWA data were both 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 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.

It should also be noted that 18 8-hr TWA exposure 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 2-3. Summary of Worker Inhalation Monitoring Data for the Manufacture of Perchloroethylene

Scenario	8- or 12-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	15- or 30-minute TWA (ppm)	Number of Short-term Data Points
Worker Monitoring Data							
8-hr TWA Results						*15-minute TWA Results*	
High-End	2.7	0.9	0.6	0.3	63[a]	15	161
Central Tendency	3.3E-2	1.1E-2	7.4E-3	2.9E-3		2.0	
12-hr TWA Results						*30-minute TWA Results*	
High-End	0.2	0.1	4.9E-2	2.5E-2	74	12	38[b]
Central Tendency	2.1E-2	1.0E-2	4.7E-3	1.9E-3		0.7	
ONU Monitoring Data							
8-hr TWA Results						No 30-minute or 15-minute data identified for ONUs	
High-End	9.2E-2	3.1E-2	2.1E-2	1.1E-2	12		
Central Tendency	3.4E-2	1.1E-2	7.7E-3	3.1E-3			
12-hr TWA Results							
High-End	4.5E-2	2.3E-2	1.0E-2	5.3E-3	3		
Central Tendency	2.3E-2	1.1E-2	5.1E-3	2.0E-3			

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[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, 2018)

2.1.4 Water Release Assessment

2.1.4.1 Water Release Sources

In general, potential sources of water releases in the chemical industry may include the following: equipment cleaning operations, aqueous wastes from scrubbers/decanters, reaction water, process water from washing intermediate products, and trace water settled in storage tanks (OECD, 2011a). Based on the process for manufacturing PCE, EPA expects the sources of water releases to be from aqueous wastes from decanters used to separate catalyst fines, caustic neutralizer columns and caustic scrubbers; and water removed from the PCE product in drying columns (U.S. EPA, 1989). Additional water releases may occur if a site uses of water to clean process equipment; however, EPA does not expect this to be a primary source of water releases from manufacturing sites as equipment cleaning is not expected to occur daily and manufacturers are expected to use an organic solvent to clean process equipment.

2.1.4.2 Water Release Assessment Results

Of the eight manufacturing sites assessed, four reported in the 2016 TRI (U.S. EPA, 2017d). For these sites, EPA assessed water releases as reported in the 2016 TRI (U.S. EPA, 2017d). For the remaining four sites, EPA assessed water releases at the maximum daily and maximum average monthly concentrations allowed under the Organic Chemicals, Plastics and Synthetic Fibers (OCPSF) Effluent Guidelines and Standards (U.S. EPA, 2019b). Effluent Guidelines (EGs) are national regulatory standards set forth by EPA for wastewater discharges to surface water and municipal sewage treatment plants. The OCPSF EG applies to facilities classified under the following SIC codes:

- 2821—Plastic Materials, Synthetic Resins, and Nonvulcanizable Elastomers;
- 2823—Cellulosic Man-Made Fibers;
- 2865—Cyclic Crudes and Intermediates, Dyes, and Organic Pigments; and
- 2869—Industrial Organic Chemicals, Not Elsewhere Classified (U.S. EPA, 2019b).

Manufacturers of PCE would typically be classified under SIC code 2869; therefore, the requirements of the OCPSF EG apply to these sites. Subparts I, J, and K of the OCPSF EG set limits for the concentration of PCE in wastewater effluents for industrial facilities that are direct discharge point sources using end-of-pipe biological treatment, direct discharge point sources that do not use end-of-pipe biological treatment, and indirect discharge point sources, respectively (U.S. EPA, 2019b). Direct dischargers are facilities that discharge effluents directly to surface waters and indirect dischargers are facilities that discharge effluents to publicly-owned treatment works (POTW). The OCPSF limits for PCE are provided in Table 2-4.

Table 2-4. Summary of OCPSF Effluent Guidelines for Perchloroethylene

OCPSF Subpart	Maximum for Any One Day (µg/L)	Maximum for Any Monthly Average (µg/L)	Basis
Subpart I – Direct Discharge Point Sources That Use End-of-Pipe Biological Treatment	56	22	BAT effluent limitations and NSPS
Subpart J – Direct Discharge Point Sources That Do Not Use End-of-Pipe Biological Treatment	164	52	BAT effluent limitations and NSPS
Subpart K – Indirect Discharge Point Sources	164	52	Pretreatment Standards for Existing Sources (PSES) and Pretreatment Standards for New Sources (PSNS)

BAT = Best Available Technology Economically Achievable; NSPS = New Source Performance Standards; PSES = Pretreatment Standards for Existing Sources; PSNS = Pretreatment Standards for New Sources.
Source: 40 C.F.R. 414

EPA did not identify PCE-specific information on the amount of wastewater produced per day. The Specific Environmental Release Category (SpERC) developed by the European Solvent Industry Group for the manufacture of a substance estimates 10 m^3 of wastewater generated per metric ton of substance produced (European Solvents Industry Group, 2012). In lieu of PCE-specific information, EPA estimated water releases using the SpERC specified wastewater production volume and the annual PCE production rates from each facility as shown in Table 2-1 in Section 2.1.1.

EPA estimated both a maximum daily release and an average daily release using the OCPSF EG limitations for PCE for maximum on any one day, and maximum for any monthly average, respectively. Prevalence of end-of-pipe biological treatment at PCE manufacturing sites is unknown; therefore, EPA used limitations for direct discharges with no end-of-pipe biological treatment and indirect dischargers to give most protective estimate. EPA estimated annual releases from the average daily release and assuming 350 days/yr of operation[1]. Details of the approach and sample calculations for estimating water release using the OCPSF EG limitations are provided in Appendix D.

Table 2-5 summarizes water releases from the manufacturing process for sites reporting to the 2016 TRI and Table 2-6 summarizes water releases from sites not reporting to the 2016 TRI.

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[1] Due to large throughput, manufacturing sites are assumed to operate seven days per week and 50 weeks per year with two weeks per year for shutdown activities.

Table 2-5. Reported Wastewater Discharges of Perchloroethylene from Manufacturing Sites Reporting to 2016 TRI

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Average Daily Release[a] (kg/day)	NPDES Code	Release Media/ Treatment Facility Type
Blue Cube Operations LLC - Plaquemine Site, Plaquemine, LA	0	N/A	0	Not available	N/A
Geon Oxy Vinyl Laporte Plant, Laporte, TX	0	N/A	0	TX0070416	N/A
Occidental Chemical Corp Geismar Plant, Geismar, LA	0.6	350	1.7E-3	LA0002933	Surface Water
Olin Blue Cube, Freeport, TX	15	350	4.1E-2	Not available	Non-POTW WWT

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment; N/A = Not applicable

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 350 days of operation per year.

Source: (U.S. EPA, 2017d)

Table 2-6. Estimated Wastewater Discharges of Perchloroethylene from Manufacturing Sites Not Reporting to 2016 TRI

Site	Annual Operating Days (days/yr)	Daily Production Volume[a] (kg/day)	Daily Wastewater Flow[b] (L/day)	Maximum Daily Release[c] (kg/day)	Average Daily Release[d] (kg/day)	Average Annual Release[e] (kg/yr)	NPDES Code	Release Media/ Treatment Facility Type
Axiall Corporation, Westlake, LA	350	100,284	1,002,836	0.2	0.1	18	Not available	Surface Water or POTW
Greenchem, West Palm Beach, FL	350	52,432	524,323	0.1	2.7E-2	9.5	Not available	Surface Water or POTW
Solvents & Chemicals, Pearland, TX	350	170	1,704	2.8E-04	8.9E-5	3.1E-2	Not available	Surface Water or POTW
Univar USA Inc, Redmond, WA	350	52,432	524,323	0.1	2.7E-2	9.5	Not available	Surface Water or POTW

POTW = Publicly-Owned Treatment Works

[a] Daily production volume calculated using the annual production volume provided in Table 2-1 and dividing by the annual operating days per year (350 days/yr).

[b] The estimated wastewater flow rate is calculated assuming 10 m^3 of wastewater is produced per metric ton of PCE produced (equivalent to 10 L wastewater/kg of PCE) based on the SpERC for the manufacture of a substance.

[c] The maximum daily release is calculated using the maximum daily concentration from the OCPSF EG, 164 μg/L, and multiplying by the daily wastewater flow.

[d] The average daily release is calculated using the maximum monthly average concentration from the OCPSF EG, 52 μg/L, and multiplying by the daily wastewater flow.

[e] The average annual release is calculated as the maximum monthly average concentration multiplied by the daily wastewater production, and 350 operating days/year.

2.2 Repackaging

2.2.1 Estimates of Number of Facilities

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. It does not include sites that import PCE and either: (1) store the chemical in a warehouse and resell directly without repackaging; (2) act as the importer of record for PCE but PCE is never present at the site[2]; or (3) import the chemical and process or use the chemical directly at the site. Case #1 presents only a de minimus exposure or release potential as the containers are never opened. In case #2, the potential for exposure and release is at the site receiving PCE, not the "import" site and exposures/releases at the site receiving PCE are assessed in the relevant scenario based on the condition of use for PCE at the site. Similarly, for case #3, the potential for exposure and release at these sites are evaluated in the relevant scenario depending on the condition of use for PCE at the site.

To determine the number of sites that may repackage PCE, EPA considered 2016 CDR (U.S. EPA, 2016d), 2016 TRI data (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. In the 2016 CDR, two manufacturing facilities reported downstream repackaging processes in the industrial processing and use section with one reporting the number of sites as CBI and one reporting 25 to 100 sites (U.S. EPA, 2016d). There are also two import sites and one manufacturing site in the 2016 CDR that report uses that are "not known or reasonably ascertainable" (NKRA) which may include repackaging activities (U.S. EPA, 2016d).

In the 2016 TRI, 27 facilities report a repackaging activity; however, 16 of these sites either report other activities to TRI or report under a NAICS related to disposal/recycling of PCE (U.S. EPA, 2017d). As described in Section 1.4.1, EPA determined that the other reported activities or activities related to disposal/recycling are the "primary" condition of use for PCE. Therefore, the evaluation of these 16 sites are included in the evaluation of the scenario related to the primary condition of use and are not included in the repackaging scenario. In addition to the sites discussed above, there are 19 sites in the 2016 TRI that report under the NAICS code 424690, Other Chemical and Allied Products Merchant Wholesalers, that reported on a Form A and, therefore, were not required to designate an activity (U.S. EPA, 2017d). EPA assumes that these sites may perform repackaging activities as well resulting in a total of 30 sites in the 2016 TRI where the repackage of PCE is the primary condition of use.

In the 2016 DMR data, there are two sites that reports under the SIC code 4225, General Warehousing and Storage; 10 sites that report under the SIC code 4226, Special Warehousing and Storage; two sites that report under SIC code 4491, Marine and Cargo Handling; seven sites that report under the SIC code 5169, Chemical and Allied Products, Not Elsewhere Classified; and 1 site reporting under SIC code 5172, Petroleum and Petroleum Products Wholesalers, Except Bulk Stations and Terminals, with 1 site reporting under SIC code 5169 being the same as one of the identified TRI sites (U.S. EPA, 2016b)[3]. EPA assumes the primary condition of use at these sites is repackaging. Therefore, EPA assesses a total of 51 sites (30+2+10+2+7+1 = 52 sites – 1 duplicate site = 51 sites) for the repackaging of PCE.

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[2] In CDR, the reporting site is the importer of record which may be a corporate site or other entity that facilitates the import of the chemical but never actually receives the chemical. Rather, the chemical is shipped directly to the site processing or using the chemical.

[3] Although the name of the SIC code 5169 (Chemical and Allied Products, Not Elsewhere Classified) does not indicate it, the "51" group of SIC codes refers to the wholesale trade of non-durable goods. EPA assumed the primary activity at a wholesaler is repackaging.

2.2.2 Process Description

In general, commodity chemicals are imported into the United States in bulk via water, air, land, and intermodal shipments (Tomer and Kane, 2015). These shipments take the form of oceangoing chemical tankers, railcars, tank trucks, and intermodal tank containers. Chemicals shipped in bulk containers may be repackaged into smaller containers for resale, such as drums or bottles. Domestically manufactured commodity chemicals may be shipped within the United States in liquid cargo barges, railcars, tank trucks, tank containers, intermediate bulk containers (IBCs)/totes, and drums. Both imported and domestically manufactured commodity chemicals may be repackaged by wholesalers for resale; for example, repackaging bulk packaging into drums or bottles.

The exact shipping and packaging methods specific to PCE are not known. For this risk evaluation, EPA assesses the repackaging of PCE from bulk packaging to drums and bottles at wholesale repackaging sites.

2.2.3 Exposure Assessment

2.2.3.1 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.

2.2.3.2 Number of Potentially Exposed Workers

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 (U.S. EPA, 2017d) or 2016 DMR (U.S. EPA, 2016b), respectively. The method for estimating number of workers is detailed in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. The employment data from the U.S. Census SUSB and the Bureau of Labor Statistics' OES data are based on NAICS code; therefore, SIC codes reported in DMR had to be mapped to a NAICS code to estimate the number of workers. A crosswalk of the SIC codes to the NAICS codes used in the analysis are provided in Table 2-7. Sites from TRI report NAICS codes; therefore, these codes were used directly in the analysis.

Table 2-7. Crosswalk of Repackaging SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
4225 – General Warehousing and Storage[a]	493100 – Warehousing and Storage
4226 – Special Warehousing and Storage, Not Elsewhere Classified[a]	493100 – Warehousing and Storage
4491 – Marine Cargo Holding[b]	488300 – Support Activities for Water Transportation
5169 – Chemicals and Allied Products, Not Elsewhere Classified	424690 – Other Chemical and Allied Products Merchant Wholesalers
5172 – Petroleum and Petroleum Products Wholesalers, Except Bulk Stations and Terminals	424720 – Petroleum and Petroleum Products Merchant Wholesalers (except Bulk Stations and Terminals)

[a] The SIC codes 4225 and 4226 may map to any of the following NAICS codes: 493110, 493120, or 493190. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 4-digit NAICS, 493100, rather than a specific 6-digit NAICS.

[b] The SIC codes 4491 may map to any of the NAICS codes 488310 or 488320. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 4-digit NAICS, 488300, rather than a specific 6-digit NAICS.

Table 2-8 provides a summary of the reported NAICS codes (or NAICS identified in the crosswalk), the number of sites reporting each NAICS code, and the estimated number of workers and ONUs for each NAICS code as well as an overall total for repackaging of PCE. There are approximately 210 workers and 75 ONUs potentially exposed during repackaging of PCE.

Table 2-8. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Repackaging

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
325199	2	39	18	77	36	114
325211	1	27	12	27	12	40
325611	1	19	4	19	4	23
424690	32	1	0.4	40	14	55
424720	1	1	0.1	1	0.1	1
488300	2	3	0.5	7	1	8
493100	12	3	1	37	7	44
Total[b]	51	4	1	210	75	280

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is

rounded to the nearest integer. The number of occupational non-users per site for NAICS 424690, 424720, and 488300 are shown as 0.4, 0.1, and 0.5, respectively, as they round down to zero.
[b] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.2.3.3 Occupational Exposure Results

EPA assessed inhalation exposures during repackaging using identified monitoring data. Table 2-9 summarizes 8-hr, 30-min and 15-min TWA samples obtained from data submitted to EPA by Dow Chemical under TSCA (Dow Chem Co, 1984) and collected by OSHA during facility inspections (OSHA, 2020). The Dow Chemical data were collected at the Joliet, IL marine terminal during the loading of PCE into trucks and sampling activities as part of an industrial hygiene (IH) study (Dow Chem Co, 1984). EPA constructed a single full-shift sample from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD did not provide information on the exact use of PCE; therefore, EPA assessed the use based on the reported NAICS code for Other Chemical and Allied Products Merchant Wholesalers(OSHA, 2020). OSHA data does not provide job titles or worker activities associated with the sample; therefore, EPA assumed the data was collected on a worker and not an ONU. Between the two sources, 11 full-shift samples were collected with sample times ranging from approximately 4 to 8.5 hour (OSHA, 2020; Dow Chem Co, 1984). EPA converted to 8-hr TWAs assuming exposures outside the sample time were zero. The 95th percentile and 50th percentile are presented as the high-end and central tendency exposure values, respectively, in Table 2-9. 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.

The Dow Chemical study also collected two approximately 15-min TWA samples and five approximately 30-min TWA samples (Dow Chem Co, 1984). 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”. These scenarios are plausible, but EPA cannot determine the statistical representativeness of the 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 Co, 1984). 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 1.4.5.2. 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).

Table 2-9. Summary of Worker Inhalation Exposure Monitoring Data for Repackaging of Perchloroethylene

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	30-min TWA (ppm)	Number of Data Points	15-min TWA (ppm)[a]	Number of Data Points
High-End	1.2	0.4	0.3	0.1	11	5.7	5	1.6	2
Central Tendency	0.5	0.2	0.1	4.2E-2		8.0E-2		0.9	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
[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.

Sources: (OSHA, 2020; Dow Chem Co, 1984)

2.2.4 Water Release Assessment

2.2.4.1 Water Release Sources

EPA expects the primary source of water releases from repackaging activities to be from the use of water or steam to clean bulk containers used to transport PCE or products containing PCE. EPA expects the use of water/steam for cleaning containers to be limited at repackaging sites as PCE is an organic substance and classified as a hazardous waste under RCRA. EPA expects the majority of sites to use organic cleaning solvents which would be disposed of as hazardous waste (incineration or landfill) over water or steam.

2.2.4.2 Water Release Assessment Results

EPA assessed water releases using the values reported to the 2016 TRI (U.S. EPA, 2017d) and the 2016 DMR (U.S. EPA, 2016b) by the 51 repackaging sites. In the 2016 TRI, all 30 sites reported zero direct discharges to surface water and zero indirect discharges to POTW (U.S. EPA, 2017d). One site reported an indirect discharge of 615 lb/yr (~279 kg/yr) to non-POTW WWT and the other 29 sites reported zero indirect discharges to non-POTW WWT (U.S. EPA, 2017d). In the 2016 DMR, one site reported a direct discharge of 2.64 lb/yr (1.20 kg/yr), one site reported 0.66 lb/yr (0.30 kg/yr), one site reported 0.05 lb/yr (0.02 kg/yr), and the remaining sites all report zero direct discharges (indirect discharges not reported in DMR) (U.S. EPA, 2016b). To estimate the daily release, EPA used a default assumption of 250 days/yr of operation (assumes operation 5 days/week and 50 weeks/year) and averaged the annual release over the operating days. Table 2-10 summarizes the releases from sites with non-zero discharges.

Table 2-10. Reported Wastewater Discharges of Perchloroethylene from Repackaging Sites

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Chemtool, Rockton, IL	0.3	250	1.2E-3	IL0064564	Surface Water	(U.S. EPA, 2016b)
Harvey Terminal, Harvey, LA	2.3E-2	250	9.1E-5	LA0056600	Surface Water	(U.S. EPA, 2016b)
Hubbard-Hall Inc, Waterbury, CT	279	250	1.1	Not available	Non-POTW WWT	(U.S. EPA, 2017d)
Vopak Terminal Westwego Inc, Westwego, LA	1.2	250	4.8E-3	LA0124583	Surface Water	(U.S. EPA, 2016b)

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 250 days of operation per year.

Sources: (U.S. EPA, 2017d, 2016b)

2.3 Processing as a Reactant

2.3.1 Estimates of Number of Facilities

To determine the number of sites that process PCE as a reactant, EPA considered 2016 CDR (U.S. EPA, 2016d), 2016 TRI (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. In the 2016 CDR, five sites reported at least one downstream processing as a reactant activity in the industrial processing and use section (U.S. EPA, 2016d)[4]. There are three reports of processing as a reactant in the "all other organic chemical manufacturing" industry sector, one in the "industrial gas manufacturing" industry sector, one in the "petroleum refineries" industry sector, and two CBI industry sectors (U.S. EPA, 2016d)[5]. There are also two reports where the submitter reports processing as a reactant but reports the function as either "solvents (for cleaning and degreasing)" or "Solvents (which become part of the product formulation or mixture)"; EPA assumes the reported processing as a reactant is an error based on the functional codes reported (U.S. EPA, 2016d). Of the seven reported instances of industrial processing as a reactant, four reported fewer than 10 sites, one reported 10 to 25 sites, and two reported the number of sites as CBI (U.S. EPA, 2016d).

In the 2016 TRI, 16 facilities reported use of PCE as a reactant; however, three of these sites also reported as manufacturers of PCE in the 2016 CDR (U.S. EPA, 2017d). The manufacturing sites are not included in the assessment for reactant uses as exposures and releases from these sites have already been assessed in Section 2.1. Some of the sites in TRI also reported other activities such as processing aids, manufacturing aids, and/or ancillary use; however, based on the reported NAICS codes and the fact that 65 to 70% of the total annual U.S. production volume is expected to be used for reactant uses, EPA expects the primary condition of use at these sites to be for reactant uses (Ntp, 2014; Hsia, 2008). Therefore, there are a total of 13 sites in the 2016 TRI where the processing of PCE as a reactant is the primary condition of use.

In the 2016 DMR data, there are five sites that report under the SIC code 2812, Alkalies and Chlorine; one site that reports under the SIC code 2816, Inorganic Pigments; 12 sites that report under the SIC code 2819, Industrial Inorganic Chemicals, Not Elsewhere Classified; 86 sites that report under the SIC code 2869, Industrial Organic Chemicals, Not Elsewhere Classified; and 3 sites that did not report a SIC code[6], with three sites: 1) Eagle US 2, LLC; 2) Honeywell International Baton Rouge Plant, and 3) Westlake Vinyls, Inc. being the same as three of the identified TRI sites (U.S. EPA, 2016b). These SIC codes include sites that are engaged in the manufacture of organic and inorganic chemicals for which PCE may be used as a reactant to create, including various organic and inorganic chlorinated compounds. Additional information for conditions of use is not provided in the DMR data; therefore, EPA assumes the primary condition of use at these sites is processing as a reactant based solely on the SIC code. Based on the DMR and TRI data, EPA assesses a total of 117 sites (13+5+1+12+86+3 = 120 sites – 3 duplicate site = 117 sites) for the processing of PCE as a reactant.

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[4] In CDR, only manufacturers and importers report; therefore, "downstream" processing and use activities may refer to additional processing/use at the reporting site or the processing/use activities of the reporting sites' customers.

[5] The number of industry sectors reported is greater than the number of sites reporting processing as a reactant as each site may report multiple industry sectors.

[6] These sites were assumed to be processing PCE as a reactant based on the company name and the fact that 70% of the national PCE production volume is used as a reactant.

2.3.2 Process Description

Processing as a reactant or intermediate is the use of PCE as a feedstock in the production of another chemical product via a chemical reaction in which PCE is consumed to form the product. In the past, PCE was used as feedstock (with chlorine) for the manufacture of one- and two-carbon (C1 and C2) CFCs (Smart and Fernandez, 2000). However, due to discovery that CFCs contribute to stratospheric ozone depletion, the use of CFCs was phased-out by the year 2000 to comply with the Montreal Protocol (Smart and Fernandez, 2000). Since the phase-out of CFCs, PCE has been used to manufacture the CFC alternatives, HCFCs, specifically the HCFC-123 alternative to CFC-11 (Smart and Fernandez, 2000). PCE is also used as a feedstock in the production of trichloroacetyl chloride (Smart and Fernandez, 2000).

HCFC-123 is produced by fluorination of PCE with liquid or gaseous hydrofluoric acid (HF). The manufacture of HCFC is more complex than the manufacture of CFCs due to potential byproduct formation or catalyst inactivation caused by the extra hydrogen atom in the HCFCs (Smart and Fernandez, 2000). Therefore, the process involved in the manufacture of HCFCs requires additional reaction and distillation steps as compared to the CFC manufacturing process (Smart and Fernandez, 2000).

PCE is also used by Honeywell International Inc. in the manufacture of HFC-125 (R-125), HCFC-124 (R-124), and CFC-113 (R-113) (Honeywell, 2017). In 2016, Honeywell used approximately 65 million pounds of PCE to manufacture R-125 and R-124 and approximately 20 million pounds to manufacture R-113 (Honeywell, 2017). The majority of the R-113 is used as an intermediate for manufacture of chlorotrifluoroethylene (CTFE) monomer; however, a small portion is used in exempted applications vital to U.S. security (Honeywell, 2017). PCE is received at the Honeywell facilities in railcars and trucks and is transferred into storage vessels with a pump and vapor balance (Honeywell, 2017). Some PCE is lost when disconnecting the hose; however, the storage tank is pressurized so there are no point emissions or breathing losses (Honeywell, 2017). The primary emission of PCE at Honeywell facilities are from fugitive emissions (Honeywell, 2017). The facilities utilize a fugitive emissions monitoring program and leak detection program to reduce fugitive emissions (Honeywell, 2017).

Honeywell representatives indicated that the R-125/R-124 processes achieve a once through PCE conversion of 95% and the remaining 5% is recovered and recycled back into the process (Honeywell, 2017). For the R-113 process, the once through conversion rate is 99% and the remaining 1% is recovered and recycled back into the process (Honeywell, 2017). The ultimate conversion from both processes is 100%. Honeywell indicated they do not detect any PCE in their products (Honeywell, 2017).

2.3.3 Exposure Assessment

2.3.3.1 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.

2.3.3.2 Number of Potentially Exposed Workers

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 identified in Section 2.3.1 in the 2016 TRI (U.S. EPA, 2017d) or 2016 DMR (U.S. EPA, 2016b), respectively. The method for estimating number of workers is detailed above in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. The employment data from the U.S. Census SUSB and the Bureau of Labor Statistics' OES data are based on NAICS codes; therefore, SIC codes reported in the DMR had to be mapped to a NAICS code to estimate the number of workers. A crosswalk of the SIC codes to the NAICS codes used in the analysis are provided in Table 2-11. In the 2016 DMR there were three sites that did not report a SIC code; for these sites, EPA used the average workers and ONUs per site calculated from the other sites with reported NAICS or SIC codes (U.S. EPA, 2016b). Sites from TRI report NAICS codes; therefore, these codes were used directly in the analysis.

Table 2-11. Crosswalk of Reactant SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
2812 – Alkalies and Chlorine	325180 – Other Basic Inorganic Chemical Manufacturing
2816 – Inorganic Pigments[a]	325100 – Basic Chemical Manufacturing
2819 – Industrial Inorganic Chemicals, Not Elsewhere Classified	325180 – Other Basic Inorganic Chemical Manufacturing
2869 – Industrial Organic Chemicals, Not Elsewhere Classified[b]	325100 – Basic Chemical Manufacturing

[a] The SIC code 2812 may map to any of the following NAICS codes: 325130 or 325180. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 4-digit NAICS, 325100, rather than a specific 6-digit NAICS.

[b] The SIC code 2869 may map to any of the following NAICS codes: 325110, 325120, 325193, 325194, or 325199. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 4-digit NAICS, 325100, rather than a specific 6-digit NAICS.

Table 2-12 provides a summary of the NAICS codes reported in the 2016 TRI and the NAICS identified in the crosswalk from the SIC codes reported in the 2016 DMR, the number of sites reporting each NAICS code or corresponding SIC code, and the estimated number of workers and ONUs for each NAICS code as well as an overall total for processing of PCE as a reactant. There are approximately 4,200 workers and 1,900 ONUs potentially exposed during processing of PCE as a reactant.

Table 2-12. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Processing as a Reactant

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
324110	6	170	75	1,021	453	1,474
325100	86	29	13	2,454	1,156	3,610
325120	2	14	7	28	13	41
325180	16	25	12	403	190	592
325199	3	39	18	116	55	170
325211	1	27	12	27	12	40
Unknown NAICS	3	51	23	152	69	221
Total[b]	117	36	17	4,200	1,900	6,100

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer. Number of workers and occupational non-users per site for sites with unknown NAICS codes are calculated by averaging the values of the known sites.

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

2.3.3.3 Occupational Exposure Results

EPA identified inhalation monitoring data at a Dow Chemical site for a “Phase Separation Facility” that may be related to processing PCE as a reactant (Dow Chemical, 1983). However, the data were not used in the assessment as details of the facility were not provided in the report to confirm the specific condition of use of PCE. It is also unclear if PCE is meant to be in the phase separation area or if it is only present as an impurity in a refrigerant product after the reaction has complete. In such a case, the low concentration of PCE as an impurity in the refrigerant product would limit potential exposures and thus not be representative of exposures of handling bulk liquid PCE at the same facility (e.g., during unloading of tank trucks or rail cars of raw PCE). Additionally, the sample times for these data are all less than three hours and, therefore, may not be representative of full-shift exposures.

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. For a discussion of these data see Section 2.1.3.3. The data are summarized in Table 2-13, where the 50th percentile is presented as the central tendency and the 95th percentile is presented as the high-end for worker and ONU 8-hr TWA exposure results, worker 12-hr TWA exposure results, 15-minute TWA exposure results, and 30 min-TWA exposure results. For ONU 12-hr TWA exposure results, all data points measured below the LOD; therefore, EPA assessed the central tendency and the high-end as the half the LOD and the LOD, respectively.

Table 2-13. Summary of Worker Inhalation Monitoring Results for Processing Perchloroethylene as a Reactant

Scenario	8- or 12-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	15- or 30-minute TWA (ppm)	Number of Short-term Data Points
Worker Monitoring Data							
8-hr TWA Results						*15-minute TWA Results*	
High-End	2.7	0.9	0.6	0.3	63[a]	15	161
Central Tendency	3.3E-2	1.1E-2	7.4E-3	2.9E-3		2.0	
12-hr TWA Results						*30-minute TWA Results*	
High-End	0.2	0.1	4.9E-2	2.5E-2	74	12	38[b]
Central Tendency	2.1E-2	1.0E-2	4.7E-3	1.9E-3		0.7	
ONU Monitoring Data							
8-hr TWA Results						No 30-minute or 15-minute data identified for ONUs	
High-End	9.2E-2	3.1E-2	2.1E-2	1.1E-2	12		
Central Tendency	3.4E-2	1.1E-2	7.7E-3	3.1E-3			
12-hr TWA Results							
High-End	4.5E-2	2.3E-2	1.0E-2	5.3E-3	3		
Central Tendency	2.3E-2	1.1E-2	5.1E-3	2.0E-3			

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[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, 2018).

2.3.4 Water Release Assessment

2.3.4.1 Water Release Sources

Potential sources of water releases are expected to be similar to those described in Section 2.1.4.1 for manufacturing and may include the following: equipment cleaning operations, aqueous wastes from scrubbers/decanters, reaction water, process water from washing intermediate products, and trace water settled in storage tanks (OECD, 2011a).

2.3.4.2 Water Release Assessment Results

EPA assessed water releases using the values reported to the 2016 TRI (U.S. EPA, 2017d) and the 2016 DMR (U.S. EPA, 2016b) by the 117 sites using PCE as a reactant. Note: Eagle US 2, LLC reported to both the 2016 TRI and 2016 DMR; EPA assessed using the reported discharge value from DMR as it is more protective than the value reported in TRI (U.S. EPA, 2017d, 2016b). In the 2016 TRI, seven sites reported non-zero direct discharges to surface water, one site reported indirect discharges to POTW, and all the sites reported zero indirect discharges to non-POTW WWT (U.S. EPA, 2017d). In the 2016 DMR, 12 sites reported non-zero direct discharges to surface water and the remainder report zero discharges to surface water (indirect discharges not reported in DMR data) (U.S. EPA, 2016b).

To estimate the daily release, EPA assumed 350 days/yr of operation[7] and averaged the annual release over the operating days. Table 2-14 summarizes the water releases from the 2016 TRI and DMR for sites with non-zero discharges.

Table 2-14. Reported Wastewater Discharges of Perchloroethylene from Sites Processing Perchloroethylene as a Reactant

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Akzo Nobel Surface Chemistry LLC, Morris, IL	4.8E-02	350	1.4E-04	IL0026069	Surface Water	(U.S. EPA, 2016b)
Atkemix Ten Inc, Louisville, KY	26	350	7.4E-02	KY0002780	Surface Water	(U.S. EPA, 2016b)
Bayer Corporation, Haledon, NJ	1.4E-02	350	3.9E-05	NJG104451	Surface Water	(U.S. EPA, 2016b)
Bayer MaterialScience, New Martinsville, WV	0.2	350	7.1E-04	WV0005169	Surface Water	(U.S. EPA, 2016b)
Chemtura North and South Plants, Morgantown, WV	8.3E-03	350	2.4E-05	WV0004740	Surface Water	(U.S. EPA, 2016b)
Dupont-Chemours Montague Site, Montague, MI	5.9	350	1.7E-02	MI0000884	Surface Water	(U.S. EPA, 2016b)
Eagle US 2 LLC - Lake Charles Complex, Lake Charles, LA	465	350	1.3	LA0000761	Surface Water	(U.S. EPA, 2016b)

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[7] Similar to manufacturing, sites using PCE as a reactant are expected to have high throughputs and as such are assumed to operate seven days per week and 50 weeks per year with two weeks per year for shutdown activities.

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Flint Hills Resources Corpus Christi LLC - West Plant, Corpus Christi, TX	24	350	6.9E-02	TXU001146	Surface Water	(U.S. EPA, 2017d)
Flint Hills Resources Pine Bend LLC, Rosemount, MN	4.1	350	1.2E-02	MN0070246	Surface Water	(U.S. EPA, 2017d)
Honeywell International Inc - Geismar Complex, Geismar, LA	7.1	350	2.0E-02	LA0006181	Surface Water	(U.S. EPA, 2016b)
Honeywell International Inc Geismar Plant, Carville, LA	7.3	350	2.1E-02	LA0006181	Surface Water	(U.S. EPA, 2017d)
Honeywell International Inc-Baton Rouge Plant, Baton Rouge, LA	17	350	4.9E-02	LAR10E873	Surface Water	(U.S. EPA, 2017d)
Indorama Ventures Olefins, LLC, Sulphur, LA	4.1E-03	350	1.2E-05	LA0069850	Surface Water	(U.S. EPA, 2016b)
Keeshan And Bost Chemical Co., Inc., Manvel, TX	1.7E-02	350	4.7E-05	TX0072168	Surface Water	(U.S. EPA, 2016b)
Phillips 66 Lake Charles Refinery, Westlake, LA	21	350	5.9E-02	LAR05P540	Surface Water	(U.S. EPA, 2017d)
Phillips 66 Los Angeles Refinery Wilmington Plant, Wilmington, CA	38	350	0.1	CA0000035	POTW	(U.S. EPA, 2017d)
Premcor Refining Group Inc Port Arthur, Port Arthur, TX	45	350	0.1	TX0005991	Surface Water	(U.S. EPA, 2017d)

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Solutia Nitro Site, Nitro, WV	5.8E-02	350	1.6E-04	WV0116181	Surface Water	(U.S. EPA, 2016b)
Solvay - Houston Plant, Houston, TX	8.3	350	2.4E-02	TX0007072	Surface Water	(U.S. EPA, 2016b)

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 350 days of operation per year.

Sources: (U.S. EPA, 2017d, 2016b)

2.4 Incorporation into Formulation, Mixture, or Reaction Product

2.4.1 Estimates of Number of Facilities

To determine the number of sites that incorporate PCE into a formulation, mixture or reaction product, EPA considered 2016 CDR (U.S. EPA, 2016d), 2016 TRI data (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. In the 2016 CDR, 10 sites reported at least one downstream incorporation of PCE into formulation activity in the industrial processing and use section (as described in Section 2.3.1, “downstream” may refer to activities at the reporting site or activities at the reporting site’s customers) (U.S. EPA, 2016d). The industry sectors reported include: soap, cleaning compound, and toilet preparation manufacturing; paint and coating manufacturing; petroleum refineries; fabricated metal product manufacturing, all other chemical product and preparation manufacturing; wholesale and retail trade; adhesive manufacturing; and one sector claimed as CBI (U.S. EPA, 2016d). Of the 10 reported instances of incorporation, seven reported fewer than 10 sites, one claimed the number of sites as CBI, and two reported the number of sites at not known or reasonably ascertainable (U.S. EPA, 2016d).

EPA identified 23 facilities in the 2016 TRI where the primary condition of use is expected to be incorporation into formulation based on the site reporting “processing as a formulation component” and the reported NAICS codes (U.S. EPA, 2017d). Note: Additional sites may have reported processing as a formulation component that are not included in the 23 sites used for this scenario because they were determined to fit best in another condition of use based on other processing activities and/or NAICS codes reported in the 2016 TRI (see Section 1.4.1 for details of this process).

In the 2016 DMR data, there is one site that reported SIC code 2841, Soap and Other Detergents, Except Specialty Cleaners; one site that reported SIC code 2843, Surface Active Agents, Finishing Agents, Sulfonated Oils, and Assistants; two sites that reported SIC code 2851, Paints, Varnishes, Lacquers, Enamels, and Allied Products; one site that reported 2891, Adhesives and Sealants; eight sites that reported 2899, Chemicals and Chemical Preparations, Not Elsewhere Classified; and three sites that reported SIC code 2992, Lubricating Oils and Greases (U.S. EPA, 2016b). There are an additional two sites in DMR that were the same as formulation sites identified in TRI; therefore, they were not included in these counts. These SIC codes cover the manufacture of various products in which PCE is a formulation component, including degreasing and cleaning solvents, aerosol degreasers and lubricants, paints, coatings, adhesives, and sealants. Therefore, EPA assumes sites reporting these SIC codes are primarily engaged in formulation activities. Additional information for conditions of use is not provided in the DMR data; therefore, EPA assessed the primary condition of use at this site based solely on the SIC code. Based on the DMR and TRI data, EPA assesses a total of 39 sites (23+1+1+2+1+8+3 = 39 sites) for the incorporation of PCE into formulations.

2.4.2 Process Description

After manufacture, PCE may be supplied directly to end-users, or may be incorporated into various products and formulations at varying concentrations for further distribution. Incorporation into a formulation, mixture, or reaction product refers to the process of mixing or blending several raw materials to obtain a single product or preparation. For example, formulators may mix PCE with other additives to formulate adhesives, coatings, inks, aerosols, and other products.

The formulation of coatings and inks typically involves dispersion, milling, finishing and filling into final packages (OECD, 2010, 2009b). Adhesive formulation involves mixing together volatile and non-volatile chemical components in sealed, unsealed or heated processes (Oecd, 2009a). Sealed processes are most common for adhesive formulation because many adhesives are designed to set or react when exposed to ambient conditions (Oecd, 2009a). Lubricant formulation typically involves the blending of two or more components, including liquid and solid additives, together in a blending vessel (Oecd, 2004).

Aerosol packing involves first adding PCE and other components into a mixing vessel and blending to create the final formulation (NIOSH, 1981b). The formulation is then gravity filled into the cans and the dispensing valves are placed and crimped on the can (NIOSH, 1981b). Then the propellent is injected into the cans and buttons are placed on top of the valves (NIOSH, 1981b). Finally, the cans are passed through a tank of heated water to check for leaks and weighed to insure the proper level of contents (NIOSH, 1981b).

2.4.3 Exposure Assessment

2.4.3.1 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. The exact activities and associated level of exposure will differ depending on the degree of automation, presence of engineering controls, and use of PPE at each facility.

2.4.3.2 Number of Potentially Exposed Workers

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 (U.S. EPA, 2017d) or 2016 DMR (U.S. EPA, 2016b), respectively. The method for estimating number of workers is detailed above in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. The employment data from the U.S. Census SUSB and the Bureau of Labor Statistics’ OES data are based on NAICS codes; therefore, SIC codes reported in the DMR had to be mapped to a NAICS code to estimate the number of workers. A crosswalk of the SIC codes to the

NAICS codes used in the analysis are provided in Table 2-15. Sites from TRI report NAICS codes; therefore, these codes were used directly in the analysis.

Table 2-15. Crosswalk of Formulation SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
2841 – Soap and Other Detergents, Except Specialty Cleaners	325611 – Soap and Other Detergent Manufacturing
2843 – Surface Active Agents, Finishing Agents, Sulfonated Oils, and Assistants	325613 – Surface Active Agent Manufacturing
2851 – Paints, Varnishes, Lacquers, Enamels, and Allied Products	325510 – Paint and Coating Manufacturing
2891 – Adhesives and Sealants	325520 – Adhesive Manufacturing
2899 – Chemicals and Chemical Preparations, Not Elsewhere Classified	325998 – All Other Miscellaneous Chemical Product and Preparation Manufacturing
2992 – Lubricating Oils and Greases	324191 – Petroleum Lubricating Oil and Grease Manufacturing

Table 2-16 provides a summary of the reported NAICS codes (or NAICS mapped to the reported SIC code), the number of sites reporting each NAICS code, and the estimated number of workers and ONUs for each NAICS code as well as an overall total for formulation of PCE-containing products. There are approximately 800 workers and 310 ONUs potentially exposed during formulation of PCE-containing products.

Table 2-16. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Formulation

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
324110	1	170	75	170	75	246
324191	3	20	9	61	27	87
325212	1	25	11	25	11	36
325510	4	14	5	57	21	79
325520	5	18	7	90	34	124
325611	2	19	4	37	9	46
325612	2	17	4	33	8	41
325613	1	22	5	22	5	27
325998	18	14	5	253	84	337
326150	1	15	4	15	4	19
336413	1	41	35	41	35	76
Total[b]	39	21	8	800	310	1,100

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer.

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

2.4.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data related to the aerosol packing of PCE-containing products. 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 simulation to assess exposures at other non-aerosol packing facilities. The modeling approach is presented in Appendix F.

2.4.3.3.1 Inhalation Exposure Results for Aerosol Packing Formulation Sites Using Monitoring Data

Table 2-17 summarizes 8-hr TWA PBZ monitoring data for aerosol packing formulation sites. The data were obtained by NIOSH during an inspection at a facility that packages commercial aerosol spot removers containing PCE and methyl chloroform and from OSHA CEHD (OSHA, 2020; NIOSH, 1981b). The NIOSH report indicates that local exhaust ventilation was present at the filling, button tipper, and hot tank locations (NIOSH, 1981b). The report also indicated that administrative controls requiring employees to rotate through various positions throughout each workday with each employee working at four different locations during an eight-hour day (NIOSH, 1981b). TWA exposures were calculated by combining short-term samples collected from each employee at each position throughout the day (NIOSH, 1981b). Total sample times ranged from 6.5 to 8 hours; for sample times less than eight hours, the 8-hr TWAs were calculated assuming exposure to be zero outside the sampling time (NIOSH, 1981b).

EPA constructed three full-shift samples from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD did not provide information on the exact use of PCE; therefore, EPA assessed the use based on the reported SIC codes, company names, and review of company websites. OSHA data does not provide job titles or worker activities associated with the sample; therefore, EPA assumed the data were collected on workers and not ONUs.

EPA calculated the 95th and 50th percentile to estimate the high-end and central tendency exposures, respectively. 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.

Table 2-17. Summary of Worker Inhalation Exposure Monitoring Data for Aerosol Packing Formulation Sites

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points
High-End	25	8.5	5.8	3.0	8
Central Tendency	8.7	2.9	2.0	0.8	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Sources: (OSHA, 2020; NIOSH, 1981b)

2.4.3.3.2 Inhalation Exposure Results for Non-Aerosol Packing Formulation Sites Using Modeling

The modeling approach used to assess exposures at non-aerosol packing formulation sites estimates exposures to workers loading formulated PCE-based products into 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 simulation.

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 divide each site identified in Section 2.4.1 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. Note: Market data for the third group were not available at a detailed level; therefore, EPA could not divide the PCE production volume amongst the product types to calculate per site throughputs. Each site was categorized based on its NAICS code. EPA categorized the NAICS codes as follows:

- Degreasing solvent formulation NAICS codes:
    - 324110 – Petroleum Refineries[8]; and
    - 325998 – All Other Miscellaneous Chemical Product and Preparation Manufacturing[9].
- Dry cleaning solvent formulation NAICS codes:
    - 325611 – Soap and Other Detergent Manufacturing;
    - 325612 – Polish and Other Sanitation Good Manufacturing; and
    - 325613 – Surface Active Agent Manufacturing.
- Miscellaneous formulation NAICS codes:
    - All NAICS codes reported not listed above.

The categorization resulted in 19 formulation sites for degreasing solvents, five for dry cleaning solvents, and 15 for miscellaneous products. EPA then used market data to estimate the throughput at each site by dividing the estimated percentage of PCE used in each formulation type by the number of formulation sites for that product. To estimate daily throughputs, EPA assumed 300 days/yr[10] of operation as given in the SpERC developed by the European Solvent Industry Group for the formulation and (re)packing of substances and mixtures and averaged the annual throughput over the operating days (European Solvents Industry Group, 2019a). The market data estimated 7-10% of the national PCE production volume is used for degreasing, 10-15% is used for dry cleaning, and 3-10% is used for miscellaneous uses (Ntp, 2014; Hsia, 2008). EPA used 7% for degreasing, 10% for dry cleaning, and 3% for miscellaneous because these values represent more recent data. Table 2-18 summarizes the estimated per site PCE-throughputs for each category.

Table 2-18. Estimated Throughputs of Perchloroethylene by Formulated Product Type

Formulation Type	Percent of National Production Volume	Annual PCE Use Rate (lb/yr)	Total Formulation Sites	Annual Per Site PCE-Throughput (lb/site-yr)	Operating Days (days/yr)	Daily PCE-Throughput (lb/site-day)
Degreasing Solvent	7%	22,696,852	19	1,194,571	300	3,982
Dry Cleaning Solvent	10%	32,424,074	5	6,484,815	300	21,616
Miscellaneous	3%	9,727,222	15	648,481	300	2,162

EPA assumed formulated products were loaded into 55-gallon drums. It is possible that some formulated products, such as coatings and adhesives, may be loaded into smaller containers (e.g., pails) for smaller commercial and consumer applications; however, EPA does not have information to estimate the

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[8] EPA does not typically expect petroleum refineries to formulate degreasing solvents; however, the one site reporting this NAICS code to the 2016 TRI also reported as an importer to the 2016 CDR and reported its entire import volume as used on-site and reported formulation of solvents for cleaning and degreasing.

[9] This NAICS codes may also include sites manufacturing aerosol products; therefore, the total number of sites for formulating degreasing solvents may be overestimated.

[10] EPA uses 300 days per year rather than 350 as used in the manufacturing and reactant scenarios because it is likely that formulation sites make multiple products not all of which will contain PCE. Drum loading of PCE-based products is only expected to occur on days were PCE-containing products are produced.

volume packaged into drums versus smaller containers. Therefore, EPA assessed the entire throughput as packaged into drums to give the most protective worker exposure estimates.

To estimate the number of drums loaded per day EPA used the per site daily throughput of PCE and the expected weight fraction of PCE in the formulated product to estimate the total volume of PCE loaded into each drum. For degreasing and dry cleaning solvents EPA assumed the PCE weight fraction to be 100%. Typically, the only materials expected to be added to degreasing and dry cleaning solvents are stabilizers used to prevent decomposition during storage and use (European Chlorinated Solvents Association, 2011). PCE generally requires less stabilizers than other chlorinated solvents with weight fractions of stabilizers expected to be less than 0.5% in degreasing solvents, and less than 0.05% in dry cleaning solvents. (European Chlorinated Solvents Association, 2011). Therefore, the assumption of 100% PCE in the model is not expected to significantly impact exposure results.

For miscellaneous products, the concentration of PCE can vary greatly depending on the product being formulated. For modeling purposes, EPA assessed used a uniform distribution of 30 to 80% PCE in the formulated product based on the expected concentrations of solvents in organic solvent-borne coatings estimated by the OECD ESD (Oecd, 2009b). This range was used as it is expected to encompass the range of compositions for the majority of PCE-based products in this category (e.g., per the OECD ESD (Oecd, 2009a) typical organic solvent concentrations in adhesives is estimated to be between 60 to 75% which falls within the range used in the model). While it is possible that some of the products contain PCE concentrations outside this range, the error from this is expected to be small as, based on the reported NAICS codes, 10 of the 15 formulation sites assessed in this category are either coatings (including maskants) or adhesive formulation sites.

Model results for each category of formulation site are presented in Table 2-19 with the 50th percentile presented as the central tendency and the 95th percentile presented as the high-end. It should be noted that an additional exposure for workers may occur during unloading of raw PCE from bulk containers (tank trucks and rail cars) into formulation equipment and is not accounted for in the results presented in Table 2-19. Although EPA can estimate exposures during this unloading activity using the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model (see Appendix E for model description), 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.

The results show that exposures at sites formulating dry cleaning solvents are an order of magnitude higher than other formulation sites. This due to the fact that dry cleaning solvents are a larger use than the other assessed categories and have the fewest number of formulation sites resulting in larger numbers of drums loaded per day at each site.

Table 2-19. Summary of Exposure Modeling Results for Formulation of Perchloroethylene-Based Products

Formulation Type	Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)
Degreasing Solvent	High-End	2.6	0.9	0.6	0.2
	Central Tendency	0.7	0.2	0.2	6.3E-2
Dry Cleaning Solvent	High-End	14	4.7	3.2	1.3
	Central Tendency	4.0	1.3	0.9	0.3
Miscellaneous	High-End	1.4	0.5	0.3	0.1
	Central Tendency	0.4	0.1	9.1E-2	3.4E-2

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

2.4.4 Water Release Assessment

2.4.4.1 Water Release Sources

The primary source of water releases from the formulation of PCE-containing products is from water used to clean the formulation equipment (OECD, 2010, 2009a, b, 2004). There is also potential for water releases from cleaning of containers used to transport raw PCE (Oecd, 2009b). For organic solvent-based products such as PCE-based products, EPA expects the majority of container and equipment cleaning to be performed using organic solvents that are not discharged to water. However, there is the potential for sites to use water as a cleaning solvent that is subsequently discharged directly to surface water or indirectly to POTWs or non-POTW WWT.

2.4.4.2 Water Release Assessment Results

EPA assessed water releases using the values reported to the 2016 TRI (U.S. EPA, 2017d) and the 2016 DMR (U.S. EPA, 2016b) by the 39 formulation sites. In the 2016 TRI, one site reported indirect discharges to POTW, one site reported indirect discharges to non-POTW WWT, and the remaining sites reported zero discharges (U.S. EPA, 2017d). In the 2016 DMR, one site reported non-zero direct discharges to surface water and the remaining sites reported zero discharges to surface water (indirect discharges not reported in DMR data) (U.S. EPA, 2016b).

To estimate the daily release, EPA assumed 300 days/yr of operation as given in the SpERC developed by the European Solvent Industry Group for the formulation and (re)packing of substances and mixtures and averaged the annual release over the operating days (European Solvents Industry Group, 2019a). Table 2-20 summarizes the water releases from the 2016 TRI and DMR for sites with non-zero discharges.

Table 2-20. Reported Wastewater Discharges of Perchloroethylene from Formulation of Perchloroethylene-Containing Products

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Lord Corp, Saegertown, PA	1,579	300	5.3	PA0101800	Non-POTW WWT	(U.S. EPA, 2017d)
Stepan Co Millsdale Road, Elwood, IL	0.5	300	1.7E-3	IL0002453	Surface Water	(U.S. EPA, 2016b)
Weatherford Aerospace LLC, Weatherford, TX	0.5	300	1.5E-3	Not available	POTW	(U.S. EPA, 2017d)

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 300 days of operation per year.

Sources: (U.S. EPA, 2017d, 2016b)

2.5 Batch Open-Top Vapor Degreasing

2.5.1 Estimates of Number of Facilities

To determine the number of sites that use PCE in batch open-top vapor degreasers (OTVD), EPA considered 2014 NEI (U.S. EPA, 2016a), 2016 TRI (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. However, due to the various reporting thresholds and requirements for each of the above sources, EPA does not expect the sites from these sources to represent the entirety of sites operating OTVDs. Therefore, EPA used methods presented in the 2017 draft ESD on Vapor Degreasing to estimate the number of sites (OECD, 2017a). Based on market data from HSIA (2008) and NTP (2014), EPA expects 7 to 10% of the production volume of PCE to be used in vapor degreasing. Due to data limitations, this portion of the production volume cannot be further divided into different degreasing types (OTVDs, closed-loop degreasing, conveyorized degreasing, web degreasing, and cold cleaning). Therefore, EPA had to perform bounding estimates on the number of sites, using the full portion of the production volume used in metal degreasing for each degreaser type. Bounding estimates may overestimate actual number of sites. To estimate the number of sites for OTVDs, EPA assessed 7% of the national production volume (10,295,119 kg/yr) as used in OTVDs. EPA used 7% rather than 10% because the 7% value is more recent and to reduce the degree of overestimation from the bounding calculation.

The ESD estimates a 50th percentile solvent (in this case PCE) use-rate for OTVDs of 2,083 kg/site-yr and a 95th percentile use rate of 25,852 kg/site-yr (OECD, 2017a). EPA calculated the number of sites corresponding to both the 50th and 95th percentile use-rates using the following equation:

Equation 2-1

$$N_s = \frac{PV}{UR}$$

Where:

N_s = Number of Sites
PV = Annual PCE Production Volume Used in Degreasing (kg/yr)
UR = Annual use-rate of PCE (kg/site-yr)

This resulted in 398 sites using the 95th percentile use-rate and 4,942 sites using the 50th percentile use-rate.

2.5.2 Process Description

Vapor degreasing is a process used to remove dirt, grease, and surface contaminants in a variety of industries, including but not limited to:

- Electronic and electrical product and equipment manufacturing;
- Metal, plastic, and other product manufacturing, including plating;
- Aerospace manufacturing and maintenance cleaning;
- Cleaning skeletal remains; and
- Medical device manufacturing (Morford, 2017).

PCE is typically chosen as a degreasing solvent for applications where flammability is a concern as PCE has no flash point and no upper and lower explosive limits (Rudnick, 2017). Figure 2-1 is an illustration of vapor degreasing operations, which can occur in a variety of industries.

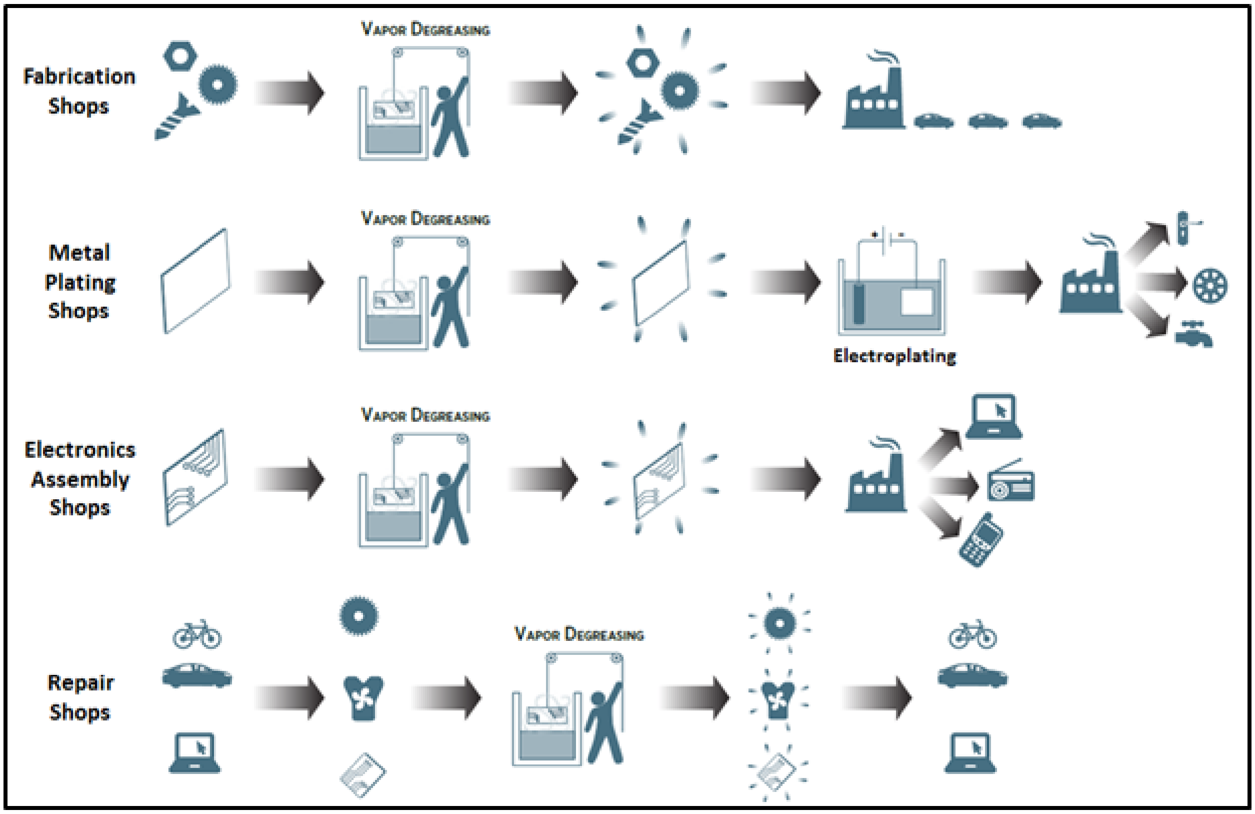

Figure 2-1. Use of Vapor Degreasing in a Variety of Industries

Vapor degreasing may take place in batches or as part of an in-line (i.e., continuous) system. In batch machines, each load (parts or baskets of parts) is loaded into the machine after the previous load is completed. With in-line systems, parts are continuously loaded into and through the vapor degreasing equipment as well as the subsequent drying steps. Vapor degreasing equipment can generally be categorized into one of the three categories: (1) batch vapor degreasers, (2) conveyorized vapor degreasers and (3) web vapor degreasers.

In batch open-top vapor degreasers (OTVDs), a vapor cleaning zone is created by heating and volatilizing the liquid solvent in the OTVD. Workers manually load or unload fabricated parts directly into or out of the vapor cleaning zone. The tank usually has chillers along the side of the tank to prevent losses of the solvent to the air. However, these chillers are not able to eliminate emissions, and throughout the degreasing process significant air emissions of the solvent can occur. These air emissions can cause issues with both worker health and safety as well as environmental issues. Additionally, the cost of replacing solvent lost to emissions can be expensive (Newmoa, 2001). Figure 2-2 illustrates a standard OTVD.

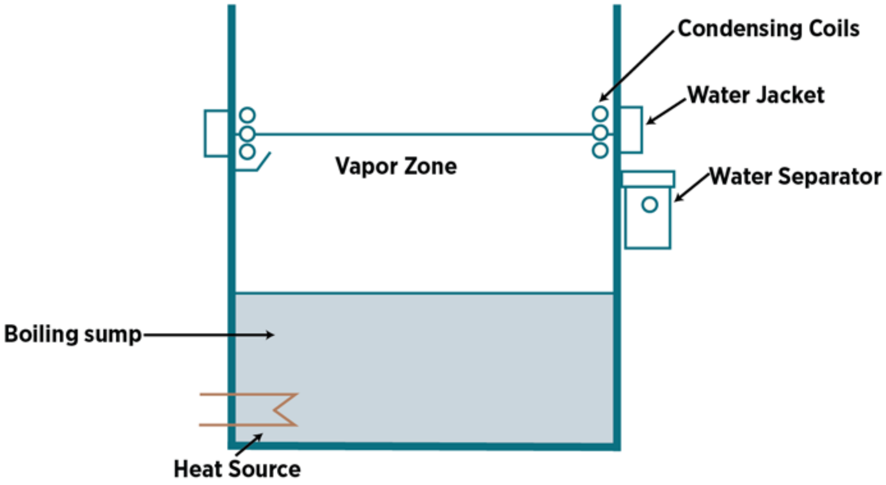

Figure 2-2. Open-Top Vapor Degreaser

OTVDs with enclosures operate the same as standard OTVDs except that the OTVD is enclosed on all sides during degreasing. The enclosure is opened and closed to add or remove parts to/from the machine, and solvent is exposed to the air when the cover is open. Enclosed OTVDs may be vented directly to the atmosphere or first vented to an external carbon filter and then to the atmosphere (EPA and Consulting, 2004). Figure 2-3 illustrates an OTVD with an enclosure. The dotted lines in Figure 2-3 represent the optional carbon filter that may or may not be used with an enclosed OTVD.

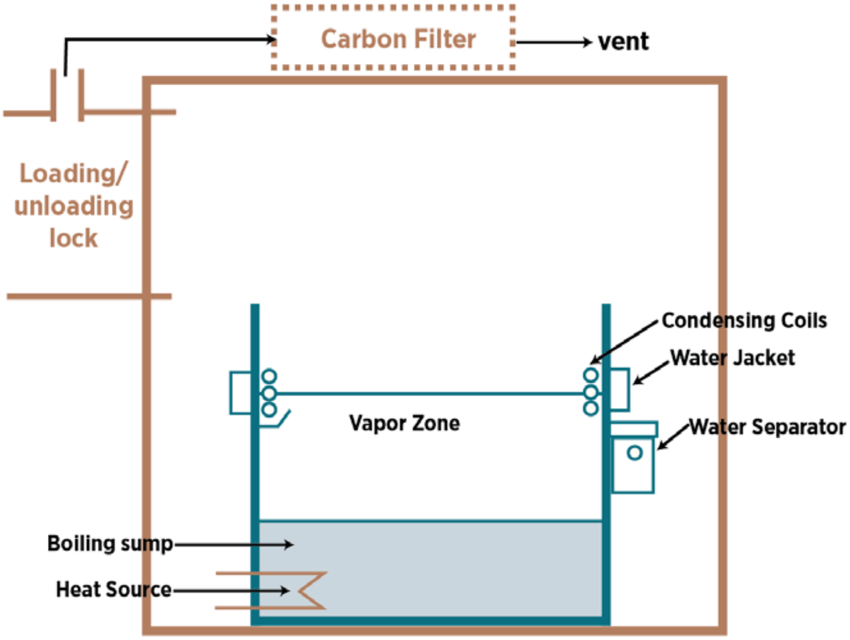

Figure 2-3. Open-Top Vapor Degreaser with Enclosure

2.5.3 Exposure Assessment

2.5.3.1 Worker Activities

The EPA defined a vapor degreasing "worker" as an employee who operates or performs maintenance tasks on the degreaser, such as draining, cleaning, and charging the degreaser bath tank. 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 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 "occupational non-user" as an employee who does not regularly handle PCE or operate the degreaser but performs work in the area around the degreaser.

2.5.3.2 Number of Potentially Exposed Workers

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 Section 2.5.1. 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 2-21 summarizes these results. Note: As described in Section 2.5.1, these are bounding estimates and may overestimate actual number of workers.

Table 2-21. Estimated Number of Workers Potentially Exposed to Perchloroethylene 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.

2.5.3.3 Occupational Exposure Results

EPA assessed exposures using identified inhalation exposure monitoring data from NIOSH investigations at five sites using PCE as a degreasing solvent in OTVDs. Table 2-22 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 median. There is only a single 15-min TWA sample. Results based on a single value are considered plausible, but EPA cannot determine the statistical representativeness of the value.

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.

The data were obtained from NIOSH Health Hazard Evaluation reports (HHEs) and NIOSH In-Depth Survey Reports. NIOSH HHEs are conducted at the request of employees, employers, or union officials, and provide information on existing and potential hazards present in the workplaces evaluated. The NIOSH In-Depth Surveys were conducted as part of an interagency agreement with OSHA to evaluate the extent of employee exposure to PCE at sites using it as a solvent in vapor degreaser and to document engineering controls and work practices at the workplace affecting exposures (NIOSH, 2002a, b, d).

Data from these sources cover exposures at several industries including aerospace parts manufacturing and repair/refurbishment, parts manufacturing for surgical implants, and brazed aluminum heat exchanger and cooling system manufacturing (NIOSH, 2002a, b, d, 1984b, 1982b). Except for one site, sample times ranged from approximately two to eight hours (NIOSH, 2002a, d, 1984b, 1982b). The other site worked on two 10-hr shifts; therefore, the majority of samples were taken for over 8.5 hours, with only five samples 8 hours or less (Niosh, 2002b). Where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero. For sample times greater than eight hours, EPA left the measured concentration as is. It should be noted that additional sources for degreasing were identified but were not used in EPA's analysis as they either: 1) did not specify the machine type in use; or 2) only provided a statistical summary of worker exposure monitoring.

Gold (2008) completed a comprehensive literature review of studies evaluating PCE exposures from a variety of uses in the U.S. The study complied data for degreasing from studies completed from 1944 to 2001 and provided the general sample times (either as <1, 1-6 or >6 hours), overall range and mean for the data as well as ranges and means for each decade and each job title (overall for the job title and by decade) identified in the studies (Gold et al., 2008). The most recent data for vapor degreasing referenced in the article were from studies completed in the 2000s (Gold et al., 2008). The overall arithmetic mean and maximum from these studies for samples where the sampling time was greater than six hours was 0.4 ppm and 0.9 ppm, respectively, for degreaser operators (Gold et al., 2008). The mean is an order of magnitude lower than the central tendency in EPA's analysis and the maximum is two orders of magnitude lower than the high-end in EPA's analysis. The difference in results is likely due to the increased number samples, the data from Gold (2008) only included nine samples, whereas, the worker data used in this analysis includes 63 samples from multiple sites (number of sites from the Gold (2008) study is unknown). It should be noted that Gold (2008) does not separate by machine type; therefore, it may include closed-loop or conveyorized systems, thus further impacting the results.

Table 2-22. Summary of Worker Inhalation Exposure Monitoring Data for Open-Top Vapor Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	4-hr TWA (ppm)	Number of Data Points	15-Minute TWA (ppm)[a]	Number of Data Points
Worker Monitoring Data									
High-End	32	11	7.3	3.8	63	1.6	3	17	1
Central Tendency	2.1	0.7	0.5	0.2		1.3			
Occupational Non-User Monitoring Data									
High-End	5.2	1.7	1.2	0.6	12	No 4-hr or 15-minute data identified for ONUs			
Central Tendency	0.6	0.2	0.1	5.5E-2					

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[a] Only one data point identified for 15-min TWAs.

Source: (NIOSH, 2002a, b, d, 1984b, 1982b)

2.5.4 Water Release Assessment

2.5.4.1 Water Release Sources

The primary source of water releases from OTVDs is wastewater from the water separator. Water in the OTVD may come from two sources: 1) Moisture in the atmosphere that condenses into the solvent when exposed to the condensation coils on the OTVD; and/or 2) steam used to regenerate carbon adsorbers used to control solvent emissions on OTVDs with enclosures (Durkee, 2014; Kanegsberg and Kanegsberg, 2011; NIOSH, 2002a, b, c, d). The water is removed in a gravity separator and sent for disposal (NIOSH, 2002a, b, c, d). The current disposal practices of the wastewater are unknown; however, a U.S. EPA (1982) report estimated 20% of water releases from metal cleaning (including batch systems, conveyorized systems, and vapor and cold systems) were direct discharges to surface water and 80% of water releases were discharged indirectly to a POTW.

2.5.4.2 Water Release Assessment Results

Water releases for OTVDs were assessed using data reported by sites in the 2016 TRI (U.S. EPA, 2017d) and 2016 DMR (U.S. EPA, 2016b) and the *EPA/OPPT Water Saturation Loss Model*. EPA identified 123 sites between the 2016 TRI and 2016 DMR data that, based on activities reported in TRI and/or the facilities' reported NAICS/SIC codes are likely performing degreasing operations. It should be noted that sites in TRI and DMR do not report information to differentiate between sites with different degreasing machine types and/or sites using PCE to perform metalworking activities instead of degreasing activities. Therefore, it is possible the actual condition of use at these sites is not OTVD but rather a different type of solvent cleaning (e.g., closed-loop degreasing, conveyorized degreasing, web cleaning, or cold cleaning) or use of PCE as a metalworking fluid. These sites are assessed as OTVD based on the fact that 7-10% of the production volume of PCE is used in metal cleaning/degreasing (compared to <3-10% for all other miscellaneous uses including metalworking) and, based on NEI reporting, OTVDs are expected to be the primary cleaning machines used in industry (23 OTVDs reported compared to 1 closed-loop system, 1 conveyorized system, and 10 web cleaning systems[11]) (U.S. EPA, 2016a; Ntp, 2014; Hsia, 2008).

Only a subset of the 123 sites reported discharges to water. This is likely due to different waste handling procedures at each site. For instance, some sites may collect wastewater and send to an off-site waste handling facility that does not discharge the wastewater to WWT or surface waters. EPA assessed annual releases as reported in the 2016 TRI (U.S. EPA, 2017d) or 2016 DMR (U.S. EPA, 2016b) and assessed daily releases by assuming 260 days of operation per year, as recommended in the draft ESD on Use of Vapor Degreasers (OECD, 2017a) and averaging the annual releases over the operating days. A summary of the water releases reported to TRI and DMR can be found in Table 2-23.

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[11] Based on the NEI reporting requirements, the counts of machine types may not be representative of the overall machine type distribution. However, EPA expects the OTVDs to be the most prevalent type of system as closed-loop systems have longer cleaning cycles that limit part throughputs and increased cost compared to OTVDs; conveyorized systems are generally limited to sites with high part throughputs; and web cleaning systems are limited to parts that are coiled or on spools such as films, wires and metal strips.

Table 2-23. Reported Wastewater Discharges of Perchloroethylene in TRI and DMR from Sites Using Perchloroethylene in Open-Top Vapor Degreasing

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
601 Nassau St Assoc LLC, North Brunswick Twp, NJ	2.4E-3	260	9.4E-6	NJG129127	Surface Water	(U.S. EPA, 2016b)
ASCO Valve Manufacturing, Aiken, SC	3.7E-2	260	1.4E-4	SC0049026	Surface Water	(U.S. EPA, 2016b)
Chemours - Beaumont Works, Beaumont, TX	1.7	260	6.5E-3	TX0004669	Surface Water	(U.S. EPA, 2016b)
Delphi Harrison Thermal Systems, Dayton, OH	1.7	260	6.5E-3	OH0009431	Surface Water	(U.S. EPA, 2016b)
Equistar Chemicals LP, La Porte, TX	3.2	260	1.2E-2	TX0119792	Surface Water	(U.S. EPA, 2016b)
Fairfield Works, Fairfield, AL	1.1	260	4.1E-3	AL0003646	Surface Water	(U.S. EPA, 2016b)
Gayston Corp, Dayton, OH	0.8	260	3.1E-3	OH0127043	Surface Water	(U.S. EPA, 2016b)
Getzen Co Inc, Elkhorn, WI	9.1E-2	260	3.5E-4	Not available	POTW	(U.S. EPA, 2017d)
GM Components Holdings LLC, Lockport, NY	18	260	7.1E-2	NY0000558	Surface Water	(U.S. EPA, 2016b)
HB Fuller Co, Morris, IL	0.2	260	7.9E-4	IL0079758	Surface Water	(U.S. EPA, 2016b)
Hyster-Yale Group, Inc, Sulligent, AL	2.3E-04	260	9.0E-7	AL0069787	Surface Water	(U.S. EPA, 2016b)
MEMC Electronic Materials Incorporated, Moore, SC	6.8E-02	260	2.6E-4	SC0036145	Surface Water	(U.S. EPA, 2016b)
Piano Factory-Grand Haven, Grand Haven, MI	0.2	260	7.2E-4	MI0054399	Surface Water	(U.S. EPA, 2016b)

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Rex Heat Treat Lansdale Inc, Lansdale, PA	0.5	260	1.9E-3	PA0052965	Surface Water	(U.S. EPA, 2016b)
Styrolution America LLC, Channahon, IL	0.2	260	6.4E-4	IL0001619	Surface Water	(U.S. EPA, 2016b)
Trane Residential Solutions - Fort Smith, Fort Smith, AR	3.4E-03	260	1.3E-5	AR0052477	Surface Water	(U.S. EPA, 2016b)
US Steel Fairless Hills Facility, Fairless Hills, PA	0.3	260	1.0E-3	PA0013463	Surface Water	(U.S. EPA, 2016b)

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are back-calculated from the annual release rate and assuming 260 days of operation per year.

Sources: (U.S. EPA, 2017d, 2016b)

As discussed in Section 2.5.1, data from TRI and DMR may not represent the entirety of sites using PCE in OTVDs. However, sites operating degreasers are regulated by the following national EGs:

- Electroplating Point Source Category Subparts A, B, D, E, F, G, and H (U.S. EPA, 2019a)[12];
- Iron and Steel Manufacturing Point Source Category Subpart J (U.S. EPA, 2019g);
- Metal Finishing Point Source Category Subpart A (U.S. EPA, 2019c)[13];
- Coil Coating Point Source Category Subpart D (U.S. EPA, 2019d);
- Aluminum Forming Point Source Category Subparts A, B, C, D, E, and F (U.S. EPA, 2019f); and
- Electrical and Electronic Components Point Source Category Subparts A and B (U.S. EPA, 2019e).

Except for the Iron and Steel EG, the above EGs set discharges limits based on the total toxic organics (TTO) concentration in the wastewater stream and not a specific PCE limit. TTO is the summation of the concentrations for a specified list of pollutants which may be different for each promulgated EG and includes PCE for the above referenced EGs. Therefore, the concentration of PCE in the effluent is expected to be less than the TTO limit. The Iron and Steel EG sets discharge limits specifically for PCE based on the operation PCE is being discharged from.

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[12] The Electroplating EG applies only to sites that discharge to POTW (indirect discharge) that were in operation before July 15, 1983. Processes that began operating after July 15, 1983 and direct dischargers are subject to the Metal Finishing EG (U.S. EPA, 2019c).

[13] The Metal Finishing EG do not apply when wastewater discharges from metal finishing operations are already regulated by the Iron and Steel, Coil Coating, Aluminum Forming, or Electrical and Electronic Components EGs.

The operation of the water separator via gravity separation is such that the maximum concentration of PCE leaving the OTVD is equal to the solubility of PCE in water, 206 mg/L (Durkee, 2014). In cases where this concentration exceeds the limit set by the applicable EGs, EPA expects sites will perform some form of wastewater treatment for the effluent stream leaving the OTVD to ensure compliance with the EG prior to discharge. To estimate the volume of PCE discharge from sites not in TRI or DMR, EPA used the *EPA/OPPT Water Saturation Loss Model*. The model assumes the concentration of PCE in the wastewater is equal to its solubility in water. EPA (1977) estimated that less than one to two gallons of wastewater are collected in the separator each day. However, this estimate does not account for wastewater generated from steam stripping of still bottoms in distillation units or from regeneration of carbon beds used for emission controls (where such controls are present). EPA did not identify reasonably available information to estimate the additional wastewater produced from these processes; therefore, EPA used an order of magnitude estimate to account for these releases. Based on the literature and the order of magnitude estimate, EPA presents a low-end and a high-end release scenario with amount of wastewater produced ranging from 2 to 20 gal/day. EPA assessed this release for all sites not accounted for in the TRI/DMR estimates, this resulted in 275 sites using the 95th percentile use-rate (398 total sites – 123 TRI/DMR sites = 275 sites) and 4,819 sites using the 50th percentile use-rate (4,942 total sites – 123 TRI/DMR sites = 4,819 sites). Table 2-24 summarizes these results. There is some uncertainty on how these 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. The model results are within the range of discharge volumes reported by sites in TRI/DMR.

Table 2-24. Model Results for Perchloroethylene Discharges from OTVD Sites Not in TRI/DMR

Scenario	Number of Sites	Volume of Wastewater (gal/day)	Daily Release (kg/day)	Annual Release Days (days/yr)	Annual Release[a] (kg/yr)	Release Media/ Treatment Facility Type
High-End	275	20	1.6E-2	260	4.1	POTW or non-POTW WWT
Low-End	275	2	1.6E-3	260	0.4	
High-End	4,819	20	1.6E-2	260	4.1	
Low-End	4,819	2	1.6E-3	260	0.4	

2.6 Batch Closed-Loop Vapor Degreasing

2.6.1 Estimates of Number of Facilities

EPA estimated the number of sites using closed-loop vapor degreasers using the draft ESD on Vapor Degreasing (OECD, 2017a) using the same methodology as described for OTVDs in Section 2.5.1. The ESD estimates a 50th percentile use-rate of 403 kg/site-yr and a 95th percentile use-rate of 740 kg/site-yr (OECD, 2017a). EPA calculated bounding estimates for number sites using the ESD use-rates and the total 7% of the national production volume reported as used in metal degreasing by HSIA (2008). This resulted in 13,912 sites using the 95th percentile use-rate and 25,546 sites using the 50th percentile use-rate. Note: Bounding estimates may overestimate actual number of sites.

2.6.2 Process Description

In closed-loop degreasers, parts are placed into a basket, which is then placed into an airtight work chamber. The door is closed, and solvent vapors are sprayed onto the parts. Solvent can also be introduced to the parts as a liquid spray or liquid immersion. When cleaning is complete, vapors are exhausted from the chamber and circulated over a cooling coil where the vapors are condensed and recovered. The parts are dried by forced hot air. Air is circulated through the chamber and residual solvent vapors are captured by carbon adsorption. The door is opened when the residual solvent vapor concentration has reached a specified level (Kanegsberg and Kanegsberg, 2011). Figure 2-4 illustrates a standard closed-loop vapor degreasing system.

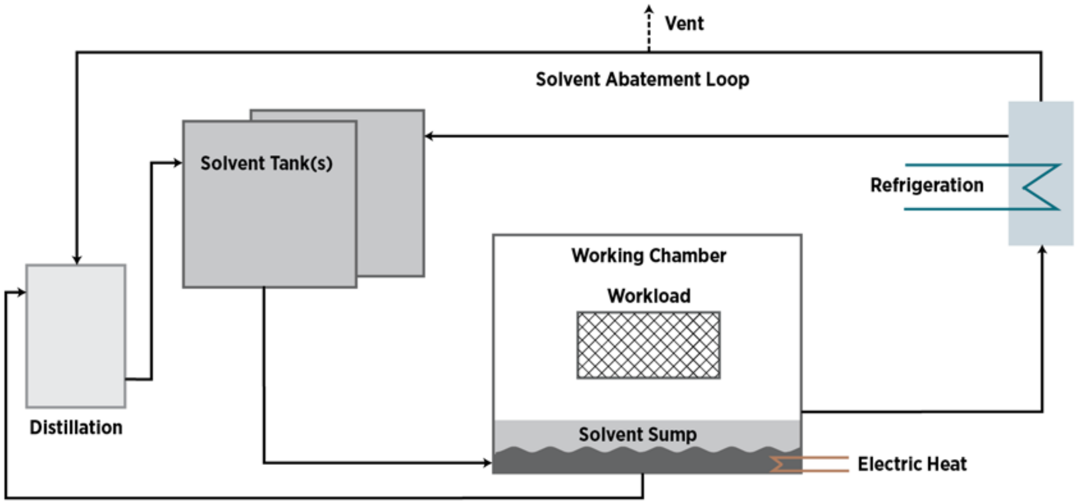

Figure 2-4. Closed-Loop/Vacuum Vapor Degreaser

Airless degreasing systems are also sealed, closed-loop systems, but remove air at some point of the degreasing process. Removing air typically takes the form of drawing vacuum but could also include purging air with nitrogen at some point of the process (in contrast to drawing vacuum, a nitrogen purge operates at a slightly positive pressure). In airless degreasing systems with vacuum drying only, the cleaning stage works similarly as with the airtight closed-loop degreaser. However, a vacuum is generated during the drying stage, typically below 5 torr (5 mmHg). The vacuum dries the parts and a vapor recovery system captures the vapors (Kanegsberg and Kanegsberg, 2011; Newmoa, 2001; U.S. EPA, 2001a).

Airless vacuum-to-vacuum degreasers are true "airless" systems because the entire cycle is operated under vacuum. Typically, parts are placed into the chamber, the chamber sealed, and then vacuum drawn within the chamber. The typical solvent cleaning process is a hot solvent vapor spray. The introduction of vapors in the vacuum chamber raises the pressure in the chamber. The parts are dried by again drawing vacuum in the chamber. Solvent vapors are recovered through compression and cooling. An air purge then purges residual vapors over an optional carbon adsorber and through a vent. Air is then introduced in the chamber to return the chamber to atmospheric pressure before the chamber is opened (Durkee, 2014; Newmoa, 2001). The general design of vacuum vapor degreasers and airless vacuum degreasers is similar as illustrated in Figure 2-4 for closed-loop systems except that the work chamber is under vacuum during various stages of the cleaning process.

2.6.3 Exposure Assessment

2.6.3.1 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).

2.6.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in closed-loop vapor degreasing 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 Section 2.6.1. 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. Table 2-25 summarizes these results. Note: As described in Section 2.6.1, these are bounding estimates and may overestimate actual number of workers.

Table 2-25. Estimated Number of Workers Potentially Exposed to Perchloroethylene 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.

2.6.3.3 Occupational 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 (NIOSH, 2002a, c). 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.

Table 2-26 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”. These scenarios are plausible, but EPA cannot determine the statistical representativeness of the value.

The data were obtained from NIOSH In-Depth Survey Reports conducted as part of an interagency agreement with OSHA to evaluate the extent of employee exposure to PCE at sites using it as a solvent in vapor degreaser and to document engineering controls and work practices at the workplace affecting exposures (NIOSH, 2002a, c). Workers and ONUs were differentiated by the job titles provided in the data, degreaser operators and assistant operators (or other similar job title assumed to be operating the degreasing machine based on worker activities described in the studies) were assigned the worker designation and non-operators were assigned the ONU designation.

Data from these sources cover exposures at a parts cleaning job site that had both a vacuum degreaser and a cold cleaner and an aircraft manufacturer that had one vacuum degreaser and two OTVDs (NIOSH, 2002a, c). Sample times at the two sites ranged from approximately 1.5 to 8 hours (NIOSH, 2002a, c). Where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero. Similarly, where sample times were less than four hours, EPA converted to 4-hr TWAs assuming exposure outside the sample time was zero. It should be noted that additional sources for degreasing were identified but were not used in EPA’s analysis as they either: 1) did not specify the machine type in use; or 2) only provided a statistical summary of worker exposure monitoring.

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 2-26. Summary of Worker Inhalation Exposure Monitoring Data for Closed-Loop Vapor Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	4-hr TWA (ppm)	Number of Data Points
Worker Monitoring Data							
High-End	0.3	8.4E-2	5.8E-2	3.0E-2	13	8.6E-2	3
Central Tendency	7.2E-2	2.4E-2	1.6E-2	6.6E-3		2.0E-2	
Occupational Non-User Monitoring Data							
Higher Value[a]	9.6E-2	3.2E-2	2.2E-02	1.1E-2	2	No 4-hr data identified for ONUs	
Midpoint Value[a]	6.5E-2	2.2E-2	1.5E-2	5.9E-3			

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[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)

2.6.4 Water Release Assessment

2.6.4.1 Water Release Sources

Similar to OTVDs, the primary source of water releases from closed-loop systems is wastewater from the water separator. However, unlike OTVDs, no water is expected to enter the system through condensation (Durkee, 2014). The reason for this is that enclosed systems flush the work chamber with water-free vapor (typically nitrogen gas) after the parts to be cleaned are added to the chamber and the chamber is sealed but before the solvent enters (Durkee, 2014). Multiple flushes can be performed to reduce the concentration of water to acceptable levels prior to solvent cleaning (Durkee, 2014). Therefore, the primary source of water in closed-loop systems is from steam used to regenerate carbon adsorbers (Durkee, 2014; Kanegsberg and Kanegsberg, 2011; NIOSH, 2002a, b, c, d). Similar to OTVDs, the water is removed in a gravity separator and sent for disposal (NIOSH, 2002a, b, c, d). As indicated in the OTVD assessment, current disposal practices of the wastewater are unknown with the latest available data from a U.S. EPA(1982) report estimating 20% of water releases were direct discharges to surface water and 80% of water releases were discharged indirectly to a POTW.

2.6.4.2 Water Release Assessment Results

EPA assesses water releases using TRI and DMR data and the *EPA/OPPT Water Saturation Loss Model*. However, EPA cannot distinguish between degreaser types in TRI and DMR data; therefore, all water releases from TRI/DMR degreasing sites is presented in Section 2.5.4.2 for OTVDs. For sites not in TRI/DMR, EPA assessed using the *EPA/OPPT Water Saturation Loss Model* as discussed for OTVDs in Section 2.5.4. The number of sites assessed is 13,789 sites using the 95th percentile use-rate (13,912 total sites – 123 TRI/DMR sites = 13,789 sites) and 25,423 sites using the 50th percentile use-rate (25,546 total sites – 123 TRI/DMR sites = 25,423 sites). Table 2-27 summarizes these results. There is some uncertainty on how these 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. The model results are within the range of discharge volumes reported by sites in TRI/DMR.

Table 2-27. Model Results for Perchloroethylene Discharges from Batch Closed-Loop Vapor Degreasers Sites Not in TRI/DMR

Scenario	Number of Sites	Volume of Wastewater (gal/day)	Daily Release (kg/day)	Annual Release Days (days/yr)	Annual Release[a] (kg/yr)	Release Media/ Treatment Facility Type
High-End	13,789	20	1.6E-2	260	4.1	POTW or non-POTW WWT
Low-End	13,789	2	1.6E-3	260	0.4	
High-End	25,423	20	1.6E-2	260	4.1	
Low-End	25,423	2	1.6E-3	260	0.4	

2.7 Conveyorized Vapor Degreasing

2.7.1 Estimates of Number of Facilities

EPA estimated the number of sites using conveyorized degreasers using the draft ESD on Vapor Degreasing (OECD, 2017a) using the same methodology as described for OTVDs in Section 2.5.1. The ESD estimates a 50th percentile use-rate of 18,112 kg/site-yr and a 95th percentile use-rate of 26,060 kg/site-yr (OECD, 2017a). EPA calculated bounding estimates for number sites using the ESD use-rates and the total 7% of the national production volume reported as used in metal degreasing by HSIA (2008). This resulted in 395 sites using the 95th percentile use-rate and 568 sites using the 50th percentile use-rate. Note: Bounding estimates may overestimate actual number of sites.

2.7.2 Process Description

In conveyorized degreasers, parts are cleaned in a continuous stream using an automated parts handling system, typically a conveyor, to continuously loads parts into and through the vapor degreasing equipment and the subsequent drying steps. Conveyorized degreasing systems are usually fully enclosed except for the conveyor inlet and outlet portals. Conveyorized degreasers are likely used in shops where there are a large number of parts being cleaned. There are seven major types of conveyorized degreasers: monorail degreasers; cross-rod degreasers; vibra degreasers; ferris wheel degreasers; belt degreasers; strip degreasers; and circuit board degreasers (U.S. EPA, 1977).

- Monorail Degreasers – Monorail degreasing systems are typically used when parts are already being transported throughout the manufacturing areas by a conveyor (U.S. EPA, 1977). They use a straight-line conveyor to transport parts into and out of the cleaning zone. The parts may enter one side and exit and the other or may make a 180° turn and exit through a tunnel parallel to the entrance (U.S. EPA, 1977). Figure 2-5 illustrates a typical monorail degreaser (U.S. EPA, 1977).

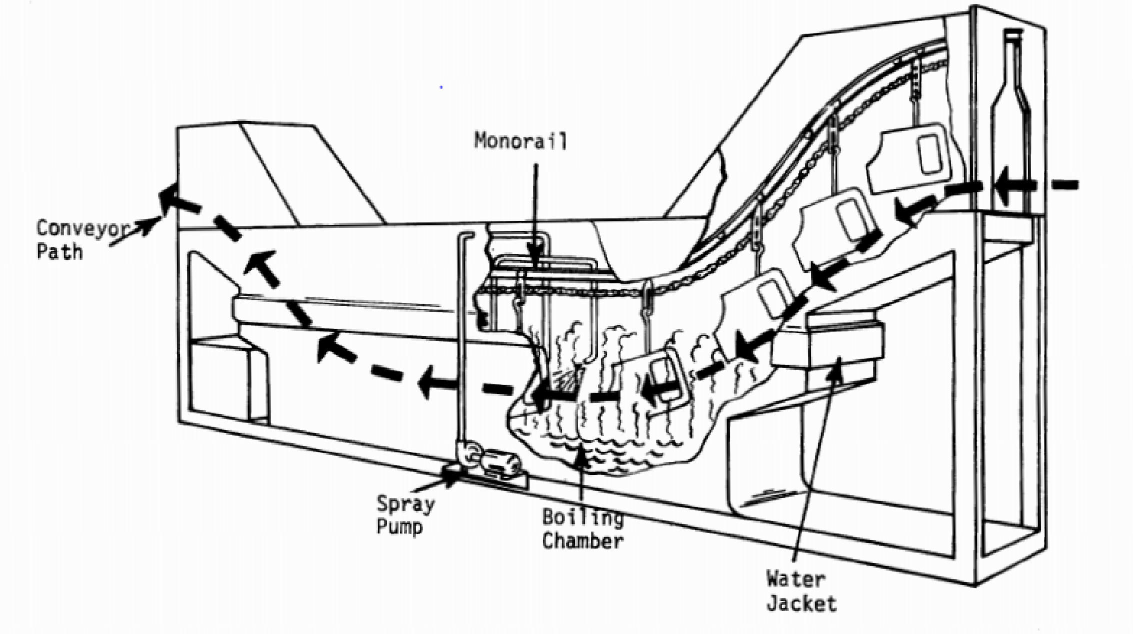

Figure 2-5. Monorail Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- Cross-rod Degreasers – Cross-rod degreasing systems utilize two parallel chains connected by a rod that support the parts throughout the cleaning process. The parts are usually loaded into perforated baskets or cylinders and then transported through the machine by the chain support system. The baskets and cylinders are typically manually loaded and unloaded (U.S. EPA, 1977). Cylinders are used for small parts or parts that need enhanced solvent drainage because of crevices and cavities. The cylinders allow the parts to be tumbled during cleaning and drying and thus increase cleaning and drying efficiency. Figure 2-6 illustrates a typical cross-rod degreaser (U.S. EPA, 1977).

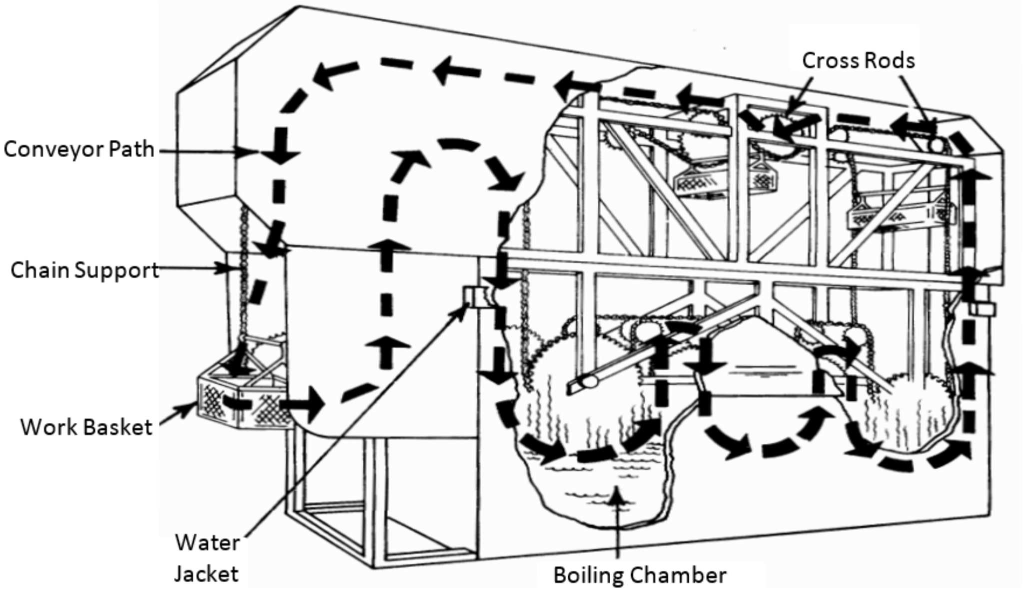

Figure 2-6. Cross-Rod Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

Vibra Degreasers – In vibra degreasing systems, parts are fed by conveyor through a chute that leads to a pan flooded with solvent in the cleaning zone. The pan and the connected spiral elevator are continuously vibrated throughout the process causing the parts to move from the pan and up a spiral elevator to the exit chute. As the parts travel up the elevator, the solvent condenses and the parts are dried before exiting the machine (U.S. EPA, 1977). Figure 2-7 illustrates a typical vibra degreaser (U.S. EPA, 1977).

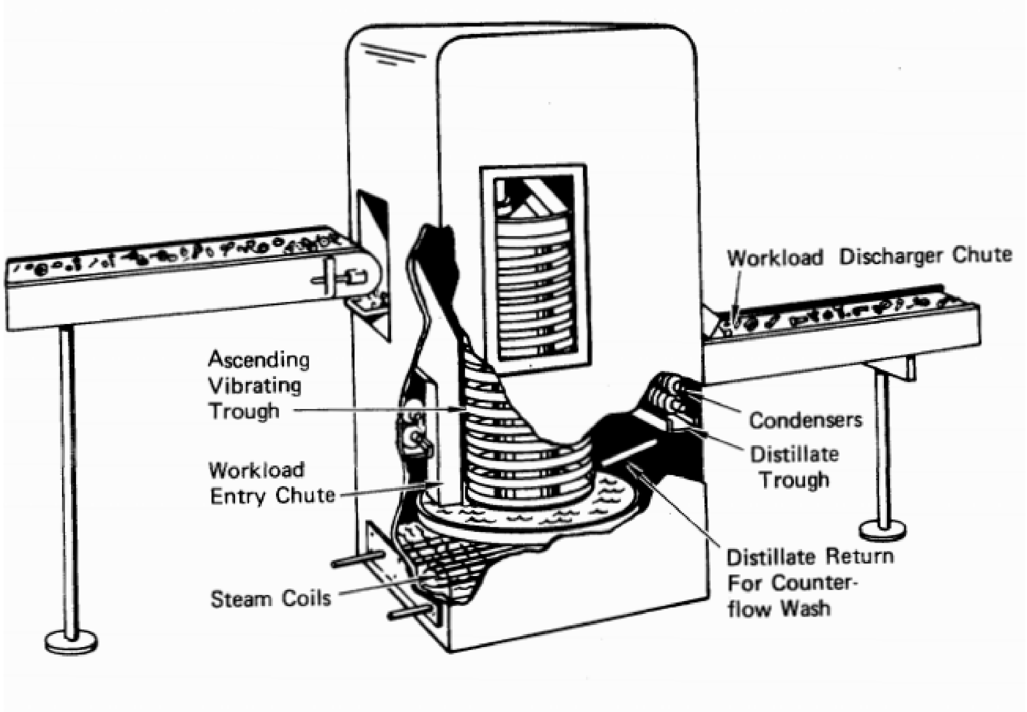

Figure 2-7. Vibra Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

Ferris wheel degreasers – Ferris wheel degreasing systems are generally the smallest of all the conveyorized degreasers (U.S. EPA, 1977). In these systems, parts are manually loaded into perforated baskets or cylinders and then rotated vertically through the cleaning zone and back out. Figure 2-8 illustrates a typical ferris wheel degreaser (U.S. EPA, 1977).

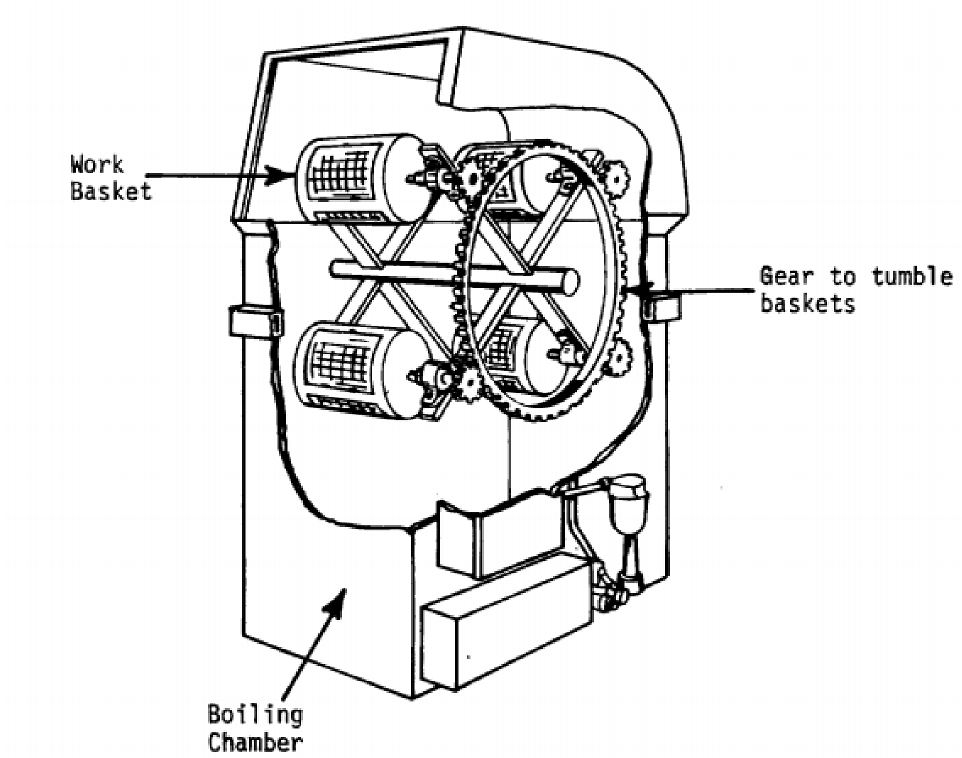

Figure 2-8. Ferris Wheel Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- Belt degreasing systems (similar to strip degreasers; see next bullet) are used when simple and rapid loading and unloading of parts is desired (U.S. EPA, 1977). Parts are loaded onto a mesh conveyor belt that transports them through the cleaning zone and out the other side. Figure 2-9 illustrates a typical belt or strip degreaser (U.S. EPA, 1977).

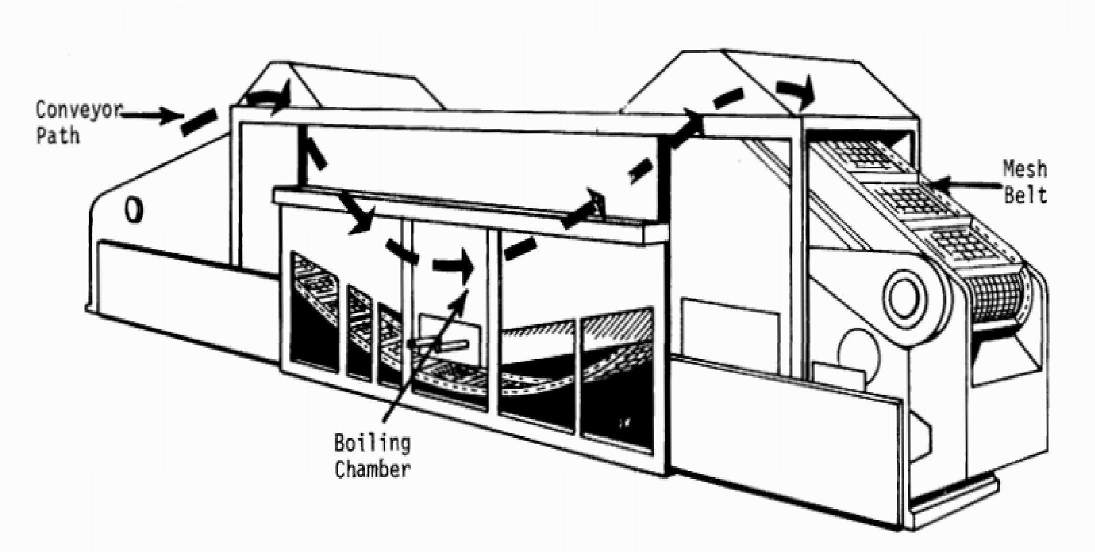

Figure 2-9. Belt/Strip Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- Strip degreasers – Strip degreasing systems operate similar to belt degreasers except that the belt itself is being cleaned rather than parts being loaded onto the belt for cleaning. Figure 2-9 illustrates a typical belt or strip degreaser (U.S. EPA, 1977).

- Circuit board cleaners – Circuit board degreasers use any of the conveyorized designs. However, in circuit board degreasing, parts are cleaned in three different steps due to the manufacturing processes involved in circuit board production (U.S. EPA, 1977).

2.7.3 Exposure Assessment

2.7.3.1 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.

2.7.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in conveyorized degreasing 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 Section 2.7.1. 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. Table 2-28 summarizes these results. Note: As described in Section 2.7.1, these are bounding estimates and may overestimate actual number of workers.

Table 2-28. Estimated Number of Workers Potentially Exposed to Perchloroethylene 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.

2.7.3.3 Occupational 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.

A more detailed description of the modeling approach is provided 0. Figure 2-10 illustrates the near-field/far-field model that can be applied to conveyorized vapor degreasing. As the figure shows, PCE vapors evaporate into the near-field (at evaporation rate G), resulting in near-field exposures to workers at a concentration C_{NF}. The concentration is directly proportional to the evaporation rate of PCE, G, into the near-field, whose volume is denoted by V_{NF}. The ventilation rate for the near-field zone (Q_{NF})

determines how quickly PCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outdoor air. 0 outlines the equations uses for this model.

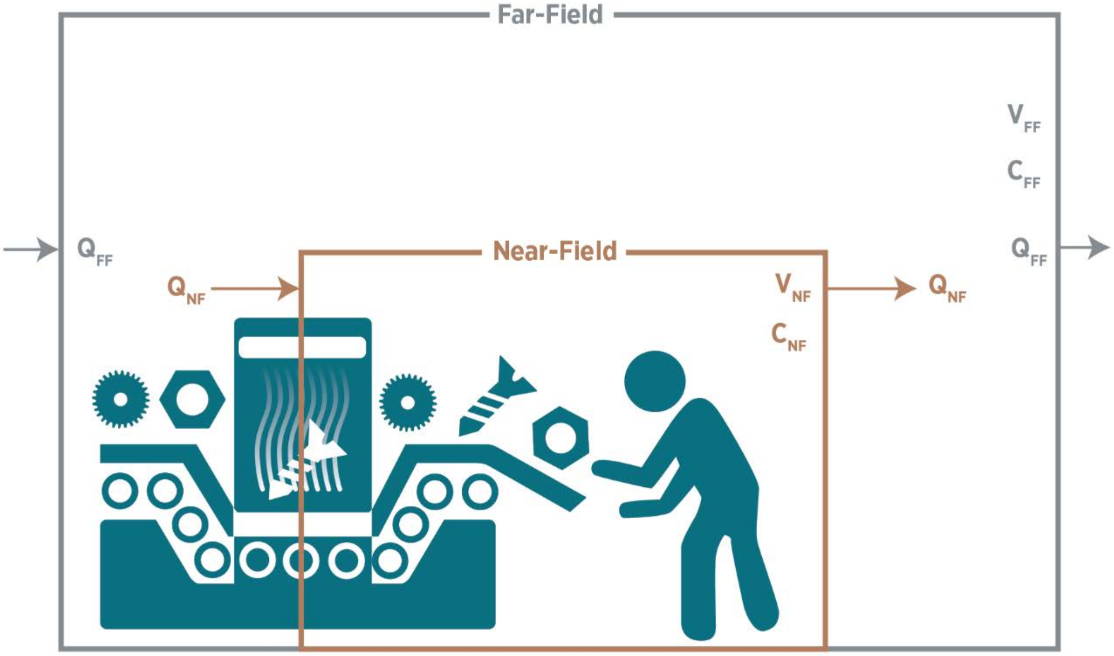

Figure 2-10. Schematic of the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model

0 presents the model parameters, parameter distributions, and assumptions for the PCE Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model. To estimate the PCE vapor generation rate, the model uses the annual emission rate and annual operating time from the single conveyorized degreasing unit reported in the 2014 NEI. The calculated emission rate used in the model is 4.08 lb/unit-hr and the operating hours used was 13 hr/day (U.S. EPA, 2016a). Because the vapor generation rate and operating hours are based on a single data point and not a distribution of data it is unknown how representative the model is of a “typical” conveyorized degreasing site.

EPA performed a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method in @Risk to calculate 8-hour TWA near-field and far-field exposure concentrations. Near-field exposure represents exposure concentrations for workers who directly operate the vapor degreasing equipment, whereas far-field exposure represents exposure concentrations for occupational non-users (i.e., workers in the surrounding area who do not handle the degreasing equipment). The modeled 8-hr TWA results and the values in Appendix B are used to calculate 24-hr AC, ADC, and LADC.

Table 2-29 presents a statistical summary of the exposure modeling results. Estimates of AC, ADC, and LADC for use in assessing risk were made using the approach and equations described in Appendix B. These exposure estimates represent modeled exposures for the workers and occupational non-users. For workers, the 50th percentile exposure is 78.09 ppm 8-hr TWA, with a 95th percentile of 186 ppm 8-hr TWA.

Table 2-29. Summary of Exposure Modeling Results for Use of Perchloroethylene in Conveyorized Vapor Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)
Worker Model Results				
High-End	186	62	42	17
Central Tendency	78	26	18	6.7
Occupational Non-User Model Results				
High-End	126	42	29	12
Central Tendency	41	14	9.3	3.5

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

2.7.4 Water Release Assessment

2.7.4.1 Water Release Sources

Similar to OTVDs, the primary source of water releases from conveyorized systems is expected to be from wastewater from the water separator with the primary sources of water being: 1) Moisture in the atmosphere that condenses into the solvent when exposed to the condensation coils on the system; and/or 2) steam used to regenerate carbon adsorbers used to control solvent emissions (Durkee, 2014; Kanegsberg and Kanegsberg, 2011; NIOSH, 2002a, b, c, d). The current disposal practices of the wastewater are unknown; however, a U.S. EPA(1982) report estimated 20% of water releases from metal cleaning (including batch systems, conveyorized systems, and vapor and cold systems) were direct discharges to surface water and 80% of water releases were discharged indirectly to a POTW.

2.7.4.2 Water Release Assessment Results

EPA assesses water releases using TRI and DMR data and the *EPA/OPPT Water Saturation Loss Model*. However, EPA cannot distinguish between degreaser types in TRI and DMR data; therefore all water releases from TRI/DMR degreasing sites is presented in Section 2.4.4.2 for OTVDs. For sites not in TRI/DMR, EPA assessed using the *EPA/OPPT Water Saturation Loss Model* as discussed for OTVDs in Section 2.5.4. The number of sites assessed is 272 sites using the 95th percentile use-rate (395 total sites – 123 TRI/DMR sites = 272 sites) and 445 sites using the 50th percentile use-rate (568 total sites – 123 TRI/DMR sites = 445 sites). Table 2-30 summarizes these results. There is some uncertainty on how these 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. The model results are within the range of discharge volumes reported by sites in TRI/DMR.

Table 2-30. Model Results for Perchloroethylene Discharges from Conveyorized Vapor Degreasers Sites Not in TRI/DMR

Scenario	Number of Sites	Volume of Wastewater (gal/day)	Daily Release (kg/day)	Annual Release Days (days/yr)	Annual Release[a] (kg/yr)	Release Media/ Treatment Facility Type
High-End	272	20	1.6E-2	260	4.1	POTW or non-POTW WWT
Low-End	272	2	1.6E-3	260	0.4	
High-End	445	20	1.6E-2	260	4.1	
Low-End	445	2	1.6E-3	260	0.4	

2.8 Web Degreasing

2.8.1 Estimates of Number of Facilities

EPA estimated the number of sites using web degreasers using the draft ESD on Vapor Degreasing (OECD, 2017a) using the same methodology as described for OTVDs in Section 2.5.1. The ESD does not present separate use-rates for web degreasers; therefore, EPA estimates the number of sites using the use-rates for conveyorized degreasers. The ESD estimates a 50th percentile use-rate of 18,112 kg/site-yr and a 95th percentile use-rate of 26,060 kg/site-yr (OECD, 2017a). EPA calculated bounding estimates for number sites using the ESD use-rates and the total 7% of the national production volume reported as used in metal degreasing by HSIA (2008). This resulted in 395 sites using the 95th percentile use-rate and 568 sites using the 50th percentile use-rate. Note: Bounding estimates may overestimate actual number of sites.

2.8.2 Process Description

Continuous web cleaning machines (also called reel-to-reel systems) are a subset of conveyorized degreasers but differ in that they are specifically designed for cleaning parts that are coiled or on spools such as films, wires and metal strips (Kanegsberg and Kanegsberg, 2011; U.S. EPA, 2006b). The part to be cleaned is a continuous object uncoiled from one spool and fed onto rollers that transport it from end-to-end through a cleaning solution, a drier, and then recoiled onto another spool (Kanegsberg and Kanegsberg, 2011; U.S. EPA, 2006b). They are generally classified as transporting the coiled part through the cleaning machine at speeds greater than 11 feet per minute (U.S. EPA, 2006b). Parts can also be cut after exiting the cleaning machine (Kanegsberg and Kanegsberg, 2011; U.S. EPA, 2006b). Figure 2-11 illustrates a typical continuous web cleaning machine.

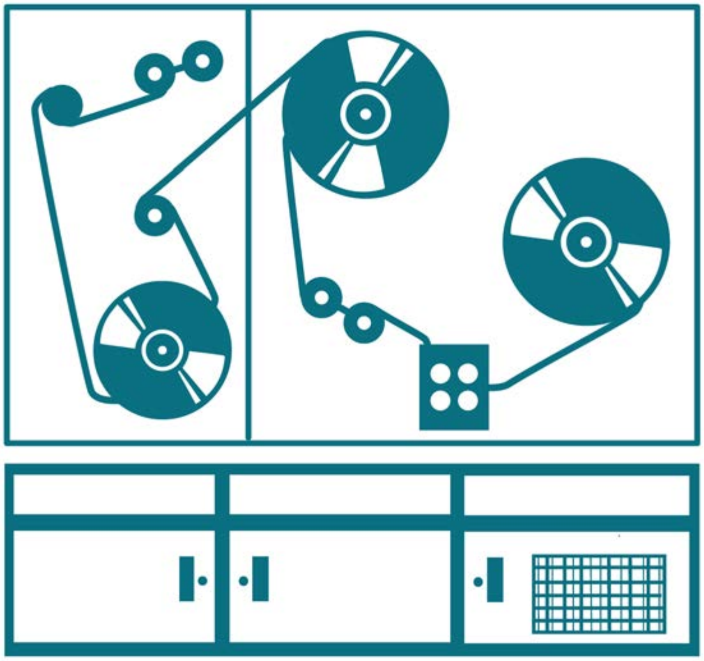

Figure 2-11. Web Degreasing System

2.8.3 Exposure Assessment

2.8.3.1 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.

2.8.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE in web degreasing 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 Section 2.8.1. 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. Table 2-31 summarizes these results. Note: As described in Section 2.8.1, these are bounding estimates and may overestimate actual number of workers.

Table 2-31. Estimated Number of Workers Potentially Exposed to Perchloroethylene 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

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]
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.

2.8.3.3 Occupational 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.

A more detailed description of the modeling approach is provided 0. Figure 2-12 illustrates the near-field/far-field model that can be applied to web degreasing. As the figure shows, PCE vapors evaporate into the near-field (at evaporation rate G), resulting in near-field exposures to workers at a concentration C_{NF}. The concentration is directly proportional to the evaporation rate of PCE, G, into the near-field, whose volume is denoted by V_{NF}. The ventilation rate for the near-field zone (Q_{NF}) determines how quickly PCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outdoor air. 0 outlines the equations uses for this model.

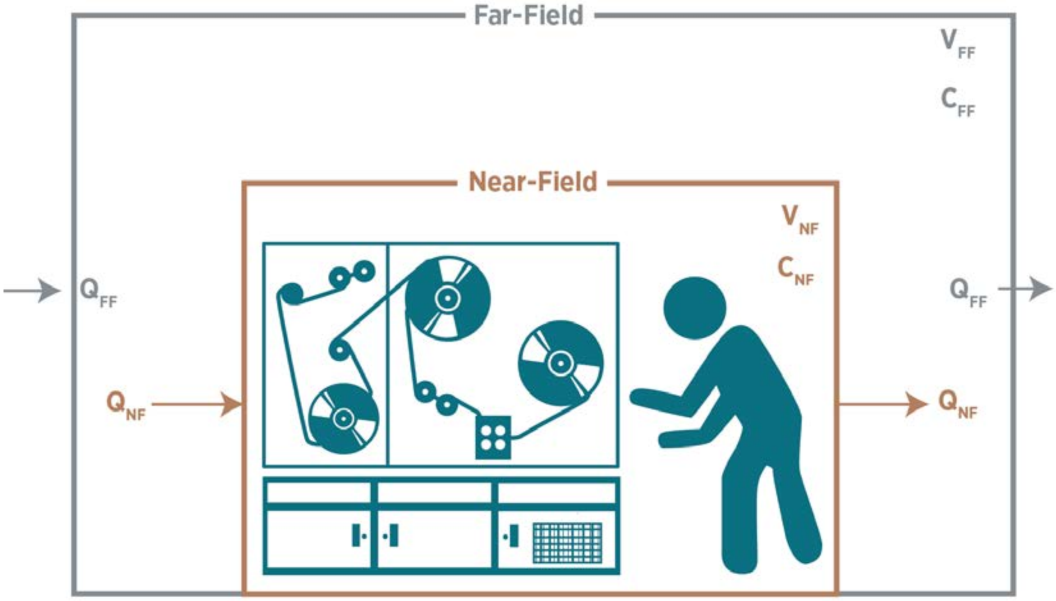

Figure 2-12. Schematic of the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model

0 presents the model parameters, parameter distributions, and assumptions for the PCE Web Degreasing Near-Field/Far-Field Inhalation Exposure Model. To estimate the PCE vapor generation rate, the model developed a distribution from the reported annual emission rates and annual operating times reported in

the 2014 NEI (U.S. EPA, 2016a). Although the vapor generation rate is based on a distribution of the emission rates from 10 web degreasing units, the data is only from web degreasers at two sites; therefore, it is unknown how representative the model is of a “typical” site (U.S. EPA, 2016a). A summary of the unit emission distribution used in the model for PCE is provided in Table 2-32.

Table 2-32. Unit Emission Rates Used to Model Perchloroethylene Web Degreasing Systems

Unit Emissions (lb PCE/unit-hr)	Fractional Probability
0.0495	0.1000
0.0495	0.1000
0.0495	0.1000
0.0495	0.1000
0.0330	0.1000
0.0330	0.1000
0.0200	0.4000

Web degreasers are assumed to operate 24 hours per day, based on NEI data on the reported operating hours for web degreasers using PCE (U.S. EPA, 2016a). EPA performed a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method in @Risk to calculate 8-hour TWA near-field and far-field exposure concentrations. Near-field exposure represents exposure concentrations for workers who directly operate the vapor degreasing equipment, whereas far-field exposure represents exposure concentrations for occupational non-users (i.e., workers in the surrounding area who do not handle the degreasing equipment). The modeled 8-hr TWA results and the values in Appendix B are used to calculate 24-hr AC, ADC, and LADC.

Table 2-33 presents a statistical summary of the exposure modeling results. Estimates of AC, ADC, and LADC for use in assessing risk were made using the approach and equations described in Appendix B. These exposure estimates represent modeled exposures for the workers and occupational non-users. For workers, the 50th percentile exposure is 0.61 ppm 8-hr TWA, with a 95th percentile of 1.80 ppm 8-hr TWA.

It showed be noted that results for web degreasing are two orders of magnitude lower than for the related conveyorized degreasers. This is expected based on the emissions reported in the 2014 NEI as the conveyorized data resulted in a unit emission of 4.06 lb/unit-hr which is two orders of magnitude greater than the high-end emission rate for web degreasers (0.0495 lb/unit-hr) (U.S. EPA, 2016a). Because the conveyorized emission rate is based on a single site and the web degreasing emission rate is based on only two sites it is unclear if this difference in exposure is a function of the available data or an actual function of the two systems. However, based on the types of parts being cleaned in the two systems, EPA expects less dragout of solvent vapors (the primary route of exposure) in web degreasing machines as the parts (e.g., film and metal sheets) are essentially two-dimensional objects compared to the three-dimensional objects being carried through a conveyorized system. Therefore, these results are in-line with EPA’s expectations of the two systems.

Table 2-33. Summary of Exposure Modeling Results for Use of Perchloroethylene in Web Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)
Worker Model Results				
High-End	1.8	0.6	0.4	0.2
Central Tendency	0.6	0.2	0.1	5.3E-2
Occupational Non-User Model Results				
High-End	1.2	0.4	0.3	0.1
Central Tendency	0.3	0.1	7.3E-2	2.7E-2

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

2.8.4 Water Release Assessment

2.8.4.1 Water Release Sources

Similar to OTVDs, the primary source of water releases from web systems is expected to be from wastewater from the water separator with the primary sources of water being: 1) Moisture in the atmosphere that condenses into the solvent when exposed to the condensation coils on the system; and/or 2) steam used to regenerate carbon adsorbers used to control solvent emissions (Durkee, 2014; Kanegsberg and Kanegsberg, 2011; NIOSH, 2002a, b, c, d). The current disposal practices of the wastewater are unknown; however, a U.S. EPA (1982) report estimated 20% of water releases from metal cleaning (including batch systems, conveyorized systems, and vapor and cold systems) were direct discharges to surface water and 80% of water releases were discharged indirectly to a POTW.

2.8.4.2 Water Release Assessment Results

EPA assesses water releases using TRI and DMR data and the *EPA/OPPT Water Saturation Loss Model*. However, EPA cannot distinguish between degreaser types in TRI and DMR data; therefore, all water releases from TRI/DMR degreasing sites is presented in Section 2.5.4.2 for OTVDs. For sites not in TRI/DMR, EPA assessed using the *EPA/OPPT Water Saturation Loss Model* as discussed for OTVDs in Section 2.5.4. The number of sites assessed is 272 sites using the 95th percentile use-rate (395 total sites – 123 TRI/DMR sites = 272 sites) and 445 sites using the 50th percentile use-rate (568 total sites – 123 TRI/DMR sites = 445 sites). Table 2-34 summarizes these results. There is some uncertainty on how these 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. The model results are within the range of discharge volumes reported by sites in TRI/DMR.

Table 2-34. Model Results for Perchloroethylene Discharges from Web Degreasers Sites Not in TRI/DMR

Scenario	Number of Sites	Volume of Wastewater (gal/day)	Daily Release (kg/day)	Annual Release Days (days/yr)	Annual Release[a] (kg/yr)	Release Media/ Treatment Facility Type
High-End	272	20	1.6E-2	260	4.1	POTW or non-POTW WWT
Low-End	272	2	1.6E-3	260	0.4	
High-End	445	20	1.6E-2	260	4.1	
Low-End	445	2	1.6E-3	260	0.4	

2.9 Cold Cleaning

2.9.1 Estimates of Number of Facilities

To determine the number of sites that use PCE in cold cleaning, EPA considered 2014 NEI (U.S. EPA, 2016a), 2016 TRI (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. Sites in TRI and DMR do not differentiate between vapor degreasers and cold cleaning and are considered to be included in the bounding estimates for the OTVD assessment and are not considered here. In the 2014 NEI, 17 sites reported operation of a total of 34 cold cleaning machines (U.S. EPA, 2016a). Therefore, EPA assesses 17 sites for cold cleaning. It should be noted that this number is expected to underestimate the total number of sites using PCE in cold cleaners as NEI data does 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 operator cold cleaning machines.

2.9.2 Process Description

Cold cleaners are non-boiling solvent degreasing units. Cold cleaning operations include spraying, brushing, flushing and immersion. Figure 2-13 shows the design of a typical batch-loaded, maintenance cold cleaner, where dirty parts are cleaned manually by spraying and then soaking in the tank. After cleaning, the parts are either suspended over the tank to drain or are placed on an external rack that routes the drained solvent back into the cleaner. Batch manufacturing cold cleaners could vary widely but have two basic equipment designs: the simple spray sink and the dip tank. The dip tank design typically provides better cleaning through immersion, and often involves an immersion tank equipped with agitation (U.S. EPA, 1981). Emissions from batch cold cleaning machines typically result from (1) evaporation of the solvent from the solvent-to-air interface, (2) “carry out” of excess solvent on cleaned parts and (3) evaporative losses of the solvent during filling and draining of the machine (U.S. EPA, 2006b).

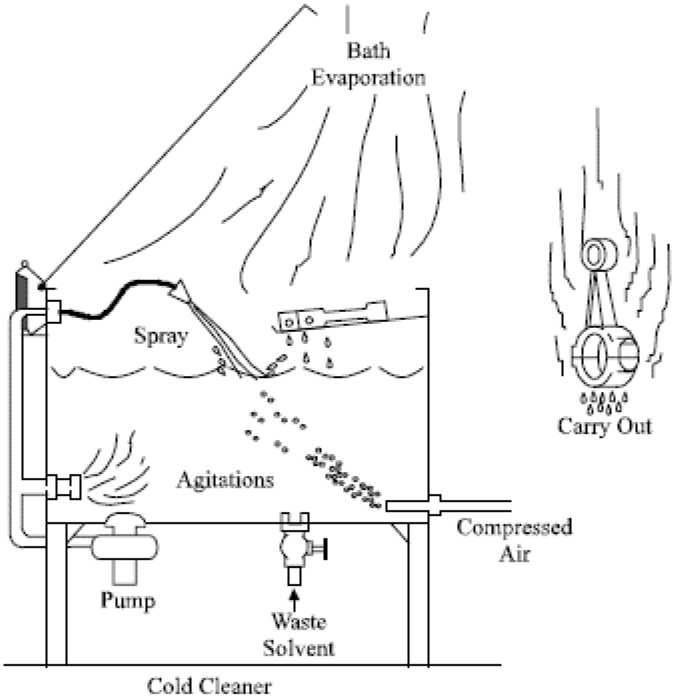

Figure 2-13. Typical Batch-Loaded, Maintenance Cold Cleaner (U.S. EPA, 1981)

Emissions from cold in-line (conveyorized) cleaning machines result from the same mechanisms, but with emission points only at the parts' entry and exit ports (U.S. EPA, 2006b).

2.9.3 Exposure Assessment

2.9.3.1 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, 2001; U.S. EPA, 1997).

2.9.3.2 Number of Potentially Exposed Workers

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 (U.S. EPA, 2016a). The method for estimating number of workers is detailed above in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. In the 2014 NEI, four sites reported NAICS code for which there was no Census data available (U.S. EPA, 2016a). To estimate the number of workers/ONUs at these sites, EPA referenced the draft ESD on the Use of Vapor Degreasers (OECD, 2017a)[14]. Table 2-35 provides the results of the number of worker analysis. There are approximately 710 workers and 420 ONUs potentially exposed during use of PCE in cold cleaning.

Table 2-35. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Use in Cold Cleaning

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
221112	1	6	8	6	8	13
322130	1	120	18	120	18	139
323111	1	2	1	2	1	3
325180	1	25	12	25	12	37
325211	1	27	12	27	12	40
327331	1	8	1	8	1	10
331110	1	53	18	53	18	71
332117	1	15	5	15	5	20
332812	2	7	2	14	3	18
332912	1	28	11	28	11	38
336414	1	372	314	372	314	686
339920	1	9	2	9	2	11
Subtotal for Known NAICS Data	13	52	31	681	405	1,086
No Data	4	7	4	27	17	44
Total[b]	17	42	25	710	420	1,100

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer.

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

2.9.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from a NIOSH investigation at a single site using PCE as a cold cleaning solvent. 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

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[14] 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.

Exposure Model. The following subsections detail the results of EPA's occupational exposure assessment for cold cleaning based on inhalation exposure monitoring data and modeling.

2.9.3.3.1 Inhalation Exposure Assessment Results Using Monitoring Data

Table 2-36 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 (1994b) under TSCA . The data only includes values for workers; data for ONUs were not identified.

The NIOSH In-Depth Survey Report was conducted as part of an interagency agreement with OSHA to evaluate the extent of employee exposure to PCE at sites using it as a solvent in degreasers and to document engineering controls and work practices at the workplace affecting exposures (NIOSH, 2002c). The cold cleaning data from this study were collected at a parts cleaning job site that had both a vacuum degreaser and a cold cleaner (NIOSH, 2002c). Sample times for cold cleaning operations were approximately 3 hours (NIOSH, 2002c). Where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero. Similarly, where sample times were less than four hours, EPA converted to 4-hr TWAs assuming exposure outside the sample time was zero.

The study submitted by Vulcan Chemicals was conducted to evaluate the feasibility of replacing 1,1,1-trichloroethane (TCA) with two solvent blends of PCE in cold cleaning applications (Vulcan Chemicals, 1994b). The study was conducted at a site that manufactures and repairs small electric motors for the aircraft industry (Vulcan Chemicals, 1994b). The study evaluated two blends, one containing 28% PCE and one containing 50% PCE. It should be noted that the PCE can also be used as a pure cold cleaning solvent (concentration >99%); therefore, results from this study may underestimate exposures from use of pure PCE cold cleaning solvent. Sample times ranged from two to eight hours; where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero (Vulcan Chemicals, 1994b). Similarly, where sample times were less than four hours, EPA converted to 4-hr TWAs assuming exposure outside the sample time was zero.

In both studies EPA assumed the exposure concentrations outside of the sample times was zero which may result in underestimates of exposure. However, both studies indicated that cold cleaning operations are not expected to occur for the duration of the work-shift. Therefore, EPA expects the overall error from this assumption to be minimal as the exposure potential when not performing cold cleaning operations is expected to be minimal.

It should be noted that additional sources for solvent cleaning were identified but were not used in EPA's analysis as they either: 1) did not specify between vapor and cold cleaning machines; or 2) only provided a statistical summary of worker exposure monitoring.

Table 2-36. Summary of Worker Inhalation Exposure Monitoring Data for Use of Perchloroethylene in Cold Cleaning

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	4-hr TWA (ppm)	Number of Data Points
High-End	4.1	1.4	0.9	0.5	29	4.3	5
Central Tendency	1.4	0.5	0.3	0.1		2.9	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Source: (NIOSH, 2002c; Vulcan Chemicals, 1994b)

2.9.3.3.2 Inhalation Exposure Assessment Results Using Modeling

A more detailed description of the modeling approach is provided 0. Figure 2-14 illustrates the near-field/far-field model that can be applied to cold cleaning. As the figure shows, PCE vapors evaporate into the near-field (at evaporation rate G), resulting in near-field exposures to workers at a concentration C_{NF}. The concentration is directly proportional to the evaporation rate of PCE, G, into the near-field, whose volume is denoted by V_{NF}. The ventilation rate for the near-field zone (Q_{NF}) determines how quickly PCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outdoor air. 0 outlines the equations uses for this model.

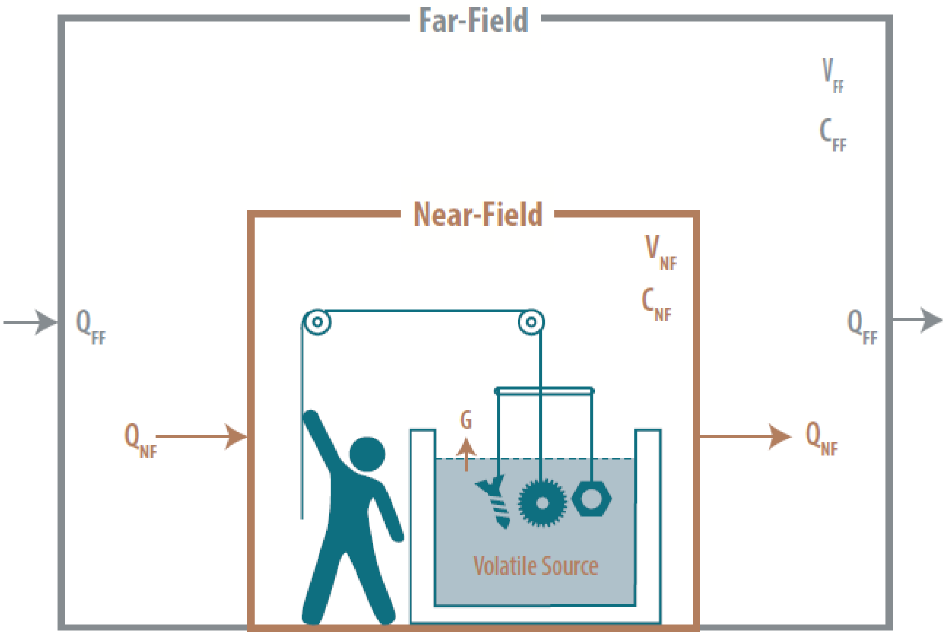

Figure 2-14. Schematic of the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model

0 presents the model parameters, parameter distributions, and assumptions for the PCE Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model. To estimate the PCE vapor generation rate, the model

developed a distribution from the reported annual emission rates and annual operating times reported in the 2014 NEI. NEI records where the annual operating time was not reported were excluded from the distribution. There were also four cold cleaning units at a single site for which the reported emission rate was zero that were excluded from the distribution (U.S. EPA, 2016a). The site indicated the use of a thermal oxidizer with 100% capture efficiency; therefore, the reported emissions are the emissions after the control device (U.S. EPA, 2016a). Workers/ONUs would be exposed to PCE that evaporates from the cold cleaner prior to its capture by the control device. Therefore, only uncontrolled emissions are used in the model. Uncontrolled emissions from the four cold cleaners from this site cannot be determined, thus, emissions from these machines are not included in the model. A summary of the unit emission distribution used in the model for PCE is provided in Table 2-37.

Table 2-37. Unit Emission Rates Used to Model Perchloroethylene Cold Cleaning

Unit Emissions (lb PCE/unit-hr)	Fractional Probability
0.12	0.04
0.08	0.04
0.02	0.04
1.17E-02	0.04
4.02E-03	0.04
8.03E-04	0.04
4.01E-04	0.04
2.67E-04	0.04
2.66E-04	0.04
2.30E-04	0.04
2.01E-04	0.08
1.34E-04	0.04
9.13E-05	0.19
2.77E-05	0.04
2.28E-05	0.04
2.17E-05	0.04
1.83E-05	0.04
1.49E-06	0.04
2.98E-07	0.08
1.13E-07	0.04

Cold cleaners are assumed to operate between 1 to 24 hours per day, based on NEI data on the reported operating hours for cold cleaners using PCE (U.S. EPA, 2016a). A summary of the unit operating hours distribution used in the model for PCE is provided in Table 2-38.

Table 2-38. Unit Operating Hours Used to Model Perchloroethylene Cold Cleaning

Unit Emissions (lb PCE/unit-hr)	Fractional Probability
24	0.70
8	0.26
1	0.04

EPA performed a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method in @Risk to calculate 8-hour TWA near-field and far-field exposure concentrations. Near-field exposure represents exposure concentrations for workers who directly operate the vapor degreasing equipment, whereas far-field exposure represents exposure concentrations for occupational non-users (i.e., workers in the surrounding area who do not handle the cold cleaning equipment). The modeled 8-hr TWA results and the values in Appendix B are used to calculate 24-hr AC, ADC, and LADC.

Table 2-39 presents a statistical summary of the exposure modeling results. Estimates of AC, ADC, and LADC for use in assessing risk were made using the approach and equations described in Appendix B. These exposure estimates represent modeled exposures for the workers and occupational non-users. For workers, the 50th percentile exposure is 0.002 ppm 8-hr TWA, with a 95th percentile of 1.54 ppm 8-hr TWA. It should be noted that the central tendency exposure estimate is three orders of magnitude less than the high-end estimate, this is due to the large variation in unit emissions estimated from NEI with three orders of magnitude separating the median and maximum emission rates from the 2014 NEI.

The high-end results of the model are on 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. 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 Perchloroethylene in Cold Cleaning

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)
Worker Model Results				
High-End	1.5	0.5	0.4	0.1
Central Tendency	2.4E-3	8.0E-4	5.5E-4	2.0E-4
Occupational Non-User Model Results				
High-End	0.8	0.3	0.2	6.7E-2
Central Tendency	1.2E-3	4.1E-4	2.8E-4	1.1E-4

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

2.9.4 Water Release Assessment

2.9.4.1 Water Release Sources

Similar to OTVDs, the primary source of water releases from cold cleaners is expected to be from wastewater from the water separator with the primary source of water expected to be from moisture in the atmosphere that condenses into the solvent. Water may also enter vapor degreasers via steam used to regenerate carbon adsorbers; however, it is unclear if carbon adsorbers would be used in conjunction with cold cleaning equipment. The current disposal practices of the wastewater are unknown; however, a U.S. EPA (1982) report estimated 20% of water releases from metal cleaning (including batch systems, conveyorized systems, and vapor and cold systems) were direct discharges to surface water and 80% of water releases were discharged indirectly to a POTW.

2.9.4.2 Water Release Assessment Results

EPA assesses water release using TRI and DMR data. However, EPA cannot distinguish between degreasers and cold cleaners in TRI and DMR data; therefore, a single set of water release for all degreasing and cold cleaning operations is presented in Section 2.5.4.2 for OTVDs. Unlike vapor degreasing OES, EPA did not assess releases for sites not in TRI/DMR using the *EPA/OPPT Water Saturation Loss Model*. EPA did not identify reasonably available information to estimate the amount of wastewater produced from cold cleaning equipment and EPA does not expect the amount estimated for vapor degreasers to be applicable to cold cleaning. In cold cleaning, the solvent is present as a liquid; therefore, the use of freeboard chillers in vapor degreasers to control emissions of volatilized solvents may not apply to cold cleaning equipment. The lack of such equipment may reduce the potential for water vapors in the atmosphere to condense into the solvent bath in cold cleaning equipment. Therefore, it is likely inappropriate to use estimates from vapor degreasing equipment to estimate cold cleaning releases.

2.10 Aerosol Degreasing and Aerosol Lubricants

2.10.1 Estimates of Number of Facilities

EPA estimated the number of facilities using aerosol degreasers and aerosol lubricants using data from the U.S. Census' SUSB (U.S. Census Bureau, 2015). The method for estimating number of facilities is detailed above in Section 1.4.1. These estimates were derived using industry-specific data from the U.S. Census. Table 2-40 presents the NAICS industry sectors relevant to aerosol degreasing and aerosol lubricants. For aerosol degreasing, EPA selected all NAICS codes associated with automotive, electronic equipment, or other machinery/equipment repair. The list of NAICS codes includes the codes for sporting goods stores and automobile dealers. The sporting goods stores NAICS code includes bike shops, golf pro shops, and gun shops which may perform aerosol degreasing when performing repairs or maintenance on the equipment. The automobile dealers NAICS code was included as many automobile dealers also have repair shops associated with them. For both NAICS codes, EPA does not expect all of the establishments within the NAICS to perform aerosol degreasing; however, information was not available to determine the percentage of sporting goods stores that fall within a category expected to have repair or maintenance activities or percentage of automobile dealers with associated repair shops. Therefore, inclusion of these NAICS codes may result in overestimate of sites using PCE-based aerosol products.

Table 2-40. NAICS Codes for Aerosol Degreasing and Lubricants

NAICS	Industry
811111	General Automotive Repair
811112	Automotive Exhaust System Repair
811113	Automotive Transmission Repair
811118	Other Automotive Mechanical and Electrical Repair and Maintenance
811121	Automotive Body, Paint, and Interior Repair and Maintenance
811122	Automotive Glass Replacement Shops
811191	Automotive Oil Change and Lubrication Shops
811198	All Other Automotive Repair and Maintenance
811211	Consumer Electronics Repair and Maintenance
811212	Computer and Office Machine Repair and Maintenance
811213	Communication Equipment Repair and Maintenance
811219	Other Electronic and Precision Equipment Repair and Maintenance
811310	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance
811411	Home and Garden Equipment Repair and Maintenance
811490	Other Personal and Household Goods Repair and Maintenance
451110	Sporting Goods Stores
441100	Automobile Dealers

There are 256,850 establishments among the industry sectors expected to use aerosol degreasers and/or aerosol lubricants (U.S. Census Bureau, 2015). A 1997 manufacturer survey from CARB found that approximately 44% of all aerosol brake cleaning products sold in California contained PCE and approximately 37% of aerosol brake cleaning products available contained PCE (Carb, 2000). Similarly, a CARB survey of automotive maintenance and repair facilities found, of the 73% of facilities that use brake cleaning products to perform brake jobs, approximately 38% of these facilities used brake cleaning products containing chlorinated chemicals (Carb, 2000).

These data only relate to aerosol brake cleaning products used in the automotive repair industry; however, aerosol degreasing and lubricant products may also be used in electronics repair, industrial equipment repair, home and garden equipment repair, or other similar industries. Market penetration data for these industries were not identified; therefore, in lieu of other information, EPA assumed a similar market penetration rate as for brake cleaning products. It is also possible the brake cleaning product manufacturer and facility surveys completed by CARB underestimate the total number of establishments that may use a PCE-containing product as some establishments may use an aerosol lubricant containing PCE but not a brake cleaning product containing PCE. However, EPA expects the potential error from this to be relatively small as only approximately 0.1% (317,000 lbs) of the total U.S production volume of PCE is expected to be used in lubricants (U.S. EPA, 2016d). For comparison, based on reported sales in 1996, CARB estimated approximately 2.7 million pounds of PCE were used in brake cleaning products in California alone (Carb, 2000).

EPA assumed the average market penetration for PCE aerosol degreasers and lubricants was the average of the low- and high-end values found by CARB, or 40.5% multiplied by the 73% of facilities that use brake cleaning products, or 29.6% (40.5% x 73%=29.6%) (Carb, 2000). This results in approximately 75,938 establishments using aerosol products containing PCE. It is unclear whether the number of establishments using PCE-based aerosol degreasers has changed since 2000.

2.10.2 Process Description

EPA's Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal for PCE (Use Document) identified 170 aerosol-based products containing PCE (U.S. EPA, 2017c). CRC Industries, Inc., a manufacturer of PCE-based degreasing products, indicates that PCE-based products are used where flammability is a concern for worker and consumer safety as PCE has no flash point and no upper and lower explosive limits (Rudnick, 2017). 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 (Rudnick, 2017; U.S. EPA, 2017c). The weight percent of PCE in these products ranges from 2.5 to 100% (U.S. EPA, 2017c). 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 (Rudnick, 2017; U.S. EPA, 2017c). The weight percent of PCE in these products ranges from <1 to 100% (U.S. EPA, 2017c). EPA expects significant overlap in the industry sectors that use aerosol-based products; therefore, these uses are combined.

Aerosol degreasing is a process that uses an aerosolized solvent spray, typically applied from a pressurized can, to remove residual contaminants from fabricated parts. A propellant is used to aerosolize the formulation, allowing it to be sprayed onto substrates. Similarly, aerosol lubricant products use an aerosolized spray to help free frozen parts by dissolving rust and leave behind a residue to protect surfaces against rust and corrosion. Based on the safety data sheets for the identified products, PCE-based aerosol products generally use carbon dioxide as the propellant, although a vandalism mark and stain remover was identified that uses liquefied petroleum gas (LPG) as a propellant (i.e., propane and butane).

2.10.3 Exposure Assessment

2.10.3.1 Worker Activities

Figure 2-15 illustrates the typical process of using aerosol degreasing to clean components in commercial settings. 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, 2014).

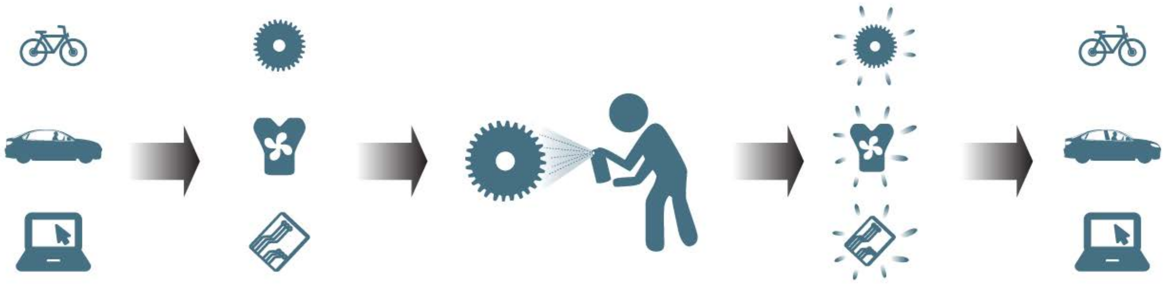

Figure 2-15. Overview of Aerosol Degreasing

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 include employees that work at the facility but do not directly apply the aerosol product to the service item and are therefore expected to have lower inhalation exposures and are not expected to have dermal exposures.

2.10.3.2 Number of Potentially Exposed Workers

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). The method for estimating number of workers is detailed above in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census.

To estimate the number of workers and ONUs, EPA multiplied the total number of workers and ONUs for each NAICS code identified in Table 2-40 (derived from the U.S. Census' SUSB and the Bureau of Labor Statistics' OES data) by the market penetration of 29.6%. EPA then summed the workers and ONUs for each identified NAICS code to estimate a total number of workers and ONUs exposed. Based on this analysis, 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 2-41) (U.S. BLS, 2016; U.S. Census Bureau, 2015; Carb, 2000).

Table 2-41. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Use of Aerosol Degreasers and Aerosol Lubricants

Number of Sites	Exposed Workers per Site[a]	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.

2.10.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data related to the use of PCE in aerosol degreasers for brake servicing and vehicle maintenance. However, as described in Section 2.10.2, 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. The following subsections detail the results of EPA's occupational exposure assessment for aerosol degreasing and aerosol lubricants based on inhalation exposure monitoring data and modeling.

2.10.3.3.1 Inhalation Exposure Assessment Results Using Monitoring Data

Table 2-42 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) (OSHA, 2020; Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018; Cosgrove and Hygiene, 1994; Vulcan Chemicals, 1993, 1992). One other study with monitoring data was identified; however, the study states it was performed at two research and development locations with conditions expected to be more severe than any "worst case scenario" at a normal brake shop (Vulcan Chemicals, 1994a). Therefore, EPA did not include this data in the analysis. All identified aerosol exposure data are for workers using the aerosol brake cleaner; data for ONUs were not identified.

One of the studies was performed by Health & Hygiene, Inc. (Cosgrove and Hygiene, 1994) who collected the samples from five different automotive repair shops during routine cleaning of disc and drum brakes. Workers at each site were supplied with an extension tube to create a concentrated liquid stream of product when sprayed on the brake parts (Cosgrove and Hygiene, 1994). Other than the supplied extensions, workers were instructed to use the aerosol product as they normally would (Cosgrove and Hygiene, 1994). Health & Hygiene, Inc. (Cosgrove and Hygiene, 1994) stated that many of the shops chose to have the garage doors opened for ventilation purposes. The authors noted that the natural air current could either direct the mist away from the worker if their back was to the air flow or towards the worker and potentially increasing exposure if they were facing the air flow (Cosgrove and Hygiene, 1994).

Two other studies were submitted to EPA under TSCA by Vulcan Chemicals (Vulcan Chemicals, 1993, 1992). The purpose of both studies was to evaluate exposures to aerosol products proposed as alternatives to 1,1,1-trichloroethane (methylchloroform) brake cleaners (Vulcan Chemicals, 1993, 1992). One study evaluated various formulations of aerosol degreasers containing 25% PCE, and the other study evaluated one formulation containing 30% PCE, and one with 60% PCE. Based on data from CARB (Carb, 2000) and modeling results (See Section 2.10.3.3.2 and Appendix H), 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.

EPA constructed five full-shift samples from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD data did not explicitly state the use of aerosol degreasers; rather, EPA assumed the use to be aerosol degreasing based on the SIC codes reported which included the codes for Sporting Goods Stores; Automotive Body, Paint, and Interior Repair and Maintenance; and Automobile and Other Motor Vehicle Merchant Wholesalers (OSHA, 2020). OSHA data does not provide job titles or worker activities associated with the samples; therefore, EPA assumed the data were collected on workers and not ONUs.

The data provided by DoD did not explicitly state the use of aerosol degreasers (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). Rather, the data indicated that samples were collected during vehicle maintenance, which EPA assumed to be related to aerosol degreasing activities.

The sample times for the identified monitoring data ranged from approximately four to nine hours. Where sample times were less than eight hours, EPA converted to 8-hr TWAs assuming zero exposures outside the sample time. It should be noted that approximately 16% of the 8-hr TWA data were measured below the LOD. 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 1.4.5.2. 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 2-42. Summary of Worker Inhalation Exposure Monitoring Data for Aerosol Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	15-Minute TWA (ppm)	Number of Data Points
High-End	7.5	2.5	1.7	0.9	144	123	67
Central Tendency	1.4	0.5	0.3	0.1		29	

AC = Acute Concentration; ADC = Average Daily Concentration and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Source: (OSHA, 2020; Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018; Cosgrove and Hygiene, 1994; Vulcan Chemicals, 1993, 1992)

2.10.3.3.2 Inhalation Exposure Assessment Results Using Modeling

A more detailed description of the modeling approach is provided in Appendix H. Figure 2-16 illustrates the near-field/far-field for the aerosol degreasing scenario. As the figure shows, PCE in aerosolized droplets immediately volatilizes into the near-field, resulting in worker exposures at a concentration C_{NF}. The concentration is directly proportional to the amount of aerosol degreaser applied by the worker, who is standing in the near-field-zone (i.e., the working zone). The volume of this zone is denoted by V_{NF}. The ventilation rate for the near-field zone (Q_{NF}) determines how quickly PCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational non-user exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outside air.

In this scenario, PCE mists enter the near-field in non-steady “bursts,” where each burst results in a sudden rise in the near-field concentration, followed by a more gradual rise in the far-field concentration. The near-field and far-field concentrations then decay with time until the next burst causes a new rise in near-field concentration.

Based on site data from maintenance and auto repair shops obtained by CARB (2000) for brake cleaning activities, the model assumes a worker will perform 11 applications of the degreaser product per brake job with five minutes between each application and that a worker may perform one to four brake jobs per day each taking one hour to complete. EPA modeled two scenarios, one where the brake cleaning jobs occurred back-to-back and one where braking cleaning jobs occurred one hour apart. Based on data from CARB (2000), EPA assumes each brake job requires one 14.4-oz can of aerosol brake cleaner. The model determines the application rate of PCE using the weight fraction of PCE in the aerosol product. EPA uses uniform distribution of weight fractions for PCE based on facility data for the aerosol products in use (Carb, 2000). It is uncertain whether the use rate and weight fractions for brake cleaning are representative of other aerosol degreasing and lubricant applications. Model parameters and assumptions for aerosol degreasing are presented in Appendix H.

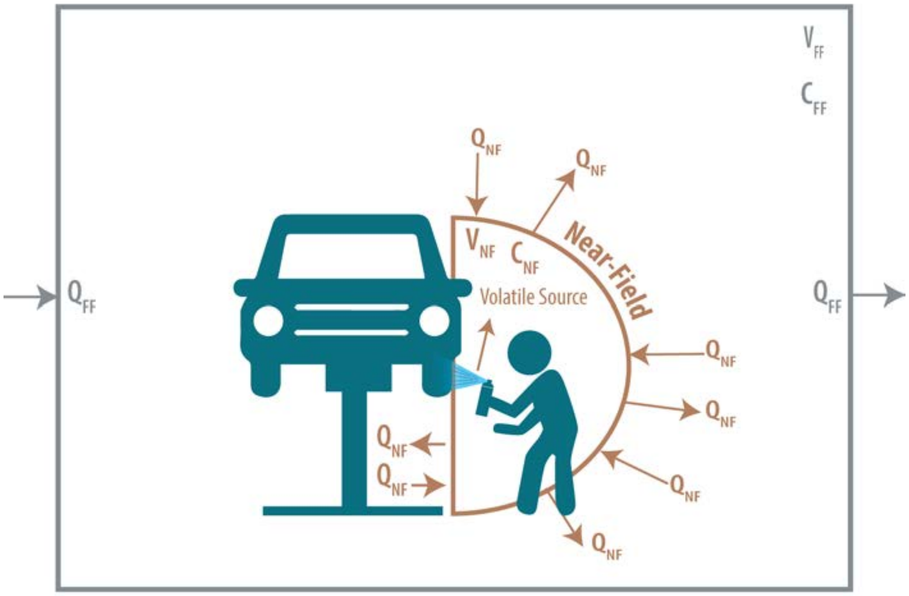

Figure 2-16. Schematic of the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model

EPA performed a Monte Carlo simulation with 100,000 iterations and the Latin hypercube sampling method to model near-field and far-field exposure concentrations in the aerosol degreasing scenario. The model calculates both 8-hr TWA exposure concentrations and maximum 1-hr TWA exposure concentrations. Table 2-43 presents a statistical summary of the exposure modeling results.

For workers, the exposures are 5.48 ppm 8-hr TWA at the 50th percentile and 17.2 ppm 8-hr TWA at the 95th percentile. 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. This 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. For occupational non-users, the model exposures are 0.10 ppm 8-hr TWA at the 50th percentile and 0.75 ppm 8-hr TWA at the 95th percentile.

Table 2-43. Summary of Worker and Occupational Non-User Inhalation Exposure Modeling Results for Aerosol Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Maximum 1-hr TWA Exposures (ppm)
Workers Model Results					
High-End	17	5.7	3.9	1.6	50
Central Tendency	5.5	1.8	1.3	0.5	17
Occupational Non-Users Model Results					
High-End	0.7	0.2	0.2	7.0E-2	2.2
Central Tendency	0.1	3.4E-2	2.0E-2	1.0E-2	0.3

AC = Acute Concentration; ADC = Average Daily Concentration and LADC = Lifetime Average Daily Concentration.
Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

2.10.4 Water Release Assessment

EPA does not expect releases of PCE to water from the use of aerosol products. Due to the volatility of PCE, the majority of releases from the use of aerosol products will likely be to air as PCE evaporates from the aerosolized mist and the substrate surface. There is a potential that any PCE that deposits on shop floors during the application process could possibly end up in a floor drain (if the shop has one) or could runoff outdoors if garage doors are open. However, EPA expects the potential release to water from this to be minimal as there would be time for PCE to evaporate before entering one of these pathways. This is consistent with estimates from the International Association for Soaps, Detergents and Maintenance Products (AISE) SpERC for Wide Dispersive Use of Cleaning and Maintenance Products, which estimates 100% of volatiles are released to air (International Association for Soaps Detergents and Maintenance Products, 2012)5178607. EPA expects residuals in the aerosol containers to be disposed of with shop trash that is either picked up by local waste management or by a waste handler that disposes shop wastes as hazardous waste.

2.11 Dry Cleaning and Spot Cleaning

2.11.1 Estimates of Number of Facilities

EPA estimated the number of dry cleaning facilities using PCE as a solvent using data from the U.S. Census' SUSB (U.S. Census Bureau, 2015). The method for estimating number of facilities is detailed above in Section 1.4.1. These estimates were derived using industry-specific data from the U.S. Census.

PCE may be used as a solvent at small commercial facilities categorized under the NAICS 812320, Drycleaning and Laundry Services (except Coin-Operated) and at large industrial dry cleaning facilities categorized under 812332, Industrial Launderers (U.S. EPA, 2006a). EPA expects the majority of PCE use to occur at small commercial facilities as large industrial launderers only account for approximately 2% of the total PCE consumption in the dry cleaning industry (U.S. EPA, 2006a).

There are 21,370 establishments in the United States under NAICS 812320, Drycleaning and Laundry Services (U.S. Census Bureau, 2015). The Dry Cleaning and Laundry Institute (DLI) and the National

Cleaners Association (NCA) estimate approximately 60% of dry cleaning machines now use PCE (Dli and Nca, 2017). In 1991, EPA estimated that 83% of all dry-cleaning facilities used PCE as solvent (U.S. EPA, 1991b). In 2008, the Halogenated Solvents Industry Alliance (HSIA) estimated that 70% of dry cleaners used PCE as a dry-cleaning solvent (Hsia, 2017). Similarly, a 2010 profile of the dry-cleaning industry conducted by King County, WA found that 69% of respondents (105 of the 152 respondents) used PCE in their primary machine (Whittaker and Johanson, 2011). Hence, there appears to be a trend towards alternatives to PCE in dry cleaning. Therefore, EPA uses a market penetration of 60% to be consistent with current conditions reported by the dry-cleaning industry. Using this factor, EPA estimated that approximately 12,822 small commercial dry cleaning establishments use PCE.

In 2006, EPA/OAQPS estimated 12 large industrial dry cleaners using PCE as a solvent (U.S. EPA, 2006a). Industrial dry cleaners include facilities that clean heavily stained articles such as work gloves, uniforms, mechanics' overalls, mops, and shop rags, and facilities that operate as a central plant for a chain of retail storefronts (U.S. EPA, 2006a). EPA did not identify more recent data for industrial dry cleaners; therefore, EPA assumes 12 industrial dry cleaners.

2.11.2 Process Description

Dry cleaning machines are typically categorized into five generations of machines. 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, and the 2006 Perchloroethylene NESHAP for Dry Cleaning Facilities banned the use of PCE in all first-generation machines (U.S. EPA, 2006a). The typical useful life of these machines is approximately 15 years; therefore, PCE is only expected to be used in third, fourth, and fifth generation machines currently (U.S. EPA, 2006a). Figure 2-17 provides an overview of the dry cleaning process.

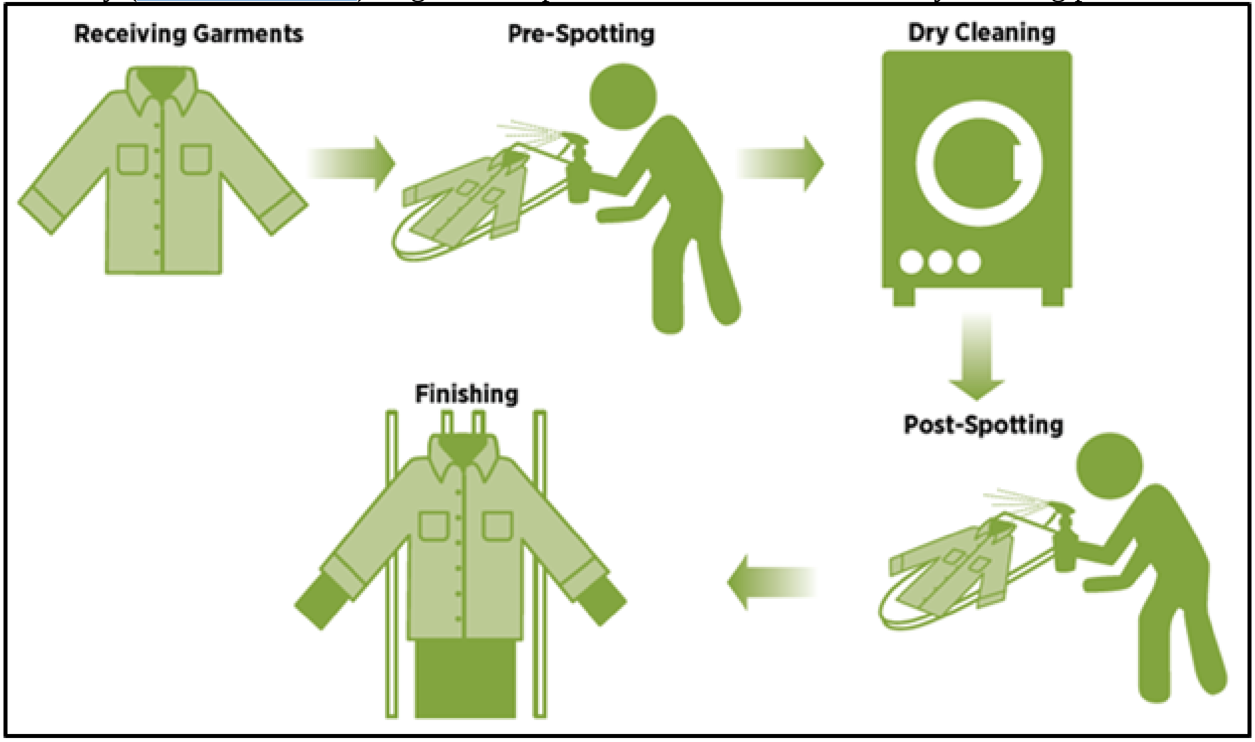

Figure 2-17. Overview of Dry Cleaning Process

Third generation equipment, introduced in the late 1970s and early 1980s, 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. 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).

PCE is also found in products used to spot clean garments. On receiving a garment, dry cleaners inspect for stains or spots they can remove as much of as possible before cleaning the garment in a dry cleaning machine. As Figure 2-18 shows, spot cleaning occurs on a spotting board and can involve the use of a spotting agent containing various solvents, such as PCE. The spotting agent can be applied from squeeze bottles, hand-held spray bottles, or even from spray guns connected to pressurized tanks. Once applied, the dry cleaner may come into further contact with the PCE if using a brush, spatula, pressurized air or steam, or their fingers to scrape or flush away the stain (Young, 2012; Niosh, 1997a).

Figure 2-18. Overview of Use of Spot Cleaning at Dry Cleaners

2.11.3 Exposure Assessment

2.11.3.1 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.

2.11.3.2 Number of Potentially Exposed Workers

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). The method for estimating number of workers is detailed above in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census.

Based on a market penetration of 60% for commercial facilities, assuming 12 industrial dry cleaners, 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 2-44).

Table 2-44. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Dry Cleaning

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
812320	12,822	3	1	43,314	13,530	56,844
812332	12	25	3	304	32	336
Total[b]	12,834	3	1	44,000	14,000	57,000

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer.

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

2.11.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data related to the use of PCE as a dry cleaning solvent. However, as estimated in Section 2.11.1, 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. The following subsections detail the results of EPA's occupational exposure assessment for dry cleaning based on inhalation exposure monitoring data and modeling.

2.11.3.3.1 Inhalation Exposure Assessment Results Using Monitoring Data

Table 2-46 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 (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018; Osha, 2017; NIOSH, 2000a, b, 1999a, b, 1995). The data are divided into two categories: 1) statistics for data collected after the promulgation of the 2006 Perchloroethylene NESHAP for Dry Cleaning Facilities; and 2) data collected for fourth or fifth generation machines only. 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. Results based on a single value are plausible, but EPA cannot determine the statistical representativeness of the value. 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 Board, 2006). Therefore, EPA expects the industry to be trending towards higher usage of fourth and fifth generation machines as compared to third generation machines. EPA assumes the post-2006 NESHAP data are representative of the machine type mix provided in the King County, WA survey (Whittaker and Johanson, 2011) 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. Table 2-45 provides a summary of the trends in dry cleaning machine types from several surveys.

Table 2-45. Summary of Survey Responses for Dry Cleaning Machine Generations

Machine Type	Percent of Survey Respondents or Projected Facilities			
	2000 HSIA Survey (Erg, 2005)	**2003 CA Survey (California Air Resources Board, 2006)**	**2006 Projection (Erg, 2005)**	**2010 King Cunty WA Survey (Whittaker and Johanson, 2011)**
1st Generation	1.4%	1%	1%	1%
2nd Generation	3%	--	1%	6%
2nd Generation Retrofitted	--	2%	--	3%
3rd Generation	65%	62%	37%	23%
4th Generation	31%	28%	61%	28%
5th Generation	--	--	--	33%
Other	--	2%	--	6%
Total	100%	95%	100%	100%

The data from OSHA were collected during compliance inspections at 24 different facilities occurring between 2006 and 2018 (OSHA, 2020, 2017). The OSHA compliance data do not provide the dry cleaning machine types; however, based on the dates of collection, EPA assumed that these data are representative of the post-2006 mix of machine types as provided in the 2010 King County, WA Survey (Whittaker and Johanson, 2011). Personal air samples for PCE were collected from approximately 2.5 to 8 hours (OSHA, 2020, 2017). Data obtained directly from OSHA CEHD (OSHA, 2020) do not provide job titles or worker activities associated with the samples; therefore, EPA assumed the data were collected on workers and not ONUs. Where the air samples were collected for times less than eight hours, EPA calculated the 8-hr TWAs by assuming exposure to be zero for the unsampled time. Seven samples calculated 8-hr TWAs based on sample times less than six hours resulting in assumption of zero exposure for over a quarter of the work shift and thus potentially underestimating actual exposure. The OSHA air sampling data contain nine short-term PCE air measurements collected over 5 to 15 minutes (Osha, 2017). The short-term exposures are characterized as 15-minute TWAs in Table 2-46. Since the OSHA data are from compliance inspections often as a result of worker complaints, they may not necessarily be representative of PCE concentrations encountered in the typical commercial dry cleaning establishment.

The data provided to EPA from DoD were collected in March 2015 and March 2017 (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). The DoD data do not provide the dry cleaning machine type; however, based on the dates of collection, EPA assumed that these data are representative of the post-2006 mix of machine types as provided in the 2010 King County, WA Survey (Whittaker and Johanson, 2011). The sample times for the data ranged from 7 to 7.5 hours; where the air samples were collected for times less than eight hours, EPA calculated the 8-hr TWAs by assuming exposure to be zero for the unsampled time (citation for DoD data). The DoD data contains one sample that was reported at being less than the LOD (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 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 1.4.5.2. 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).

The 1995 NIOSH (1995) report summarizes data collected as part of an industry study to evaluate engineering controls to reduce exposure to PCE at dry cleaners. The 1995 report is part of a series of studies completed by NIOSH that included data from several sites with first through fifth generation machines. Only data from this report are included because the other reports either: 1) only included data for first or second generation machines which are no longer in use; 2) only included area samples rather that PBZ data; or 3) did not provide full-shift sample results. In this study, the 8-hr TWAs were constructed from four samples taken for approximately 120 min each over a single day with total sample times ranging from approximately five to eight hours (Niosh, 1995). Where samples times were less than eight hours, EPA converted to 8-hr TWAs assuming zero exposure outside the sample time.

The 1999 and 2000 NIOSH (NIOSH, 2000a, 1999a, b) reports are part of a series of studies conducted as part of an industry study to evaluate exposures and control technologies for shops with fourth and fifth generation machines. The studies evaluated exposures to pressers, machine operators, and other dry cleaning employees at eight different shops (NIOSH, 2000a, 1999a, b). Sample times ranged from approximately 3 to 10 hours with 18 of the 111 samples exceeding 8.5 hours. Where samples times were less than eight hours, EPA converted to 8-hr TWAs assuming zero exposure outside the sample time and where sample times exceeded 8 hours, EPA left the data “as is”.

The 2000 NIOSH (2000b) report summarized data collected as part of an industry study to evaluate the effectiveness of local exhaust ventilation (LEV) to reduce exposures in the shop. The study evaluated exposures both pre- and post-installation of LEV at a shop utilizing third generation machines (Niosh, 2000b). Sample times ranged from approximately four to seven hours; where samples times were less than eight hours, EPA converted to 8-hr TWAs assuming zero exposure outside the sample time.

Additional PCE worker exposure monitoring data from dry cleaners were identified in other studies such as Brodkin (1995), Gold (2008), Materna (1985), Ludwig (1983), and Solet (1990). However, these studies are not used in EPA’s assessment because they do not provide discrete data points. They are presented here as a qualitative comparison to the results in Table 2-46.

EPA’s systematic review process identified three studies conducted in the U.S. from 1985 to 1995 that provided arithmetic means for workers ranging from 4.6 to 28.2 ppm and one study conducted in the U.S. in 1983 that provided a geometric mean of 16 ppm (Brodkin et al., 1995; Solet et al., 1990; Materna, 1985; Ludwig et al., 1983). The low end of this range of means is generally consistent with EPA’s 50th percentile for the Post-2006 NESHAP data in Table 2-46; however, the high-end of the means is significantly greater than any of EPA’s 50th percentiles. The difference in these studies from the results in EPA’s assessment may be a result of differences in machine types as the studies only indicate that the exposures are from “dry-to-dry” machines without further specification of machine type. Therefore, the results may include second generation machines that are no longer in use and may result in higher exposures than current generation machines.

Gold (2008) completed a comprehensive literature review of studies evaluating PCE exposures from a variety of uses in the U.S. The most recent data for dry cleaning referenced in the article were from studies completed between the years 1990 and 2002 (Gold et al., 2008). The overall arithmetic means from these studies for samples where the sampling time was greater than six hours were 11 ppm for machine operators of dry-to-dry machines, 6.8 ppm for spotters, 1.3 ppm for pressers/seamstresses, and 7.4 ppm for counter clerks (Gold et al., 2008). These data are higher than the 50th percentiles in EPA’s analysis; however, Gold (2008) only divides operator data between “transfer” and “dry-to-dry” machines without further specification of machine types and does not differentiate non-operator (spotters, pressers, counter clerks) exposure data between machine types. Therefore, machine operator data may include second generation machines and data for non-operators may include employees at sites using first or second generation machines.

Table 2-46. Summary of Worker Inhalation Exposure Monitoring Data for Dry Cleaning

Category	Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	15-Minute TWA (ppm)	Number of Data Points
Worker Monitoring Data								
Post-2006 NESHAP Statistics[a]	High-End	17	5.7	4.5	2.3	74	94	9
	Central Tendency	2.2	0.7	0.5	0.2		33	
Fourth and Fifth Generation Statistics[b]	High-End	5.6	1.9	1.5	0.8	114	899	6
	Central Tendency	1.0	0.3	0.2	9.2E-2		48	
Occupational Non-User Monitoring Data								
Post-2006 NESHAP Statistics[a]	High-End[c]	0.3	0.1	9.3E-2	4.8E-2	1[d]	No 15-minute TWA data available for ONUs	
	Central Tendency[c]	0.3	0.1	8.2E-2	3.3E-2			
Fourth and Fifth Generation Statistics[b]	High-End	0.1	4.1E-2	3.3E-2	1.7E-2	4		
	Central Tendency	1.4E-2	4.7E-3	3.3E-3	1.3E-3			

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[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: (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018; Osha, 2017; NIOSH, 2000a, b, 1999a, b, 1995)

2.11.3.3.2 Inhalation Exposure Assessment Results Using Modeling

Because there are multiple activities with potential PCE exposure at a dry cleaner, a multi-zone modeling approach is used to account for PCE vapor generation from multiple sources. This model framework was peer reviewed as part of the 2016 draft 1-BP Risk Assessment (U.S. EPA, 2016e). The model has been updated to address public and peer review comments. The model also reflects additional information that became available since 2016; specifically, several model input parameters have been refined. Figure 2-19 illustrates this multi-zone approach, which considers the following worker activities:

- **Spot cleaning of stains on both dirty and clean garments:** On receiving a garment, dry cleaners inspect for stains or spots they can remove as much of as possible before cleaning the garment in a dry cleaning machine. Spot cleaning may also occur after dry cleaning if the stains or spots were not adequately removed. Spot cleaning occurs on a spotting board and can involve the use of a spotting agent containing various solvents, such as PCE. Workers are exposed to PCE when applying it via squeeze bottles, hand-held spray bottles, or even from spray guns connected to pressurized tanks. Once applied, the worker may come into further contact with the PCE if using a brush, spatula, pressurized air or steam, or their fingers to scrape or flush away the stain (Young, 2012; Niosh, 1997a). For modeling, EPA assumed the near-field is a rectangular volume covering the body of a worker.

- **Unloading garments from dry cleaning machines:** At the end of each dry cleaning cycle, workers manually open the machine door to retrieve cleaned garments. During this activity, workers are exposed to PCE vapors remaining in the dry cleaning machine cylinder. For modeling, EPA assumed that the near-field consists of a hemispherical area surrounding the machine door, and that the entire cylinder volume of air containing PCE exchanges with the workplace air, resulting in a "spike" in PCE concentration in the near-field, C_D, during each unloading event. This concentration is directly proportional to the amount of residual PCE in the cylinder when the door is opened. The near-field concentration then decays with time until the next unloading event occurs.

- **Finishing and pressing:** The cleaned garments taken out of the cylinder after each dry clean cycle contain residual solvents and are not completely dried (Von Grote, 2003). The residual solvents are continuously emitted into the workplace during pressing and finishing, where workers manually place the cleaned garments on the pressing machine to be steamed and ironed. EPA assumed any residual solvent is entirely evaporated during pressing, resulting in an increase in the near-field PCE concentration during this activity. Workers are exposed to PCE vapors while standing in vicinity of the press machine. For modeling, EPA assumed the near-field is a rectangular volume covering the body of a worker.

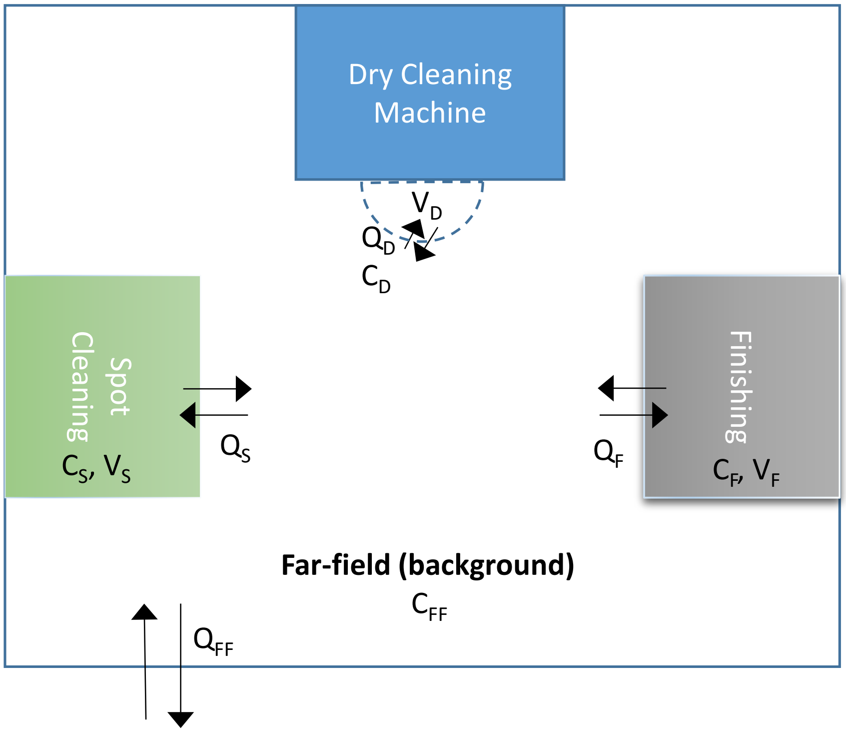

Figure 2-19. Illustration of the Dry Cleaning Multi-Zone Inhalation Exposure Model

As the figure shows, PCE vapor is generated in each of the three near-fields, resulting in worker exposures at concentrations C_S, C_D, and C_F. The volume of each zone is denoted by V_S, V_D, and V_F. The ventilation rate for the near-field zone (Q_S, Q_D, Q_F) determines how quickly PCE dissipates into the far-field (i.e., the facility space surrounding the near-fields), resulting in occupational non-user exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outside air. Appendix I summarizes the parameters and equations for the multi-zone model.

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 TCE-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 C_{FF}.

The dry cleaning industry is characterized by a large number of small businesses, many are family-owned and operated. EPA assumed small dry cleaners operate up to 12 hours a day and up to six days a week. In addition, EPA assumed each facility has a single machine. The assumption of a single machine per facility is supported by a recent industry study conducted in King County, Washington, where 96 percent of 151 respondents reported having only one machine at their facility. Four reported having two machines, and two reported having three machines (Whittaker and Johanson, 2011). Based on the survey results, this assumption is presumably representative of the majority of small dry cleaning shops.

For PCE, the model accounts for variation in the machine generations operated at each facility. Specifically, the model uses a distribution to estimate the machine generation and then based on the sampled machine generation in each iteration selects a distribution of machine cylinder concentrations and residual solvent in clothing. The distribution of machine types is based on the 2010 survey of dry cleaners in King County, WA, which estimated 7% were first or second generation, 26% of machines were third generation or retrofitted second generation[15], 61% were fourth or fifth generation, and 6% were "other" (e.g., hydrocarbon or CO_2 machines) (Whittaker and Johanson, 2011). Due to the limited information on other machine types, the model only considers two scenarios: 1) facilities operating third generation machines; and 2) facilities operating a fourth or fifth generation machine[16]. This is not expected to introduce significant error in the exposure estimates as EPA expects the use of first and second generation machines to be eliminated with the industry trending towards increasing usage of fourth and fifth generation machines (see discussion in Section 2.11.3.3.1). Therefore, the 7% for these machine types were assumed to be replaced by fourth or fifth generation resulting in 26% third generation machines and 68% fourth or fifth generation machines. EPA then re-normalized the distribution to consider only PCE machines resulting in a distribution of 28% third generation machines and 72% fourth or fifth generation machines.

The model estimates exposures for three types of workers within the modeled dry cleaning facility: 1) a worker who performs spot cleaning; 2) a worker who unloads the dry cleaning machine and finishes and presses the garments; and 3) an occupational non-user. However, the model for PCE assumes facilities do not use PCE spot cleaning agents (discussed above in this section); therefore, spot cleaners are exposed at concentrations equivalent to occupational non-users and are not assessed separately. Each worker type is described in further detail below. EPA assumed each worker activity is performed over the full 12-hour operating day.

- EPA assumed spot cleaning occurs for a duration varying from two to five hours in the middle of the twelve-hour work day. For PCE, the spot cleaning use rate is zero, so the worker is exposed at the far-field concentration for the entire day. Spot cleaning can be performed for both dry cleaned loads and for laundered loads.

- EPA assumed a separate worker unloads the dry cleaning machine and finishes and presses the garments. After each load, EPA assumed this worker spends five minutes unloading the machine, during which he or she is exposed at the machine near-field concentration. After unloading, the worker spends five minutes in the finishing near-field to prepare the garments. Then, the worker spends another 20 minutes finishing and pressing the cleaned garments. During this 20-minute period of finishing and pressing, the residual PCE solvent is off-gassed into the finishing near-field. The amount of residual PCE solvent is estimated using measured data presented in von Grote (2003). These unloading and finishing activities are assumed to occur at regular intervals throughout the twelve-hour day. The frequency of unloading and finishing depends on the number of loads dry cleaned each day, which varies from 1 to 14, where 14 was the maximum

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[15] For modeling purposes, retrofitted second generation machines are assumed to be equivalent to third generation machines.
[16] The model treats fourth and fifth generation machines as equivalent as both are expected to reduce machine cylinder concentrations to approximately 300 ppm (Niosh, 1997b). The primary difference being that fifth generation machines have an interlock preventing the machine door from being opened until the concentration is below 300 ppm whereas fourth generation machines do not.

number of loads observed in the NIOSH (2010) and Blando (2010) studies. When this worker is not unloading the dry cleaning machine or finishing and pressing garments, the worker is exposed at the far-field concentration.

- EPA assumed one occupational non-user is exposed at the far-field concentration for twelve hours a day. The occupational non-user could be the cashier, tailor, or launderer, who works at the facility but does not perform dry cleaning activities.

Table 2-47 presents the Monte Carlo results with the Latin hypercube sampling method and 10,000 iterations. Statistics of the 12-hr TWA exposures (95th and 50th percentiles) are then calculated at the end of the simulation after all iterations have completed. The AC, ADC, and LADC calculations are integrated into the Monte Carlo simulation, such that the exposure frequency matches the model input values for each iteration.

When comparing 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 2-47. Summary of Worker and Occupational Non-User Inhalation Exposure Modeling Results for Dry Cleaning

Scenario	12-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)
Workers Model Results				
High-End	30	15	10	4.1
Central Tendency	1.4	0.7	0.5	0.2
Occupational Non-Users/Spot Cleaners Model Results				
High-End	1.5	0.8	0.6	0.2
Central Tendency	0.1	5.4E-2	3.8E-02	1.4E-2

2.11.4 Water Release Assessment

2.11.4.1 Water Release Sources

The primary source of water releases from dry cleaning machines is wastewater from the water separator. Water may be added to the system to remove water soluble impurities from the solvent or dry sludge at the end of distillation (Ecb, 2005). It may also be present in the garments being dry cleaned (Ecb, 2005). The refrigerated condenser used in third, fourth, and fifth generation machines condenses both the PCE and any water in the air stream from the dry cleaning machine (U.S. EPA, 1998). The liquid stream is then fed to the water separator where the water is removed from the stream as waste and PCE is recycled back to the system for reuse (U.S. EPA, 1998). Fourth and fifth generation machines generate additional wastewater from the use of steam to regenerate carbon adsorbers used as secondary vapor controls (U.S. EPA, 1998).

How facilities handle their produced separator water may be subject to state regulations. Under RCRA regulations, produced water that contains at least 0.7 mg/L of PCE is a hazardous waste based on its toxicity characteristic (U.S. EPA, 2019h). Various states may have regulations on permissible disposal and treatment options for produced separator water containing PCE. For example, the Oregon Department of Environmental Quality (DEQ) prohibits dry cleaners from disposing of their separator water in the following manners, even if the separator water does not meet or exceed 0.7 mg/L PCE: discharging to sewer, septic system, or state waters; using in a boiler; pouring on the ground; or disposing in municipal trash (Oregon DEQ, 2018). The Oregon DEQ only allows the following treatment and disposal methods for separator water: drumming the wastewater and shipping it offsite to a hazardous waste facility; hard piping the separator water from the dry cleaning machine to an onsite treatment unit; and manually transferring the separator water from the dry cleaning machine to an onsite treatment unit (Oregon DEQ, 2018). Allowable onsite treatment units include secondary separators and initial and secondary filters. Separator water treated to reduce PCE levels below 0.7 mg/L may be discharged via evaporation to air (Oregon DEQ, 2018).

Best management practices published by Massachusetts also prohibits the discharge to sewer of separator water that is hazardous waste but does allow the evaporation to air of the separator water as well as the drumming of separator water as hazardous waste for offsite disposal via a licensed treatment, storage, and disposal facility (TSDF) (Massachusetts DEP, 2015).

Additional water releases of PCE may occur at sites using wet cleaning and hydrocarbon machines from:

- Residual PCE in clothing previously cleaned in a PCE dry cleaning machine and then washed in the water or hydrocarbon machine;
- Cross contamination at facilities that have both a water or hydrocarbon machine and a PCE machine; and
- PCE in spot cleaners used to pre-spot garments prior to cleaning in a water or hydrocarbon machine (Irta, 2007; Morris and Wolf, 2005).

The extent to which these releases occur is unknown and therefore not included in this release assessment. However, one study found up to 5.3 mg/L PCE in wet cleaning machine wash water and 1.1 mg/L PCE in wet cleaning machine rinse water at sites using both water machines and PCE machines; 0.48 mg/L PCE in the wet cleaning machine wash water from a site using water machines and PCE as a spot cleaner; and up to 30 mg/L PCE in separator water from sites using hydrocarbon machines (the source of the PCE at each of the studied facilities using hydrocarbon machines is not explicitly stated in the study, but the authors state the same general sources as listed above) (Irta, 2007; Morris and Wolf, 2005). The representativeness of these values for similar garment cleaning sites is unknown. EPA expects spent water from wet cleaning machines is primarily discharged to sewer.

Given the variability in state regulations regarding the disposal practices of separator water and the potential for PCE-contaminated wet cleaning machine water to be discharged to sewer, which is not included in EPA's release assessment, EPA assesses the modeled produced separator water as discharged to sewer (POTW). EPA expects this assumption will overestimate PCE releases to water from dry cleaning machine separator water, but the release assessment underestimates PCE releases to water from wet cleaning machines as these releases are not included. The overall directional bias of the release assessment, accounting for both the overestimate and underestimate, is not known.

2.11.4.2 Water Release Assessment Results

To assess water releases from dry cleaners, EPA used data from the 2016 DMR (U.S. EPA, 2016b). EPA reviewed the reported SIC codes for each point source and assigned each point source to one of the PCE conditions of use. However, the sites in the pollutant loading tool are not expected to contain all of the dry cleaning sites in the U.S.; therefore, EPA supplemented the DMR data with modeled releases. EPA considered industrial launderers and commercial dry cleaners separately for purposes of assessing water releases.

In the 2016 DMR (U.S. EPA, 2016b), EPA identified eight sites that are likely industrial launderers based on the reported SIC codes of 7212, 7216, and 7218[17]. Based on the 2006 Dry Cleaning NESHAP Economic Impact Analysis (U.S. EPA, 2006a), there are an additional four industrial launderers that are not in the 2016 DMR. 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). Of the eight sites in the 2016 DMR, only two were identified as having non-zero discharges (U.S. EPA,

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[17] Seven of the eight sites reported one of these SIC codes, the other site did not report a SIC; rather, it was determined to be an industrial launderer after review of the company's website.

2016b). The results from the sites with non-zero releases are presented in Table 2-48. To calculate the daily release, EPA averaged the annual release over the operating days of 289 days/yr (high-end release) and 307 days/yr (central tendency release). The operating days are based on the distribution of operating days used in the model discussed below, with the 50th percentile value being used to calculate the high-end daily release and the 95th percentile value being used to calculate the central tendency daily release.

Table 2-48. Reported Wastewater Discharges of Perchloroethylene for Industrial Launderers in 2016 DMR

Site	Annual Release per Site (kg/yr)	High-End Release Operating Days (days/yr)	Central Tendency Release Operating Days (days/yr)	High-End Release (kg/day)	Central Tendency Release (kg/day)	NPDES Code	Release Media/ Treatment Facility Type
Boise State University, Boise, ID	5.9E-2	289	307	2.1E-4	1.9E-4	IDG911006	Surface Water
Unifirst, Williamstown, VT	1.4E-2	289	307	4.7E-5	4.5E-5	VT0000850	Surface Water

Source: (U.S. EPA, 2016b)

In the 2016 DMR (U.S. EPA, 2016b), EPA identified four sites with non-zero discharges that are likely commercial dry cleaners either based on reported SIC codes or review of company information available online. It is unclear whether these sites are representative of typical commercial dry cleaning sites; therefore, EPA used the Solvent Release in Water Discharge from Dry Cleaning Machines Model to estimate releases from commercial dry cleaners.

The amount of wastewater generated from each site is dependent on the type of machine, the number of dry cleaning machines at the site, the number of loads of garments cleaned per machine per day, the weight of garments cleaned in each load, and the number of days per year the machine operates. To account for variability in these parameters, EPA performed a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method to model water releases from dry cleaning sites using the Solvent Release in Water Discharge from Dry Cleaning Machines Model. A more detailed description of the modeling approach is provided in Appendix J.

Based on data from a CARB survey of dry cleaners performed in 2003, the model assumes that the volume of water released per pound of clothes cleaned is 0.0032 gal water/lb clothes for third generation machines and 0.0037 gal water/lb clothes for fourth and fifth generation machines (California Air Resources Board, 2006). The model uses the same machine type distribution as described for the Dry Cleaning Multi-Zone Inhalation Exposure Model discussed in Section 2.11.3.3.2.

The model assumes the load size ranges from 7 to 150 lb based on the King County survey (Whittaker and Johanson, 2011) and the number of loads per day ranges from 1 to 14 based on observations from NIOSH (2010) and Blando (2010). Based on survey data from CARB (2006) and Whittaker (2011), the model assumes dry cleaning shops have between one and three machines. The model assumes that the concentration of PCE in the wastewater stream is equal to the solubility of PCE in water, 206 mg/L. The model results for both daily and annual releases per site and across all sites are presented in Table 2-49. It should be noted that the distribution of release days/yr is taking into account when the annual release is calculated in each iteration of the model; therefore, an exact value corresponding to the high-end and central tendency annual release is not available. The values presented in the table are back-calculated by dividing the estimated annual release by the daily release and rounding to the nearest whole number, they are not necessarily representative of the 50th or 95th percentile operating days.

Table 2-49. Model Results for Perchloroethylene Discharges to POTW from Dry Cleaning Sites

Scenario	Daily Release per Site (kg/site-day)	Annual Release per Site (kg/site-yr)	Annual Release for All Sites[a] (kg/yr-all sites)	Release Days (days/yr)	Release Media/ Treatment Facility Type
High-End	1.7E-3	0.5	6,310	288	POTW
Central Tendency	5.6E-4	0.2	2,057	287	POTW

[a] Releases for all sites calculated by multiplying per site releases by total number of commercial sites (12,822 commercial sites).

For comparison results from the four commercial sites in the 2016 DMR are provided in Table 2-50. Except for one site that reported an annual discharge of 2.8 kg, these discharges are comparable to the annual PCE discharges to sewer estimated by the model.

Table 2-50. Summary of Direct Discharge Data for Commercial Dry Cleaning Reporters in the 2016 DMR

Facility	2016 Reported Annual PCE Discharge to Surface Water (kg/yr)
Chase Tower, Dallas, TX	2.8
San Jacinto Tower, Dallas, TX	3.1E-3
The Martin, Las Vegas, NV	3.8E-2
The Stirling Club, Las Vegas, NV	0.2
Average	**0.7**
Median	**0.1**

Source: (U.S. EPA, 2016b)

2.12 Adhesives, Sealants, Paints, and Coatings

2.12.1 Estimates of Number of Facilities

To determine the number of sites that use PCE-containing adhesives, sealants, paints, and coatings, EPA considered 2014 NEI (U.S. EPA, 2016a), 2016 TRI (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. Sites in TRI and DMR do not differentiate between conditions of use; therefore, they have been considered under other scenarios (e.g., OTVDs, processing aids, etc.) and are not considered again here. In the 2014 NEI, EPA identified 60 sites reporting adhesive/sealant or paint/coating uses (including one site reporting paint stripping) with 84 reports of spray applications, 4 reports of roll coating applications, 5 reports of dip coating applications, 1 report of paint stripping, and 60 reports of unspecified applications methods (U.S. EPA, 2016a)[18]. Of the 60 sites, 46 were identified as paints/coatings uses, 11 were identified as adhesive/sealant uses, and 3 were identified as having both coating and adhesive uses (U.S. EPA, 2016a). It should be noted that this number may underestimate the total number of sites using PCE-containing adhesives, sealants, paints, and coatings as NEI data only covers specific industries which may not capture the entirety of industries using these products. Additionally, NEI 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.

EPA did not identify data to determine the volume of PCE used in adhesives and coatings or the use rate at each site. Based on market data, EPA expects no more than 3 to 10% of the national PCE production volume is used for "miscellaneous" uses which includes coatings and adhesives (Ntp, 2014; Hsia, 2008). Because EPA did not identify any adhesive or coatings sites in TRI (including those identified in NEI), any site using a PCE-based coating is assumed to be using less than 10,000 lb/yr of PCE based on the "otherwise use" threshold for reporting to TRI. Therefore, EPA assessed the use rate for adhesive and coating application sits to be 9,999 lb/yr.

The concentration of PCE in adhesive and coating products can vary significantly depending on the product. For example, the adhesive and coating products identified in the Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: Tetrachloroethylene (Perchloroethylene) (U.S. EPA, 2017c) had concentrations reported on SDS's ranging from 0.1 to <100% for adhesives and 8.79 to <100% for coatings. The OECD ESD on the Use of Adhesives (Oecd, 2015) does not have PCE-specific concentrations but estimates organic solvent concentrations from 60 to 75% in adhesives. Similarly, the OECD ESD on Coating Industry (Paints, Laquers and Varnishes) (Oecd, 2009b) estimates organic solvent concentrations from 30 to 80% in coatings.

2.12.2 Process Description

Based on products identified in Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: Tetrachloroethylene (Perchloroethylene) (U.S. EPA, 2016a) and 2016 CDR reporting (U.S. EPA, 2016d), PCE may be used in various adhesive, sealant, coating, paint, and paint stripper products for industrial, commercial and consumer applications. Based on reporting in the 2014 NEI typical application methods may include spray, roll, and dip applications (U.S. EPA, 2016a). In the 2014 NEI (U.S. EPA, 2016a) there are 60 instances where the application method is not specified; therefore, other applications methods (e.g., curtain, syringe/bead, roller/brush, electrodeposition/electrocoating, and autodeposition) may also be used for these products.

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[18] Number of application methods is greater than the number of sites due to sites reporting multiple application methods.

The general process for adhesives and coatings include unloading liquid adhesives or coatings from containers into the coating reservoir/application equipment, then applying the adhesive or coating to a flat or three-dimensional substrate (Oecd, 2015, 2009b). For adhesives substrates are then joined and allowed to cure with the volatile solvent (in this case PCE) evaporating during the curing stage (Oecd, 2015). For solvent-based coatings, after application the substrates typically undergo a drying stage in which the solvent evaporates from the coating (Oecd, 2009b).

2.12.3 Exposure Assessment

2.12.3.1 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.

2.12.3.2 Number of Potentially Exposed Workers

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 (U.S. EPA, 2016a). The method for estimating number of workers is detailed above in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. In the 2014 NEI, there were two sites with coating operations that reported a NAICS code for which no Census data were available (U.S. EPA, 2016a). 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. Table 2-51 provides the results of the number of worker analysis for adhesives/sealants and Table 2-52 provides the results of the number of worker analysis for paints/coatings[19]. 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.

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[19] Worker and ONU estimates for sites identified as having both adhesive and coating operations are included only in the adhesives table.

Table 2-51. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Use of Adhesives and Sealants

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
316210	1	11	23	11	23	35
325998	2	14	5	28	9	37
326291	2	43	7	85	14	99
326299	3	27	4	82	13	96
332993	1	63	24	63	24	87
333132	1	21	10	21	10	31
334417	1	41	37	41	37	78
336390	1	45	13	45	13	58
336612	1	16	5	16	5	21
339113	1	20	6	20	6	27
Total[b]	14	30	11	410	160	570

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer.

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

Table 2-52. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Use of Paints and Coatings

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
211111	1	2	4	2	4	6
221112	1	6	8	6	8	13
322130	1	120	18	120	18	139
324110	1	170	75	170	75	246
327390	1	11	2	11	2	13
331210	1	39	9	39	9	48
332812	4	7	2	29	7	35
332813	1	8	2	8	2	10

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
332994	1	11	4	11	4	15
332999	2	6	2	11	4	16
333120	1	23	11	23	11	34
333996	1	18	9	18	9	27
334220	1	17	18	17	18	35
334416	1	22	20	22	20	41
336211	4	33	4	133	18	150
336214	2	40	5	79	10	89
336390	1	45	13	45	13	58
336410	1	75	64	75	64	139
336411	3	184	155	551	465	1,016
336412	1	47	39	47	39	86
336413	3	41	35	123	104	227
336415	1	132	111	132	111	243
336611	1	61	19	61	19	80
336612	1	16	5	16	5	21
337110	1	3	2	3	2	6
337127	1	9	7	9	7	16
339920	1	9	2	9	2	11
339950	1	5	1	5	1	7
339992	1	7	2	7	2	9
339999	1	5	1	5	1	6
541710	2	1	9	2	19	21
Subtotal for Known Data	44	41	24	1,790	1,073	2,863
No Data	2	38	21	76	43	118
Total[b]	46	41	24	1,900	1,100	3,000

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer.

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

2.12.3.3 Occupational 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 (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018; Gromiec et al., 2002; NIOSH, 1993, 1986; Ford Motor Co, 1981; NIOSH, 1981a). 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.

Gromiec (2002) studied chemicals and their air concentrations in a repair shop where rubber conveyor belts were repaired at a brown coal mine in Poland. PCE was identified as a component of one of the adhesives used to repair the convey belts (Gromiec et al., 2002). The study collected a total of 13 PBZ samples for employees in the repair shop and sample times were a minimum of 360 min (75% of the working shift) (Gromiec et al., 2002). The samples were collected from employees with the following job titles: milling machine operators, assembler-vulcanizer, rolling machine operator, vulcanization press operator, and roller and barrel vulcanizer (Gromiec et al., 2002). Based on the job descriptions in the report, only the assembler-vulcanizers are expected to handle the adhesive directly (Gromiec et al., 2002).

The study did not indicate the application method of the adhesive or the concentration of PCE in the adhesive formulation; therefore, it is unknown how representative these data are of a "typical" PCE-based adhesive formulation. The study did not provide discrete sample results; therefore, the high-end exposure value is based on the max concentration of 0.81 ppm and the central tendency is based on the mean concentration of 0.09 ppm reported in the study (Gromiec et al., 2002). The study also did not differentiate between worker and ONU exposures; therefore, EPA only presents a single set of exposure results for the use of PCE-based adhesive. A summary of the inhalation exposure results for adhesives can be found in Table 2-53.

Table 2-53. Summary of Inhalation Exposure Monitoring Data for Use of Perchloroethylene-Based Adhesives

Scenario	8-hr TWA (ppm)[a]	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points
High-End	0.8	0.3	0.2	9.5E-2	13
Central Tendency	8.8E-2	2.9E-2	2.0E-2	8.0E-3	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[a] 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: (Gromiec et al., 2002)

The NIOSH studies (NIOSH, 1993, 1986, 1981a) include the use of PCE-based paints and coatings during construction of a nuclear power plant, at a specialty packaging products manufacturing site, and an aluminum foundry. At the nuclear power plant, the PCE-based coating was applied as the second coat of a three-step epoxy coating process (primer, second coat, and finish coat) (NIOSH, 1981a). Each coating in the three-step process was a two-part epoxy coating with the two parts being mixed together just prior to application (NIOSH, 1981a). The coatings were applied primarily using an airless spray gun; however, some applications were done via troweling (NIOSH, 1981a). Sample times ranged from ~2.5 to 4.5 hours; where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero.

At the specialty packaging products manufacturing site, PCE was identified as a component of one of the coatings used in the coating of industrial-sized backing paper (NIOSH, 1993). In the process, the backing paper was unraveled and conveyed through a coating system consisting of a coating tray, application roller, and leveling rod (NIOSH, 1993). After coatings the paper was passed through an oven for drying and curing and then re-rolled, cut to size and packaged for shipping (NIOSH, 1993). The study collected samples from four workers working in the coating area (NIOSH, 1993). Sample times ranged from ~1.5 to 6.5 hours; where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero. It should be noted that two of the samples measured concentrations between the limits of detection and the limit of quantitation (NIOSH, 1993).

At the aluminum foundry, PCE was identified as a component of a silver pigmented paint (NIOSH, 1986). The paint was applied via brushing or dipping to 10-15% of all the aluminum cores produced at the site (NIOSH, 1986). The coating is used to prevent shrinkage of the aluminum as it cools in the mold (NIOSH, 1986). The study collected two samples from workers applying the coating to the aluminum cores (NIOSH, 1986). Sample times ranged from 5 to 7 hours; where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero.

The study submitted to EPA under TSCA, measured exposure to workers at a truck plant during paint mixing and pot spraying applications (Ford Motor Co, 1981). Paint applications occur in a boot with ventilation to control emissions (Ford Motor Co, 1981). The study collected three full-shift samples and calculated a fourth full-shift TWA by combining four 15-min samples and one approximately 5-hour sample collected on the same worker on the same day (Ford Motor Co, 1981). Sample times for the three full-shift samples were not provided, but EPA assumed exposures concentrations were representative of an 8-hr shift.

The data provided to EPA from DoD contained two samples collected in August 2007 and one sample collected in June 2016 (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). All three samples were identified as for high-volume low-pressure spray applications (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). The one data point from June 2016 was reported as having a sample time of zero (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). It is unclear what the result for this data point represents; therefore, this data was not used in EPA's analysis. The other two data points had a sample time of 15-min and 180 min (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). EPA converted the 180 min sample to an 8-hr TWA by assuming zero exposure outside the sample time. The DoD data did not report a duration for the spray coating; however, EPA assumes the sample time is reflective of the duration of spray coating at the site and that the worker will not perform other activities throughout the day that will result in PCE exposures.

A summary of the inhalation exposure results for coating applications can be found in Table 2-54. For the 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. No data for ONUs were identified; therefore, the table only includes results for workers. It should be noted that the PCE concentration in the coatings used for each of the NIOSH studies were not provided; therefore, it is unclear how representative these data are of a "typical" coating application.

Table 2-54. Summary of Inhalation Exposure Monitoring Data for Use of Perchloroethylene-Based Paints/Coatings

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	15-minute TWA (ppm)	Number of Data Points
High-End	4.6	1.5	1.0	0.5	15	7.9	5
Central Tendency	0.2	7.8E-2	5.3E-2	2.1E-2		4.1	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Source: (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018; NIOSH, 1993, 1986; Ford Motor Co, 1981; NIOSH, 1981a)

2.12.4 Water Release Assessment

2.12.4.1 Water Release Sources

The source of water releases at sites using PCE-based adhesives and coatings will vary depending on the application methods and the control technologies used. The primary sources of water releases may include: overspray losses from spray applications using water curtains to capture overspray and splatter and mists generated during curtain and roll coating that are subsequently discharged to water (Oecd, 2015, 2009b). Other potential sources include from the use of water to clean the containers and/or equipment (Oecd, 2015, 2009b). However, for organic solvent-based products such as PCE-based adhesives and coatings, EPA expects the majority of equipment and container cleaning to be performed using organic solvents that are not discharged to water.

2.12.4.2 Water Release Assessment Results

EPA assessed water release estimates using the PCE use-rate of 9,999 lb/yr estimated in Section 2.12.1 and loss fractions obtained from the ESD on Use of Adhesives (Oecd, 2015) and the ESD on Coating Industry (Paints, Laquers and Varnishes) (Oecd, 2009b). Releases vary by the type of site using the PCE-based coating or adhesive (i.e., automotive, aerospace, etc.), the amount of PCE-based coating or adhesive used, and the application method of coating or adhesive. EPA assessed two scenarios for water releases from adhesives and coatings sites: one for roll and curtain coating applications and one for spray coating applications that use a water curtain to control mists.

For roll and curtain coating applications, the ESD on the Use of Adhesives (Oecd, 2015) estimates the transfer efficiencies may vary from 90 to 98% with splatter/mists generated during application disposed of to water (POTW), incineration, or landfill (Oecd, 2015). EPA assessed both a high- and low-end release estimate for sites using roll coating applications using these transfer efficiencies. EPA assumed all splatter/mists generated are captured and discharged to POTW for sites using roll or curtain application methods (Oecd, 2015).

For spray coating applications, discharges to water are only expected for sites that use water curtains to capture mists rather than dry filters. Dry filters are expected to be disposed of to landfills or incineration (Oecd, 2009b). For sites with water curtain capture systems, EPA assessed water releases using the *EPA/OPPT Automobile OEM Coating Overspray Loss Model* which uses Equation 2-2 to estimate releases to water:

Equation 2-2

$$AR = UR \times (1 - TE) \times McE \times (1 - SrE)$$

Where:

AR = Annual release of PCE from the application line (kg/yr)
TE = fractional transfer efficiency of spray gun (unitless)
McE = fractional spray mist capture efficiency (unitless)
SrE = fractional solid removal efficiency from captured mist (unitless)
UR = use-rate of PCE (kg/site-yr).

The *EPA/OPPT Automobile OEM Coating Overspray Loss Model* provides the following default values:

TE = 20% (conventional spray guns) to 65% (high volume, low pressure spray guns)
McE = 96%
SrE = 90%

EPA assessed high- and low-end releases for sites using spray coating applications with water curtains using Equation 2-2 and the default values from the model including the range of TE. The ESD on the Coatings Industry (Oecd, 2009b) does not indicate the prevalence of on-site treatment versus discharges to POTW; EPA assumed wastewater will be handled similar to adhesive application sites and assessed discharges to POTW.

Table 2-55 provides high- and low-end estimates for sites using roll/curtain applications and spray applications with water curtains. To estimate daily discharges, EPA averaged the estimated annual discharges over 250 operating days/yr. Due to limitation in TRI, DMR and NEI reporting programs, the number of sites that may use either method for applying PCE-based adhesives or coatings is unknown but may include the 60 sites identified in the 2014 NEI.

It should be noted that the models used to develop water discharge estimates from coating and adhesive applications represent estimates for the solids (i.e., non-volatile) portions of the coating or adhesive and does 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. However, it should be noted that releases from coatings and adhesives sites for a similar solvent, trichloroethylene (TCE), ranged from 9.1E-4 to 74.4 kg/site-yr for three sites reporting in TRI. The high-end of this range is within an order of magnitude of EPA's low-end for PCE.

EPA assumes releases from other application methods such as syringe/bead applications and dip applications to be negligible (Oecd, 2009b).

Table 2-55. Parameters for Estimating Water Discharges from Spray Coating Applications

Application Type	PCE Use Rate (kg/site-yr)[a]	Low-End Annual Release (kg/site-yr)[b]	High-End Annual Release (kg/site-yr)[b]	Annual Release Days (days/yr)	Low-End Daily Release (kg/site-day)[c]	High-End Daily Release (kg/site-day)[c]	Release Media/ Treatment Facility Type
Roll Coating	4,535	91	454	250	0.4	1.8	POTW
Spray Coating with Water Curtain	4,535	152	348	250	0.6	1.4	POTW

[a] Assumed to be the maximum use-rate that would not trigger reporting to TRI.

[b] Annual release estimates calculated by multiplying the PCE use rate by the fraction not transferred to the substrate for roll coating or using Equation 2-2 for spray coating.

[c] Daily release estimates calculated by averaging the annual release estimate over the release days.

2.13 Maskant for Chemical Milling

2.13.1 Estimates of Number of Facilities

EPA estimated the number of sites using PCE as a maskant for chemical milling using information obtained during meetings between EPA and industry stakeholders involved in the production, supply, and use of chemical maskants. Data for estimates of the number of facilities is based on information from AC Products (ACP) who supply over 99% of the solvent-based maskants sold in the U.S (AC Products, 2017). According to AC Products (2017), a total of 679,000 gallons of maskants were sold in North America in 2016 and 83% (by volume) were either solely or primarily PCE-based. ACP estimates in 2016 it sold 539,133 gallons of PCE-based maskants to approximately 71 U.S. customers(AC Products, 2017). A 2020 comment from ACP provided percentage of PCE-based maskants sold to each of 65 customers (ACP, 2020). It is unclear if the remaining 6 sites from the 2016 data are still using PCE based maskants; therefore, EPA assumed the use rate at these sites is the median of the known use rates. EPA used the median rather than the mean as the use rates are highly skewed with two sites accounting for approximately 92% of the total maskant use; therefore, the median is expected to be more representative of a “typical” site than the mean. There was also one site that ACP indicated they sold 0% of the PCE maskants to; it is unclear if this site is still using PCE-based maskants. Therefore, EPA assessed the use rate as the median of the other 64 sites. Table 2-56 summarizes the estimated use rates for the 71 sites. Note: These volumes are for the total maskant formulation used not the volume of PCE used as the concentration of PCE in the maskants in unknown. Therefore, the annual use rate of PCE per site could not be determined.

Table 2-56. Estimated Perchloroethylene-Based Maskant Use Rates

ACP Customer	Percent of PCE-based Maskant Sold to Customer	PCE-Based Maskant Use Rate (gal/site-yr)
Customer 1	85%	458,263
Customer 2	7%	37,739

ACP Customer	Percent of PCE-based Maskant Sold to Customer	PCE-Based Maskant Use Rate (gal/site-yr)
Customer 3	4%	21,565
Customer 4	2%	10,783
Customer 5	2%	10,783
Customer 6	0.3037%	1,637
Customer 7	0.1012%	546
Customer 8	0.0705%	380
Customer 9	0.0590%	318
Customer 10	0.0590%	318
Customer 11	0.0268%	144
Customer 12	0.0192%	104
Customer 13	0.0169%	91
Customer 14	0.0169%	91
Customer 15	0.0153%	82
Customer 16	0.0169%	91
Customer 17	0.0123%	66
Customer 18	0.0084%	45
Customer 19	0.0077%	42
Customer 20	0.0061%	33
Customer 21	0.0153%	82
Customer 22	0.0054%	29
Customer 23	0.0054%	29
Customer 24	0.0046%	25
Customer 25	0.0046%	25
Customer 26	0.0077%	42
Customer 27	0.0046%	25
Customer 28	0.0038%	20
Customer 29	0.0031%	17
Customer 30	0.0031%	17
Customer 31	0.0031%	17
Customer 32	0.0031%	17

ACP Customer	Percent of PCE-based Maskant Sold to Customer	PCE-Based Maskant Use Rate (gal/site-yr)
Customer 33	0.0023%	12
Customer 34	0.0023%	12
Customer 35	0.0023%	12
Customer 36	0.0023%	12
Customer 37	0.0023%	12
Customer 38	0.0023%	12
Customer 39	0.0023%	12
Customer 40	0.0015%	8.1
Customer 41	0.0031%	17
Customer 42	0.0015%	8.1
Customer 43	0.0015%	8.1
Customer 44	0.0015%	8.1
Customer 45	0.0015%	8.1
Customer 46	0.0015%	8.1
Customer 47	0.0015%	8.1
Customer 48	0.0015%	8.1
Customer 49	0.0008%	4.3
Customer 50	0.0008%	4.3
Customer 51	0.0008%	4.3
Customer 52	0.0008%	4.3
Customer 53	0.0008%	4.3
Customer 54	0.0008%	4.3
Customer 55	0.0008%	4.3
Customer 56	0.0008%	4.3
Customer 57	0.0008%	4.3
Customer 58	0.0008%	4.3
Customer 59	0.0008%	4.3
Customer 60	0.0008%	4.3
Customer 61	0.0008%	4.3
Customer 62	0.0008%	4.3

ACP Customer	Percent of PCE-based Maskant Sold to Customer	PCE-Based Maskant Use Rate (gal/site-yr)
Customer 63	0.0008%	4.3
Customer 64	0.0008%	4.3
Customer 65	Unknown (reported as 0% by ACP and assessed at median of known sites)	17
Customer 66	Unknown (assessed at median of known sites)	17
Customer 67	Unknown (assessed at median of known sites)	17
Customer 68	Unknown (assessed at median of known sites)	17
Customer 69	Unknown (assessed at median of known sites)	17
Customer 70	Unknown (assessed at median of known sites)	17
Customer 71	Unknown (assessed at median of known sites)	17

Source: (ACP, 2020)

2.13.2 Process Description

Chemical maskants are elastomer-based coatings that are used to protect a substrate during exposure to a chemical process (AC Products, 2017). They are used in chemical milling, plating, and anodizing processes in the aerospace (military, commercial, and space), medical implants, and non-aerospace military industries (AC Products, 2017; Tech Met Inc., 2017).

Maskants are typically applied in dedicated coating application rooms via dipping of parts in a coating tank or through automated airless spraying of coating onto the substrate (AC Products, 2017; Ducommun Inc., 2017; Spirit AeroSystems Inc., 2017; Tech Met Inc., 2017; Triumph Precision Components, 2017; Weatherford Aerospace, 2017). The maskant coating is then cured, scribed, and selectively removed in the desired locations to allow chemical milling (Spirit AeroSystems Inc., 2017; Tech Met Inc., 2017; Weatherford Aerospace, 2017). The maskant forms a strong flexible film that can withstand the chemical milling process such that only the exposed metal is milled (Spirit AeroSystems Inc., 2017; Tech Met Inc., 2017; Weatherford Aerospace, 2017). Once the process is complete the maskant can be peeled off the metal substrate (Weatherford Aerospace, 2017). According to AC Products (2017), 95% (by volume) of the PCE-based maskants used in the U.S. are re-captured by the customer and returned to the maskant manufacturer to make fresh maskant.

2.13.3 Exposure Assessment

2.13.3.1 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 Inc., 2017; Spirit AeroSystems Inc., 2017; Tech Met Inc., 2017). However, at least one stakeholder indicated that employees may be exposed during maintenance operations (Spirit AeroSystems Inc., 2017). Specific maintenance activities were not described but may include adding fresh maskant and handling of re-captured maskants.

Based on information from public commenters, employees who directly operate masking equipment (including filling maskant tanks) 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 (ACP, 2020). 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 (ACP, 2020; Spirit Aerosystems, 2020).

2.13.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of PCE as a chemical maskant using data submitted from public comments. AC Products (2020), indicated its third largest customer estimated 3 workers and 3 ONUs potentially exposed at its site and AC Products fourth largest customer estimated 2 workers and 45 ONUs potentially exposed. Spirit AeroSystems Inc. (2020), the largest user of PCE-based maskants in the world, estimated between 11-18 workers and 28-56 ONUs potentially exposed, depending on the facility's current production rate. EPA used the data from public comments to estimate the number of workers and ONUs for the three sites where data were provided. For Spirit Aerosystems Inc., EPA assessed the midpoint of the range provided in the comment, resulting in 15 workers and 42 ONUs. Data for the other 68 sites were not reasonably available. Therefore, EPA used the average number of workers and ONUs from the three sites where data were available to estimate the number of workers and ONUs at these sites. This resulted in an average of 7 workers and 30 ONUs per site and a total of approximately 460 workers and 2,100 ONUs potentially exposed during maskant uses of PCE (see Table 2-57).

Table 2-57. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Use of Chemical Maskants

Site	Number of Sites	Exposed Workers per Site	Exposed Occupational Non-Users per Site	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
AC Products Third Largest Customer	1	3	3	3	3	6
AC Products Fourth Largest Customer	1	2	45	2	45	47
Spirit AeroSystems Inc.	1	15	42	15	42	57
Subtotal for Known Sites	3	7	30	20	90	110
Sites with No Data	68	7	30	442	2,040	2,482
Total[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.

2.13.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from a NIOSH investigation at an aircraft parts manufacturing site using a dip coating application process for the maskants, public comments, and OSHA CEHD (ACP, 2020; OSHA, 2020; Spirit Aerosystems, 2020; NIOSH, 1977). The data from the NIOSH investigation 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 (ACP, 2020; Spirit Aerosystems, 2020) did not indicate emissions controls implemented as a result of the NESHAP reduced exposures. For comparison, 8-hr TWAs for workers in the NIOSH (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 (ACP, 2020; Spirit Aerosystems, 2020).

The data from NOSH are from a site investigation in 1977 (NIOSH, 1977). The study collected data from multiple chemical mill operators, scribes, and demaskers at the site with sample times ranging from approximately 2 to 7 hours (NIOSH, 1977). The report indicated that workers were rotated out of the chemical mill area every four hours to minimize exposures (NIOSH, 1977). EPA calculated 8-hr- and 4-hr TWAs assuming exposure outside the sample time was zero.

The data from public comments were collected during industrial hygiene investigations at four sites using PCE-based maskants (ACP, 2020; Spirit Aerosystems, 2020). The data were collected for sample times ranging from approximately 5.5 to 8 hours. EPA calculated 8-hr TWAs assuming exposure outside the sample time was zero. The comments generally describe the data as being representative of typical operations at the site they were collected (ACP, 2020; Spirit Aerosystems, 2020).

EPA constructed 21 full-shift samples from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD data did not explicitly state the use of maskants; rather, EPA assumed the use to be maskant uses based on the SIC codes reported and review of company websites. OSHA data does not provide job titles or worker activities associated with the samples; therefore, EPA assumed the data were collected on workers and not ONUs.

Table 2-58 summarizes the 8-hr and 4-hr TWA monitoring data for the use of PCE in maskants. The 95th percentile of the data is presented as the high-end and the 50th percentile as the central tendency. Table 2-58 also includes a summary of 15-min TWA samples collected by the DoD between July 2013 and May 2017 during masking activities (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). Nine of the 20 15-min TWA data points collected by DoD measured below the LOD (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 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 1.4.5.2. 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 2-58. Summary of Worker Inhalation Exposure Monitoring Data for Chemical Maskants

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	4-hr TWA (ppm)	Number of Data Points	15-minute TWA (ppm)	Number of Data Points
High-End	57	19	13	6.6	43	2.4	6	28	20
Central Tendency	2.2	0.7	0.5	0.2		2.2		0.6	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Source: (ACP, 2020; OSHA, 2020; Spirit Aerosystems, 2020; Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018; NIOSH, 1977)

2.13.4 Water Release Assessment

2.13.4.1 Water Release Sources

According to AC Products (2017), 95% by volume of the PCE-based maskants sold in the U.S. are recaptured and returned to the maskant manufacturer for production of new maskant. Therefore, the volume of PCE that may be released to any environmental media is expected to be no more than 5% of the use volume. Based on information from public comments and stakeholder meetings and the volatility of PCE, EPA expects the majority of the PCE that does not participate in the recapture process to be released to air (Ducommun Inc., 2017; Spirit AeroSystems Inc., 2017; Tech Met Inc., 2017; Triumph Precision Components, 2017; Weatherford Aerospace, 2017). However, there is some potential for PCE to be released to water from the use of steam to regenerate carbon adsorbers used to control emissions in the chemical milling area.

2.13.4.2 Water Release Assessment Results

EPA identified 13 sites in the 2016 TRI (U.S. EPA, 2017d) and 14 sites in the 2016 DMR (U.S. EPA, 2016b) that may be using PCE-based maskants. EPA assessed water releases from these sites using the annual reported discharges from each site. In the 2016 TRI, only 2 of the 13 sites reported non-zero discharges with both sites reporting discharges to POTW (U.S. EPA, 2017d). In the 2016 DMR, only 3 sites reported non-zero direct discharges to surface water (indirect discharges not reported in DMR) and the remaining 11 sites reported zero direct discharges (U.S. EPA, 2016b).

To estimate the daily release, EPA used operating data from the 2014 NEI. In the 2014 NEI, there were six sites reporting maskant operations with four reporting specifically for PCE and two reporting for VOC only (U.S. EPA, 2016a). Each site provided operating hours per year for the masking operation. EPA assumed eight hours per day of operation to calculate the number of operating days per year. If assuming eight hours per day resulted in over 365 operating days per year; EPA assumed 24 operating hours per day. EPA then mapped the operating days from NEI directly to sites in TRI and DMR where possible and used the sites reported operating time to estimate daily releases. For sites that did not report to NEI, EPA used the average operating time of 4,130 hr/yr and 24 hr/day to estimate the daily release (U.S. EPA, 2016a). Release estimates for the five sites with water releases are presented in Table 2-59.

Table 2-59. Reported Wastewater Discharges of Perchloroethylene from Chemical Maskant Sites

Site	Annual Release (kg/yr)	Operating Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Alliant Techsystems Operations LLC, Elkton, MD[b]	1.0E-3	172	5.9E-6	MD0000078	Surface Water	(U.S. EPA, 2016b)
Ducommun Aerostructures Inc Orange Facility, Orange, CA[b]	0.5	172	2.6E-3	Not available	POTW	(U.S. EPA, 2017d)
GE Aviation, Lynn, MA[b]	0.1	172	8.6E-4	MA0003905	Surface Water	(U.S. EPA, 2016b)
McCanna Inc., Carpentersville, IL[b]	7.0E-2	172	4.0E-4	IL0071340	Surface Water	(U.S. EPA, 2016b)
Weatherford Aerospace LLC, Weatherford, TX[c]	2.3	208	1.1E-2	Not available	POTW	(U.S. EPA, 2017d)

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment

[a] Daily releases are back-calculated from the annual release rate reported in the 2016 TRI or 2016 DMR and the operating days.

[b] Operating days for these sites are based on the average operating time of 4,130 hr/yr and assuming 24 hr/day.

[c] Operating days for this site is based on the sites reported operating time of 4,992 hr/yr in the 2014 NEI and assuming 24 hr/day.

Sources: (U.S. EPA, 2017d, 2016b)

It should be noted, that the majority of the sites identified from TRI and DMR as sites using PCE-based maskants are based on reported NAICS and SIC codes, activities reported in TRI, and, where available, information from public comments and stakeholder meetings. There is the potential that these sites perform a different activity (e.g. metal degreasing) instead of or in addition to chemical milling operations. Water releases in TRI and DMR are reported at the site level, not the operation level; therefore, they are only considered under one expected condition of use to avoid double counting.

EPA did not identify any data to estimate releases from the other 44 sites that use PCE-based maskants. However, sites that use PCE-based maskants are expected to be regulated by the Metal Finishing EG (U.S. EPA, 2019c). As discussed in Section 2.5 for OTVDs, the Metal Finishing EG sets a discharge limit for TTO concentration in wastewater stream not a PCE-specific limit. The Metal Finishing EG sets a one-day maximum TTO discharge limit of 2.13 mg/L for BPT, BAT, PSES, NSPS, and PSNS. Therefore, the concentration of PCE in wastewater streams using PCE-maskants is expected to be below the TTO limit.

2.14 Industrial Processing Aid

2.14.1 Estimates of Number of Facilities

To determine the number of sites that use PCE as a processing aid, EPA considered 2016 CDR (U.S. EPA, 2016d), 2016 TRI (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b). In the 2016 CDR, two sites reported use of PCE as a processing aid in the industrial processing and use section (U.S. EPA, 2016d)[20]. Each site reported use as a processing aid in the petrochemical manufacturing industry and the pesticide, fertilizer, and other agricultural chemical manufacturing (U.S. EPA, 2016d). Each site reported the number sites using PCE as a processing aid as not known or reasonably ascertainable (U.S. EPA, 2016d).

Based on the activities and NAICS codes reported in the 2016 TRI, EPA identified 64 facilities where the primary condition of use is expected to be use of PCE as a processing aid (U.S. EPA, 2017d). In the 2016 DMR data, there are 41 sites for which EPA expects the primary condition of use to be use of PCE as a processing aid with seven sites being the same as TRI sites (U.S. EPA, 2016b). NAICS and SIC codes assumed to be using PCE as a processing aid include those related to petrochemical manufacturing, agricultural product manufacturing (based on CDR reporting) and petroleum refineries (for catalyst regeneration—see process description in Section 2.14.2). Based on the DMR and TRI data, EPA assesses a total of 98 sites (64+41 = 105 sites – 7 duplicate sites = 98 sites) for the use of PCE as a processing aid.

2.14.2 Process Description

According to the TRI *Reporting Forms and Instructions (RFI) Guidance Document*, a processing aid is a "chemical that is added to a reaction mixture to aid in the manufacture or synthesis of another chemical substance but is not intended to remain in or become part of the product or product mixture is otherwise used as a chemical processing aid. Examples of such chemicals include, but are not limited to, process solvents, catalysts, inhibitors, initiators, reaction terminators, and solution buffers" (U.S. EPA, 2018c). Additionally, processing aids are intended to improve the processing characteristics or the operation of

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[20] The industrial processing and use section of CDR is reported by manufacturers/importers of a chemical for the downstream uses of the chemical. This includes processing and use activities at both the manufacture/import site and at customer sites. Therefore, the total number of sites related to these reported uses may be equal to or greater than the number of CDR reporting sites.

process equipment, but not intended to affect the function of a substance or article created (U.S. EPA, 2016c).

One processing aid use of PCE is for catalyst regeneration at petroleum refineries (American Fuel and Petroleum Manufacturers, 2017; Dow Chemical, 2008). According to public comments from the American Fuel and Petrochemical Manufacturers (2017), PCE is used in both the reforming and isomerization processes at refineries. In the reforming process, PCE is added directly to a regenerator in a Continuous Catalytic Regeneration reforming unit, and in the isomerization process, PCE is added to the hydrocarbon feed (American Fuel and Petroleum Manufacturers, 2017). In both processes, PCE provides chlorine ions to regenerate the catalysts and is consumed in the process (American Fuel and Petroleum Manufacturers, 2017). Other specific processing aid uses of PCE were not identified; however, EPA expects use as a process solvent to be amongst the major processing aid uses.

2.14.3 Exposure Assessment

2.14.3.1 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.

2.14.3.2 Number of Potentially Exposed Workers

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 (U.S. EPA, 2017d) or 2016 DMR (U.S. EPA, 2016b), respectively. The employment data from the U.S. Census SUSB and the Bureau of Labor Statistics' OES data are based on NAICS code; therefore, SIC codes reported in the 2016 DMR had to be mapped to a NAICS code to estimate the number of workers. A crosswalk of the SIC codes to the NAICS codes used in the analysis are provided in Table 2-60.

Table 2-60. Crosswalk of Processing Aid SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
2865 – Cyclic Organic Crudes and Intermediates, and Organic Dyes and Pigments	325194 – Cyclic Crude, Intermediate, and Gum and Wood Chemical Manufacturing
2879 – Pesticides and Agricultural Chemicals, Not Elsewhere Classified	325320 – Pesticide and Other Agricultural Chemical Manufacturing
2911 – Petroleum Refining	324110 – Petroleum Refineries
2999 – Products of Petroleum and Coal, Not Elsewhere Classified	324199 – All Other Petroleum and Coal Products Manufacturing

Table 2-61 provides a summary of the reported NAICS codes (or NAICS mapped to the reported SIC code), the number of sites reporting each NAICS code, and the estimated number of workers and ONUs for each NAICS code as well as an overall total for use of PCE as a processing aid. It should be noted, that in the 2016 DMR, two sites did not report a SIC code. To estimate the number of workers and ONUs from these sites EPA calculated the average number of workers and ONUs per site from the other known sites. There are approximately 14,000 workers and 6,000 ONUs potentially exposed during use of PCE as a processing aid. The NAICS code 324110 for petroleum refineries has significantly more workers and ONUs per site than other NAICS codes. This is likely due to the size of petroleum refineries as compared to other chemical manufacturing industries. Refineries tend to be larger with multiple process areas which may result in higher number of employees.

Table 2-61. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Use as a Processing Aid

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
212393	1	24	6	24	6	30
324110	76	170	75	12,934	5,732	18,667
324199	3	17	8	52	23	75
325180	1	25	12	25	12	37
325194	7	34	16	239	113	352
325199	2	39	18	77	36	114
325311	1	17	5	17	5	23
325320	5	25	7	127	37	165
Unknown NAICS	2	44	18	88	37	125
Total[b]	98	140	61	14,000	6,000	20,000

[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 in the relevant NAICS codes. The workers/ONUs per site are then

multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer.

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

2.14.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from four studies submitted to EPA under TSCA by Dow Chemical (Dow Chem Co, 1983a, b, 1982, 1979). The exact function of PCE is each study is not explicitly stated; however, the data was 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.

Data were collected for a variety of workers in the process areas including operators, tank truck loading, pipefitters, foreman, and technicians (Dow Chem Co, 1983a, b, 1982, 1979). Sample times ranged from approximately 5.5 to 8 hours (Dow Chem Co, 1983a, b, 1982, 1979). Where sample times were less than eight hours, EPA calculated an 8-hr TWA assuming zero exposure outside the sample time. The data set also included 22 data points for which the exact sample time was not provided; however, the submitted studies indicate the results were calculated 8-hr TWAs; therefore, EPA included with the 8-hr TWAs calculated from data with known sample times.

Table 2-62 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) as discussed in Section 1.4.5.2. 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 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.

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. These scenarios are plausible, but EPA cannot determine the statistical representativeness of the value.

Table 2-62. Summary of Worker inhalation Monitoring Data for Use of Perchloroethylene as a Processing Aid

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	30-minte TWA (ppm)[a]	Number of Data Points
High-End	1.2	0.4	0.3	0.1	89	2.2	2
Central Tendency	6.0E-2	2.0E-2	1.4E-2	5.4E-3		1.7	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[a] 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 Co, 1983a, b, 1982, 1979)

2.14.4 Water Release Assessment

2.14.4.1 Water Release Sources

Potential sources of water releases are expected to be similar to those described in Section 2.1.4.1 for manufacturing and may include the following: equipment cleaning operations, aqueous wastes from scrubbers/decanters, reaction water, process water from washing intermediate products, and trace water settled in storage tanks (OECD, 2011a).

2.14.4.2 Water Release Assessment Results

EPA assessed water releases using the annual discharge values reported to the 2016 TRI (U.S. EPA, 2017d) and the 2016 DMR (U.S. EPA, 2016b) by the 98 sites using PCE as a processing aid. In the 2016 TRI, 11 sites reported non-zero direct discharges to surface water and two of these 11 sites also reported indirect discharges to POTW (U.S. EPA, 2017d). All other sites in TRI reported zero direct or indirect discharges (U.S. EPA, 2017d). In the 2016 DMR, one sites reported a direct discharge to surface water (indirect discharges not reported in DMR data) and the remainder reported zero indirect discharges (U.S. EPA, 2016b).

To estimate the daily release, EPA assumed 300 days/yr of operation as given in the SpERC developed by the European Solvent Industry Group for the manufacture of a substance (which includes use as a process chemical or extraction agent) and averaged the annual release over the operating days (European Solvents Industry Group, 2012). Table 2-63 summarizes the water releases from the 2016 TRI and DMR for sites with non-zero discharges.

Table 2-63. Reported Wastewater Discharges of Perchloroethylene from Processing Aid Sites

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Chevron Products Co - Salt Lake Refinery, Salt Lake City, UT	1.7	300	5.8E-3	UTG070261	Surface Water	(U.S. EPA, 2017d)

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Chevron Products Co Richmond Refinery, Richmond, CA	0.9	300	3.0E-3	CA0005134	Surface Water	(U.S. EPA, 2017d)
CHS McPherson Refinery, McPherson, KS	9.1E-2	300	3.0E-4	KS0000337	Surface Water	(U.S. EPA, 2017d)
ExxonMobil Oil Beaumont Refinery, Beaumont, TX	7.3	300	2.4E-2	Not available	Surface Water	(U.S. EPA, 2017d)
HollyFrontier El Dorado Refining LLC, El Dorado, KS	0.9	300	3.0E-3	KS0000761	Surface Water	(U.S. EPA, 2017d)
Hunt Refining Co - Tuscaloosa Refinery, Tuscaloosa, AL	4.0	300	1.3E-2	AL0000973	Surface Water	(U.S. EPA, 2016b)
Marathon Petroleum Co LP, Garyville, LA	2.7	300	9.1E-3	LAU009485	Surface Water	(U.S. EPA, 2017d)
Occidental Chemical Corp Niagara Plant, Niagara Falls, NY	26	300	8.6E-2	NY0003336	Surface Water	(U.S. EPA, 2017d)
	26		8.8E-2		POTW	
Tesoro Los Angeles Refinery-Carson Operations, Carson, CA	0.5	300	1.5E-3	CA0000680	Surface Water	(U.S. EPA, 2017d)
	108		0.4		POTW	
The Dow Chemical Co, Midland, MI	10	300	3.5E-2	MI0000868	Surface Water	(U.S. EPA, 2017d)
Valero Refining Co -Oklahoma Valero Ardmore Refinery, Ardmore, OK	2.3	300	7.6E-3	OK0001295	Surface Water	(U.S. EPA, 2017d)

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Valero Refining-Texas LP Corpus Christi West Plant, Corpus Christi, TX	2.7	300	9.1E-3	TX0063355	Surface Water	(U.S. EPA, 2017d)

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment
[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 300 days of operation per year.
Sources: (U.S. EPA, 2017d, 2016b)

2.15 Metalworking Fluids

2.15.1 Estimates of Number of Facilities

EPA did not identify information to estimate the number of facilities using metalworking fluids containing PCE using information from CDR, TRI, or DMR or systematic review. However, sites using metalworking fluids likely fall into similar NAICS codes as those identified for vapor degreasing/cold cleaning. Therefore, it is possible that sites assessed under one of those conditions of use actually perform metalworking activities rather than or in addition to degreasing. However, a HSIA (2008) report estimated no more than 3% of the national PCE production volume is used for "miscellaneous" uses (which includes metalworking fluids) compared to 7% for metal degreasing. Therefore, EPA expects the majority of those sites to be performing degreasing activities with PCE rather than metalworking activities and they are not considered again here to avoid double counting[21]. It should be noted that only a single PCE-based metalworking fluid product was identified (see process description in Section 2.15.2); therefore, the number of sites using PCE-containing metalworking fluids is expected to be small.

2.15.2 Process Description

EPA identified one cutting fluid product in the Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal for PCE (U.S. EPA, 2017c) that contains PCE. The safety data sheet (SDS) and the company's product page indicate that PCE is present at <10 wt% in the formulation and that the product's recommended use is an oil-based cutting and tapping fluid for use with copper, iron, aluminum and magnesium materials (MSC Industrial Supply Inc., 2019; Winfield Brooks Company, 2014). Metalworking, cutting, and tapping fluids are all used in various metal shaping operations. Cutting and tapping fluids are a subset of metalworking fluids that are used for the machining of internal and external threads using cutting tools like taps and thread-mills (Oecd, 2011b). While some cutting and tapping fluids may be used by consumers in a DIY setting, there is no indication that this product is marketed solely to consumers, therefore, EPA assesses the industrial use of metalworking fluids in the metal products and machinery (MP&M) industry. In general, industrial metal shaping operations include machining, grinding, deformation, blasting, and other operations and may use different types of

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[21] This statement is in reference to activities that involve PCE at each site. EPA expects that many sites may have both metalworking and degreasing activities. The assumption is only that most of the sites use PCE as a degreasing solvent rather than as a metalworking fluid, not whether metalworking activities (using non-PCE containing metalworking fluids) are actually occurring at the site.

metalworking fluids to provide cooling and lubrication and to assist in metal shaping and protect the part being shaped from oxidation (Oecd, 2011b).

The OECD ESD on the Use of Metalworking Fluids (Oecd, 2011b) provides a generic process description of the industrial use of both water-based and straight oil metalworking fluids in the MP&M industry. Based on the recommended use of "oil-based cutting and tapping fluid" listed in the SDS, EPA assesses as a straight oil (Winfield Brooks Company, 2014). Metalworking fluids are typically received in containers ranging from 5-gallon pails to bulk containers (Oecd, 2011b). Straight oils are transferred directly into the trough of the metalworking machine without dilution (Oecd, 2011b). The metalworking fluids are pumped from the trough and usually sprayed directly on the part during metal shaping (OECD, 2011). The fluid stays on the part and may drip dry before being rinsed or wiped clean. Any remaining metalworking fluid is usually removed during a cleaning or degreasing operation (Oecd, 2011b).

2.15.3 Exposure Assessment

2.15.3.1 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, 2011b).

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.

2.15.3.2 Number of Potentially Exposed Workers

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, 2011b). The ESD indicates that the "small" shops refer to sites that machine a variety of products according to customer orders, rather than sites manufacturing a large quantity of the same part (e.g., automobile part manufacturing) (Oecd, 2011b). The ESD also cites an EPA effluent 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, 2011b).

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, 2011b). Although, per the ESD, it is possible the shift supervisors may perform some tasks that may lead to direct handling of the metalworking fluid, EPA assesses these shift supervisors as ONUs as their exposures are expected to be less than the machinist exposures and EPA is assessing the machinists as workers, which yields a high worker-to-ONU ratio of 23-to-1 (Oecd, 2011b). The number of establishments that use PCE-based metalworking fluids is unknown; therefore, EPA does not have data to estimate the total workers and ONUs exposed to PCE from use of metalworking fluids.

2.15.3.3 Occupational 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, 2011b). The ESD estimates typical and high-end exposures for different types of metalworking fluids. These estimates are provided in Table 2-64 and are based on a NIOSH study of 79 small metalworking facilities (Oecd, 2011b). The concentrations for these estimates are for the solvent-extractable portion and do not include water contributions (Oecd, 2011b). The “typical” mist concentration is the geometric mean of the data and the “high-end” is the 90th percentile of the data (Oecd, 2011b).

Table 2-64. ESD Exposure Estimates for Metalworking Fluids Based on Monitoring Data

Type of Metalworking Fluid	Typical Mist Concentration (mg/m^3)[a]	High-End Mist Concentration (mg/m^3)[b]
Conventional Soluble	0.19	0.87
Semi-Synthetic	0.20	0.88
Synthetic	0.24	1.10
Straight Oil	0.39	1.42

[a] The typical mist concentration is the geometric mean of the data (Oecd, 2011b).
[b] The high-end mist concentration is the 90th percentile of the data (Oecd, 2011b).
Source: (Oecd, 2011b)

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. Straight oils are not diluted; therefore, the concentration of PCE specified in the SDS (<10%) is equal to the concentration of PCE in the mist. However, it should be noted that due to the evaporation of PCE from the metalworking fluid, the actual concentration of PCE in the mist is expected to be less than the 10% estimated in the metalworking fluid, resulting in an overestimate of exposure to PCE in the mist. Table 2-65 presents the exposure estimates for the use of PCE-based metalworking fluids. The ESD estimates an exposure duration of eight hours per day; therefore, results are presented as 8-hr TWA exposure values.

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. This exposure is difficult to estimate and 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.

Table 2-65. Summary of Exposure Results for Use of PCE in Metalworking Fluids Based on ESD Estimates

Scenario	8-hr TWA (ppm)[a]	AC (ppm)	ADC (ppm)	LADC (ppm)
High-End	2.1E-2	7.0E-3	4.8E-3	2.5E-3
Central Tendency	5.8E-3	1.9E-3	1.3E-3	5.2E-4

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[a] The PCE exposure concentrations are calculated by multiplying the straight oil mist concentrations in Table 2-64 by 10% (the concentration of PCE in the metalworking fluid) and converting to ppm.

2.15.4 Water Release Assessment

2.15.4.1 Water Release Sources

The ESD states that water releases from use of straight oil metalworking fluids may come from disposal of container residue and dragout losses from cleaning the part after shaping (Oecd, 2011b). Facilities typically treat wastewater onsite due to stringent discharge limits to POTWs (Oecd, 2011b). Control technologies used in onsite wastewater treatment in the MP&M industry include ultrafiltration, oil/water separation, and chemical precipitation (Oecd, 2011b). Facilities that do not treat wastewater onsite contract waste haulers to collect wastewater for off-site treatment (Oecd, 2011b).

2.15.4.2 Water Release Assessment Results

EPA assesses water release using TRI and DMR data. However, EPA cannot distinguish between sites using metalworking fluids and sites using PCE in degreasers in TRI and DMR data; therefore, a single set of water release for degreasing and metalworking fluid operations is presented in Section 2.5.4.2 for OTVDs.

2.16 Wipe Cleaning and Metal/Stone Polishes

2.16.1 Estimates of Number of Facilities

EPA did not identify information from EPA databases (e.g., CDR, TRI, or DMR) or in the results of the systematic review process to estimate the number of sites using PCE for wipe cleaning and metal/stone polishes. It is possible some sites using vapor degreasers or cold cleaners also use PCE for wipe cleaning.

2.16.2 Process Description

PCE can be used as a solvent in non-aerosol (i.e., liquid) degreasing and cleaning products. Non-aerosol cleaning products typically involve dabbing or soaking a rag with cleaning solution and then using the rag to wipe down surfaces or parts to remove contamination (U.S. EPA, 2014). The cleaning solvent is usually applied in excess and allowed to air-dry (U.S. EPA, 2014). Parts may be cleaned in place or removed from the service item for more thorough cleaning (U.S. EPA, 2014).

2.16.3 Exposure Assessment

2.16.3.1 Worker Activities

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/polishing. Additional activities and use patterns will vary depending on the specific site at which PCE product is being used.

2.16.3.2 Number of Potentially Exposed Workers

EPA did not identify information to estimate the number of workers or ONUs exposed to PCE during use for wipe cleaning and metal/stone polishing. Wipe cleaning and metal/stone polishes can be used in a large variety of industries that cannot be drilled down to a specific set of NAICS codes. Additionally, EPA does not have information on market penetration to estimate number of workers even if a set of "likely" NAICS codes were identified. Therefore, methodologies used in other conditions of use to estimate workers cannot be used for this condition of use. It is possible some workers/ONUs at sites using vapor degreasers or cold cleaners are also exposed to PCE from wipe cleaning activities.

2.16.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from NIOSH investigations at two sites using PCE for wipe cleaning. EPA did not identify exposure data specific to metal/stone polish applications; therefore, these 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 shop types 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 polish; therefore, the assessment is based on the identified monitoring data. Table 2-66 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. 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, 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) as discussed in Section 1.4.5.2. 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).

The data were obtained from NIOSH HHEs conducted at a taxidermy shop and an air filter manufacturer (NIOSH, 1983b, 1979). At the taxidermy shop, workers hand-rub a mixture of crushed corn cobs and PCE on the animal fur to remove oils and fats that are deposited during the mounting process (NIOSH, 1979). The mixture is then removed from the fur by blowing it with air (NIOSH, 1979). The study notes that the entire taxidermy process is done without adequate ventilation (NIOSH, 1979). The sample times ranged from approximately one hour to four hours; however, the study states that workers perform the same task throughout the work shift and the exposures are representative of an eight-hour exposure (NIOSH, 1979). Therefore, EPA consider these data as 8-hr TWA exposure values.

The air filter manufacture shop manufactures engine and machine filters for airplanes, trucks, railroads, tank engines, and office machines (NIOSH, 1983b). Workers use rags dampened with solvent (primarily PCE) to clean excess resins and adhesives from metal parts (NIOSH, 1983b). The study indicates that workers are rotated between activities as an administrative control (NIOSH, 1983b). The study collected one three-hour from a worker and four 15-mintue samples. EPA calculated both 4-hr and 8-hr TWAs from the three-hour sample assuming zero exposure outside the sample time.

Table 2-66. Summary of Worker Inhalation Monitoring Data for Use of Perchloroethylene as a Wipe Cleaning Solvent and Metal/Stone Polishes

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	4-hr TWA (ppm)	Number of Data Points	15-minute TWA	Number of Data Points
Worker Monitoring Data									
High-End	228	76	52	27	4	9.5	1	103	4
Central Tendency	132	44	30	12				66	
Occupational Non-User Monitoring Data									
High-End	23	7.7	5.3	2.7	6	No 4-hr or 15-minute data identified for ONUs			
Central Tendency	2.2E-2	7.3E-3	5.0E-3	2.0E-3					

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Source: (NIOSH, 1983b, 1979)

2.16.4 Water Release Assessment

EPA does not expect releases of PCE to water from the use of PCE as a wipe cleaning solvent and metal/stone polishes. Due to the volatility of PCE the majority of releases from the use of wipe cleaning and metal/stone polish products will likely be to air as PCE evaporates from the rag/cloth used to apply the solvent and the substrate surface. EPA expects any PCE residue that remains in the container or on the rag/to be disposed of with shop trash that is either picked up by local waste management or by a waste handler that disposes shop wastes as hazardous waste. There is a potential that PCE may drip from the rag/cloth or the substrate surface onto shop floors or ground (for outdoor applications) and could possibly end up in a floor drain (if the shop has one) or runoff into surface water or stormwater drains. However, EPA expects the potential release to water from this to be minimal as there would be time for PCE to evaporate before entering these pathways. This is consistent with estimates from the International Association for Soaps, Detergents and Maintenance Products (AISE) SpERC for Wide Dispersive Use of Cleaning and Maintenance Products, which estimates 100% of volatiles are released to air (International Association for Soaps Detergents and Maintenance Products, 2012).

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

2.17.1 Estimates of Number of Facilities

EPA did not identify information from EPA databases (e.g., CDR, TRI, or DMR) or in the results of the systematic review process to estimate the number of sites using PCE in other spot cleaning/spot removers.

2.17.2 Process Description

EPA expects the use of spot cleaners/spot removers to involve spray applying PCE to the stained textile (e.g., carpet) and then using brush or fingers to scrape away the stain. This condition of use includes both professional carpet cleaning activities as well as spot cleaning activities at textile mills.

2.17.3 Exposure Assessment

2.17.3.1 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.

2.17.3.2 Number of Potentially Exposed Workers

EPA did not identify information from the systematic review process to estimate the total number of workers and ONUs exposed from use of spot cleaners/spot removers. However, 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.

2.17.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from a single NIOSH investigation at a garment manufacturer and from OSHA facility inspections (OSHA, 2020; NIOSH, 1996). It is unclear how representative these data are of a “typical” spot cleaning/spot remover scenario. The site in the NIOSH (1996) investigation had two spotting stations in the finishing department used to remove stains from garments on an “as needed” basis (NIOSH, 1996). The investigation collected three samples from workers in the finishing department with sample times ranging from approximately 5.5 to 9 hours (NIOSH, 1996). Where sample times were less than eight hours, EPA converted to an 8-hr TWA assuming exposure outside the sample time was zero.

EPA constructed two full-shift sample from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD did not provide information on the exact use of PCE; therefore, EPA assessed the use based on the reported NAICS code for Carpet and Upholstery Cleaning Services (OSHA, 2020). OSHA data does not provide job titles or worker activities associated with samples; therefore, EPA assumed the data was collected on a worker and not an ONU. Table 2-67 summarizes the 8-hr TWA monitoring data for the use of PCE in spot cleaners/spot removers. Because there are only 4 worker exposure data points, EPA assessed the maximum as the high-end and the median (50th percentile) as the central tendency. For ONU exposures, only one data point was identified; 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.

Table 2-67. Summary of Worker Inhalation Exposure Monitoring Data for Other Spot Cleaning/Spot Removers (Including Carpet Cleaning)

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points
Worker Monitoring Data					
High-End	3.4	1.1	0.8	0.4	4
Central Tendency	1.5	0.5	0.3	0.1	
Occupational Non-User Monitoring Data					
High-End[a]	3.0E-2	1.0E-2	6.8E-3	3.5E-3	1
Central Tendency[a]	3.0E-2	1.0E-2	6.8E-3	2.7E-3	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[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: (OSHA, 2020; NIOSH, 1996)

2.17.4 Water Release Assessment

EPA does not have information to estimate the releases to water from spot cleaners/spot removers. The Fabric Finishing GS (U.S. EPA, 1994a) and ESD on the Use of Textile Dyes (OECD, 2017b) do not address potential releases from spot cleaners. Due to the volatility of PCE, EPA expects the primary release of PCE to be to air. However, there is the possibility that PCE deposits into water streams at textile plants and is subsequently discharged other directly to water or indirectly to POTW or non-POTW WWT.

2.18 Other Industrial Uses

2.18.1 Estimates of Number of Facilities

To determine the number of sites that use PCE for other industrial uses, EPA considered 2016 TRI (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. EPA identified 19 facilities in the 2016 TRI and 111 facilities in the 2016 DMR where EPA could not determine the condition of use or the condition of use falls into an industrial use discussed in Section 2.18.2. Therefore, EPA assessed a total of 130 sites for use of PCE in “other industrial uses”.

2.18.2 Process Description

Based on information identified in EPA’s preliminary 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, market profile, and NAICS/SIC codes reported in TRI and DMR, 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 (U.S. EPA, 2017a, c, d, 2016b). EPA did not identify information on how PCE may be used at these facilities.

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 this 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.

2.18.3 Exposure Assessment

2.18.3.1 Worker Activities

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.

2.18.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during other industrial uses 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 (U.S. EPA, 2017d) or 2016 DMR (U.S. EPA, 2016b), respectively. The method for estimating number of workers is detailed above in Section 1.4.4. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. The employment data from the U.S. Census SUSB and the Bureau of Labor Statistics’ OES data are based on NAICS code; therefore, SIC codes reported in the 2016 DMR had to be mapped to a NAICS code to estimate the number of workers. A crosswalk of the SIC codes to the NAICS codes used in the analysis are provided in Table 2-68. In the 2016 DMR 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.

Table 2-68. Crosswalk of Other Industrial Use SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
1041 – Gold Ores	211120 – Gold Ore Mining
1221 – Bituminous Coal and Lignite Surface Mining	212111 – Bituminous Coal and Lignite Surface Mining
1311 – Crude Petroleum and Natural Gas	211120 – Crude Petroleum Extraction
1423 – Crushed and Broken Granite	212313 – Crushed and Broken Granite Mining and Quarrying
1429 – Crushed and Broken Stone, Not Elsewhere Classified	212319 – Other Crushed and Broken Stone Mining and Quarrying
1442 – Construction Sand and Gravel	212321 – Construction Sand and Gravel Mining
2026 – Fluid Milk	311511 – Fluid Milk Manufacturing
2033 – Canned Fruits, Vegetables, Preserves, Jams, and Jellies	311421 – Fruit and Vegetable Canning
2046 – Wet Corn Milling	311221 – Wet Corn Milling
2066 – Chocolate and Cocoa Products	311351 – Chocolate and Confectionery Manufacturing from Cacao Beans
2082 – Malt Beverages	312120 – Breweries
2087 – Flavoring Extracts and Flavoring Syrups, Not Elsewhere Classified[a]	311900 – Other Food Manufacturing
2099 – Food Preparations, Not Elsewhere Classified[a]	311900 – Other Food Manufacturing
2611 – Pulp Mills	322110 – Pulp Mills
2672 – Coated and Laminated Paper, Not Elsewhere Classified	322220 – Paper Bag and Coated and Treated Paper Manufacturing
2679 – Converted Paper and Paperboard Products, Not Elsewhere Classified	322299 – All Other Converted Paper Product Manufacturing
2812 – Alkalies and Chlorine	325180 – Other Basic Inorganic Chemical Manufacturing
2822 – Synthetic Rubber (Vulcanizable Elastomers)	325212 – Synthetic Rubber Manufacturing
2823 – Cellulosic Manmade Fibers	325220 – Artificial and Synthetic Fibers and Filaments Manufacturing
2824 – Manmade Organic Fibers, Except Cellulosic	325220 – Artificial and Synthetic Fibers and Filaments Manufacturing
2833 – Medicinal Chemicals and Botanical Products	325411 – Medicinal and Botanical Manufacturing

SIC Code	Corresponding NAICS Code
2836 – Biological Products, Except Diagnostic Substances	325414 – Biological Product (except Diagnostic) Manufacturing
2892 – Explosives	325920 – Explosives Manufacturing
3264 – Porcelain Electrical Supplies	327110 – Pottery, Ceramics, and Plumbing Fixture Manufacturing
3297 – Nonclay Refractories	327120 – Clay Building Material and Refractories Manufacturing
4911 – Electric Services[b]	221100 – Electric Power Generation, Transmission and Distribution
5171 – Petroleum Bulk stations and Terminals	424710 – Petroleum Bulk Stations and Terminals
8731 – Commercial Physical and Biological Research[c]	541700 – Scientific Research and Development Services
8733 – Noncommercial Research Organizations[c]	541700 – Scientific Research and Development Services

[a] The SIC codes 2087 and 2099 may map to any of the following NAICS codes: 311920, 311930, 311941, 311942, 311991, or 311999. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 4-digit NAICS, 311900, rather than a specific 6-digit NAICS.

[b] The SIC code 4911 may map to any of the following NAICS codes: 221111, 221112, 221113, 221114, 221115, 221116, 221117, 221118, 221121, or 221122. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 4-digit NAICS, 221100, rather than a specific 6-digit NAICS.

[c] The SIC codes 8731 and 8733 may map to any of the following NAICS codes: 541713, 541714, 541715, or 541720. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 4-digit NAICS, 541700, rather than a specific 6-digit NAICS.

Table 2-69 provides a summary of the reported NAICS codes (or NAICS identified in the crosswalk), the number of sites reporting each NAICS code, and the estimated number of workers and ONUs for each NAICS code as well as an overall total for other industrial uses. It should be noted, that in the 2016 DMR, nine sites either did not report a SIC code or reported a SIC code for which no employment data were available for the corresponding NAICS code. To estimate the number of workers and ONUs from these sites EPA calculated the average number of workers and ONUs per site from the other known sites. There are approximately 2,700 workers and 1,300 ONUs potentially exposed during other industrial uses.

Table 2-69. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Other Industrial Uses

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
212111	1	15	6	15	6	20
212221	3	29	11	86	33	119

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
212313	1	6	1	6	1	7
212319	1	5	1	5	1	7
212321	2	4	1	7	2	9
221100	32	5	7	169	230	399
311221	1	39	39	39	39	78
311351	1	9	2	9	2	11
311411	1	57	9	57	9	65
311421	1	22	3	22	3	25
311511	1	39	8	39	8	47
311900	2	16	3	32	7	39
312120	1	8	1	8	1	9
322110	1	100	15	100	15	116
322220	1	35	5	35	5	40
322299	1	19	2	19	2	22
324110	3	170	75	511	226	737
325110	4	64	30	255	120	375
325180	2	25	12	50	24	74
325199	3	39	18	116	55	170
325211	3	27	12	82	36	119
325212	2	25	11	49	22	71
325220	8	47	21	378	166	545
325411	2	24	15	49	30	79
325414	1	54	33	54	33	88
325612	1	17	4	17	4	20
325920	3	32	10	95	31	126
327110	1	13	2	13	2	16
327120	1	24	4	24	4	28
424710	30	1	0	43	5	48
541700	5	1	9	5	45	50

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed
541712	1	1	10	1	10	12
Unknown NAICS	9	30	12	274	108	382
Total[b]	130	21	10	2,700	1,300	4,000

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer.

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

2.18.3.3 Occupational 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 2-71 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.”

EPA constructed 38 full-shift samples for textile processing, 13 full-shift samples for wood furniture manufacturing, 4 full-shift samples for foundry applications, and 2 full-shift samples for miscellaneous uses from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD data did not provide information on the exact use of PCE; therefore, EPA assumed the use based on the reported NAICS and SIC codes (OSHA, 2020). The codes for textile processing were: Apparel Accessories and Other Apparel Manufacturing; Men’s and Boys’ Cut and Sew Apparel Manufacturing; Finishers of Broadwoven Fabrics of Cotton; Curtain and Linen Mills; Textile and Fabric Finishing Mills; and Textile & Textile Products (OSHA, 2020). The codes for wood furniture manufacturing were: Wood Household Furniture, Except Upholstered; Wood Office Furniture; All Other Miscellaneous Wood Product Manufacturing; and Wood Container and Pallet Manufacturing (OSHA, 2020). The codes for foundry applications were: Other Nonferrous Metal Foundries (Except Die-Casting); Nonferrous Metal Die-Casting Foundries; Aluminum Foundries (Except Die-Casting); and Iron Foundries (OSHA, 2020). The code for miscellaneous was Electric Services (OSHA, 2020). OSHA data does not provide job titles or worker activities associated with the samples; therefore, EPA assumed the data were collected on workers and not ONUs.

The data provided by DoD included 49 data points for PCE from samples taken during a variety of processes. Of these 49 data points, 41 were determined to fit under conditions of use assessed in this risk evaluation and are not discussed further here (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018). The remaining eight samples were collected during one of the following processes:

1. Oil Analysis;
2. Water Pipe Repair;
3. Conducting industrial hygiene surveys/Taking industrial hygiene samples;
4. Cable End Molding; and
5. Soldering/Desoldering (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018).

A summary of the personal breathing zone samples for these five DoD activities are summarized in Table 2-70. EPA assumes all sample results indicated with a less than symbol were below the LOD.

Table 2-70. Summary of DoD Inhalation Monitoring Data Not Included in Assessments for Other Conditions of Use

Process	Worker Activity Frequency	Process Duration	Min. Sample Result (ppm)	Max. Sample Result (ppm)	Number of Samples	Sample Duration (min)	Sample Date
Oil Analysis	2-3 times/week	1-2 hours	4.14	6.61	2	15-64	February 25, 2008
Water Pipe Repair	2-3 times/month	Not provided	-	<3.0	1	370	March 15, 2003
Conducting industrial hygiene surveys/ Taking industrial hygiene samples	2-3 times/week	Not provided	<0.22	<0.98	3	15-134	September 30, 2006
Cable End Molding	Daily	Not provided	-	<0.29	1	51	May 30, 2013
Soldering/Desoldering	Daily	Not provided	-	<0.23	1	64	April 27, 2016

Source: (Defense Occupational and Environmental Health Readiness System - Industrial Hygiene, 2018)

EPA did not assess exposures from the following processes as the sample times were less than 50% of an 8-hr shift (assumed shift-time for these activities) and, therefore, may not be representative of actual 8-hr TWA exposures:

- Conducting industrial hygiene surveys/Taking industrial hygiene samples;
- Cable End Molding; and
- Soldering/Desoldering.

EPA assessed exposures from the oil analysis and water pipe repair processes separately due to differences in the frequency of activities. For the oil analysis process, EPA calculated an 8-hr TWA exposure using the single sample result collected over 64 minutes. EPA believes this to be a reasonable assumption as the process duration is specified as one to two hours. Therefore, EPA expects the sample time to be representative of the time the worker spent handling PCE in the process with little potential for exposure for the remainder of the shift[22]. The process duration for the water pipe repair process was not provided; however, the sample time is sufficiently long (>6 hours) such that EPA assumes it is representative of the duration that the worker handles PCE during the work-shift. summarizes the results for both the oil analysis and water pipe repair processes.

Only one data point was available for the oil analysis. Results based on a single value are considered plausible, but EPA cannot determine the statistical representativeness of the value. There was only one data point available for the water pipe repair 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) which estimates the exposure value as $\frac{LOD}{2}$ 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 (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. These scenarios are plausible, but EPA cannot determine the statistical representativeness of the value.

For the oil analysis, DoD reported the frequency as two to three times per week. Therefore, when calculating the ADC and LADC, EPA adjusted the exposure frequency to reflect the expected number of exposure days. For the high-end calculations, EPA used the maximum process frequency of three times per week and for the central tendency calculations, EPA used the midpoint of the frequency, 2.5 times per week. Assuming 50 weeks per year of exposure (standard EPA assumption allowing for two weeks off), results in 150 exposure days/yr at the high-end and 125 exposure days at the central tendency.

For the water pipe repair, DoD reported the frequency as two to three times per month. Therefore, EPA similarly adjusted the exposure frequency to reflect the expected number of exposure days when calculating the ADC and LADC. For the high-end calculations, EPA used the maximum process frequency of three times per month and for the central tendency (i.e., midpoint) calculations, EPA used the midpoint of the frequency, 2.5 times per month. Assuming 12 months per year of exposure, results in 36 exposure days/yr at the high-end and 30 exposure days at the central tendency.

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[22] The 15-min TWA for the oil analysis process was not used to calculate an 8-hr TWA exposure as it is not expected to be representative of the duration the worker is handling PCE based on the reported process duration.

Table 2-71. Summary of Exposure Monitoring Results for Other Industrial Uses of Perchloroethylene

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points
Textile Processing					
High-End	18	6.1	4.1	2.1	38
Central Tendency	1.2	0.4	0.3	0.1	
Wood Furniture Manufacturing					
High-End	44	15	10	5.2	13
Central Tendency	7.4	2.5	1.7	0.7	
Foundry Applications					
High-End	240	80	55	28	4
Central Tendency	15	4.9	3.4	1.3	
Miscellaneous					
High-End	4.4	1.5	1.0	0.5	2
Central Tendency	3.7	1.2	0.8	0.3	
DoD Use – Oil Analysis					
High-End	0.9[a]	0.3	0.1	6.2E-2	1
Central Tendency		0.3	0.1	4.0E-2	
DoD Use – Water Pipe Repair					
High-End	2.3	0.8	7.6E-2	3.9E-2	1[b]
Central Tendency	1.2	0.4	3.2E-2	1.3E-2	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[a] 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.

[b] 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: (OSHA, 2020; U.S. DOD and Environmental Health Readiness System - Industrial, 2018)

2.18.4 Water Release Assessment

2.18.4.1 Water Release Sources

Specifics of the processes and potential sources of release for other industrial uses are unknown. However, general potential sources of water releases in the chemical industry may include the following: equipment cleaning operations, aqueous wastes from scrubbers/decanters, reaction water, process water from washing intermediate products, and trace water settled in storage tanks (OECD, 2011a).

2.18.4.2 Water Release Assessment Results

EPA assessed water releases using the annual discharge values reported to the 2016 TRI (U.S. EPA, 2017d) and the 2016 DMR (U.S. EPA, 2016b) by the 130 sites using PCE in other industrial uses. In the 2016 TRI, one site reported non-zero direct discharges to surface water and all the other sites reported zero indirect or direct discharges (U.S. EPA, 2017d). In the 2016 DMR, six sites reported a direct discharge to surface water (indirect discharges not reported in DMR data) and the remaining sites reported zero direct discharges (U.S. EPA, 2016b).

To estimate the daily release, EPA assumed a 250 days/yr of operation and averaged the annual release over the operating days. Table 2-72 summarizes the water releases from the 2016 TRI and DMR for sites with non-zero discharges.

Table 2-72. Reported Wastewater Discharges of Perchloroethylene from Other Industrial Uses

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
ExxonMobil Oil Corp JoiIet Refinery, Channahon, IL	1.2	250	4.7E-03	ILR10H432	Surface Water	(U.S. EPA, 2017d)
Natrium Plant, New Martinsville, WV	7.9	250	3.1E-02	WV0004359	Surface Water	(U.S. EPA, 2016b)
Oxy Vinyls LP - Deer Park PVC, Deer Park, TX	78	250	0.3	TX0007412	Surface Water	(U.S. EPA, 2016b)
Princeton Plasma Physics Lab (FF), Princeton, NJ	0.1	250	5.3E-04	NJ0023922	Surface Water	(U.S. EPA, 2016b)
Tree Top Inc Wenatchee Plant, Wenatchee, WA	7.6E-03	250	3.0E-05	WA0051527	Surface Water	(U.S. EPA, 2016b)
Vesuvius USA Corp Buffalo Plant, Buffalo, NY	3.1E-02	250	1.2E-04	NY0030881	Surface Water	(U.S. EPA, 2016b)
William E. Warne Power Plant, Los Angeles County, CA	2.8E-04	250	1.1E-06	CA0059188	Surface Water	(U.S. EPA, 2016b)

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 250 days of operation per year.

Sources: (U.S. EPA, 2017d, 2016b)

2.19 Other Commercial Uses

2.19.1 Estimates of Number of Facilities

EPA did not identify information from EPA databases (e.g., CDR, TRI, or DMR) or in the results of the systematic review process to estimate the number of sites using PCE for other commercial uses. EPA did identify seven facilities in the 2016 DMR where EPA could not determine the condition of use or the condition of use falls into a commercial use discussed in Section 2.19.2. However, due to the large variety of PCE-based products and uses of PCE, these seven sites are not expected to represent the entirety of sites using PCE in other commercial applications.

2.19.2 Process Description

Based on information identified in EPA's preliminary data gathering and information obtained from public comments, a variety of other commercial uses of PCE may exist. Examples of these uses include, but are not limited to, metal (e.g., stainless steel) and stone polishes, inks and ink removal products, photographic film applications, and mold cleaning, release, and protectant products. For many of these uses PCE is expected to act similar to a cleaning solvent used to remove dirt or other contaminates from substrates (e.g., metal polishes and ink removal products). However, in the photographic film industry, PCE is used as a liquid-gate fluid to help protect scratching of optical negatives during filming (NIOSH, 1980a). Due to changes in technology (e.g., the use of digital equipment in place of traditional film), the prevalence of use of PCE as a liquid-gate fluid is unknown.

2.19.3 Exposure Assessment

2.19.3.1 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.

2.19.3.2 Number of Potentially Exposed Workers

EPA has not identified information from the systematic review process 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.

2.19.3.3 Occupational Exposure Results

EPA assessed exposure to these uses of PCE using data from identified studies. Table 2-73 summarizes the 8-hr TWA and 15-min TWA data identified for these uses. For printing uses (includes uses of both inks and ink removal products and commercial print shops), EPA identified data from six NIOSH investigations at six printing facilities and 21 full-shift samples from OSHA inspections. Four of the printing sites investigated by NIOSH used PCE for cleaning machines or printing plates, and 2 did not describe the function of PCE at the shop (NIOSH, 1994, 1984a, 1983a, 1982a, 1981c, 1980b). EPA constructed 21 full-shift samples from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD data did not provide information on the exact use of PCE; therefore, EPA assumed the use to be printing based on the SIC codes reported which included the codes Stationery Product Manufacturing; Commercial Printing (Except Screen and Books); Office Supplies (Except Paper) Manufacturing; and Book Printing (OSHA, 2020). OSHA data does not provide job titles or worker activities associated with the samples; therefore, EPA assumed the data were collected on workers and not ONUs. A total of 44 samples were collected at the sites with sample times ranging from approximately 2 to 8.5 hours. Where sample times were less than eight hours, EPA calculated the 8-hr TWA assuming exposure outside the sample time was zero. For the 8-hr TWA, the 95th percentile is presented as the high-end and the 50th percentile as the central tendency. There was a single 15-minute TWA sample. Results based on a single value are plausible, but EPA cannot determine the statistical representativeness of the value. There was single 8-hr TWA sample that measured below the LOD. To estimate exposure concentrations for this data point, EPA followed the *Guidelines for Statistical Analysis of Occupational Exposure Data* (U.S. EPA, 1994b) as discussed in Section 1.4.5.2. 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).

EPA also identified PCE exposure data at a U.S. photocopy shop using dry-process photocopiers (Stefaniak et al., 2000). The study collected three PBZ samples from workers at the photocopy shop with sample times ranging from 7.5 to 8 hours (Stefaniak et al., 2000). Where sample times were less than eight hours, EPA calculated the 8-hr TWA assuming exposure outside the sample time was zero. Only three data points were available; therefore, EPA presented the maximum as the high-end and the median as the central tendency.

For photographic film uses, EPA identified a single NIOSH study that investigated PCE exposures at 14 optical film shops (NIOSH, 1980a). A total of 55 samples were collected at the sites with sample times ranging from approximately two to eight hours (NIOSH, 1980a). Where sample times were less than eight hours, EPA calculated the 8-hr TWA assuming exposure outside the sample time was zero. The 95th percentile Is presented as the high-end and the 50th percentile as the central tendency.

For mold release products, EPA did identify PBZ data from a NIOSH investigation at a plastics component site where PCE was used as a mold release product (NIOSH, 1985). Sample times in the study ranged from one hour to six hours (NIOSH, 1985). Where sample times were less than eight hours, EPA calculated the 8-hr TWA assuming exposure outside the sample time was zero. All the data for mold release products measured below the LOD; therefore, EPA assessed half the LOD and the LOD for the central tendency and high-end exposure results, respectively.

There is a wide range of exposure results across the different commercial uses summarized in Table 2-73. This is likely due to the difference in how PCE is handled within each use and how easily PCE can evaporate into the workers breathing zone.

Table 2-73. Summary of Exposure Monitoring Data for Other Commercial Uses of Perchloroethylene

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	15-minute TWA (ppm)	Number of Data Points
Results for Printing Applications (Ink and Ink Removal Products)							
High-End	13	4.5	3.1	1.6	44	0.2	1
Central Tendency	1.6	0.5	0.4	0.1			
Results for Photocopying							
High-End	5.0E-4	1.7E-4	1.1E-4	5.9E-5	3	No 15-minute data identified for this use	
Central Tendency	1.9E-4	6.3E-5	4.3E-5	1.7E-5			
Results for Photographic Film Applications							
High-End	56	19	13	6.6	62	117	40
Central Tendency	6.3	2.1	1.4	0.6		13	
Results for Mold Release Products							
High-End	0.1	3.8E-2	2.6E-2	1.3E-2	7	No 15-minute data identified for this use	
Central Tendency	5.7E-2	1.9E-2	1.3E-2	5.1E-3			

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Source: (Gold et al., 2008; Stefaniak et al., 2000; NIOSH, 1994, 1984a, 1983a, 1982a, 1981c, 1980a, b)(OSHA, 2020; NIOSH, 1985)

2.19.4 Water Release Assessment

2.19.4.1 Water Release Sources

Specifics of the processes and potential sources of release for these uses are unknown. Based on the volatility of PCE, EPA expects the majority of PCE used for these applications to evaporate and be released to air. EPA expects residuals in containers to be disposed of with general site trash that is either picked up by local waste management or by a waste handler that disposes wastes as hazardous waste.

2.19.4.2 Water Release Assessment Results

Table 2-74 summarizes non-zero water releases from sites using PCE in other commercial uses reported in the 2016 DMR (U.S. EPA, 2016b). To estimate the daily release for the sites in Table 2-74, EPA assumed 250 days/yr of operation and averaged the annual release over the operating days. These data are not expected to capture the entirety of water releases from these uses; however, EPA does not have information to estimate water releases from sites not reporting to DMR. Based on the SIC codes reported in the DMR, the industries covered by these sites include special trade contractors, heavy construction, and line-haul railroad operations.

Table 2-74. Reported Wastewater Discharges of Perchloroethylene from Other Commercial Uses in the 2016 DMR

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type
Union Station North Wing Office Building, Denver, CO	0.7	250	2.9E-03	COG315293	Surface Water
Confluence Park Apartments, Denver, CO	7.5E-02	250	3.0E-04	COG315339	Surface Water
Wynkoop Denver LLCP St, Denver, CO	3.8E-02	250	1.5E-04	COG603115	Surface Water
100 Saint Paul, Denver County, CO	1.1E-02	250	4.3E-05	COG315289	Surface Water
BPI-Westminster, LLC(Owner)/Arcadis (Op), Denver, CO	8.6E-03	250	3.4E-05	COG315146	Surface Water
Safeway Inc, Denver, CO	3.9E-03	250	1.6E-05	COG315260	Surface Water
Illinois Central Railroad, Thompsonville, IL	3.3E-03	250	1.3E-05	IL0070696	Surface Water

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 250 days of operation per year.
Sources: (U.S. EPA, 2016b)

2.20 Laboratory Chemicals

2.20.1 Estimates of Number of Facilities

EPA did not identify information from the systematic review process to estimate the number of sites using PCE as a laboratory chemical.

2.20.2 Process Description

PCE is used in a variety of laboratory applications as a chemical reagent (Aerospace Industries Association, 2017). Specific process descriptions for how PCE is used in lab applications is not known. In general, PCE is expected to be received in small containers and used in small quantities on a lab bench in a fume cupboard or hood. After use, waste PCE is collected and disposed or recycled. Figure 2-20 this general process.

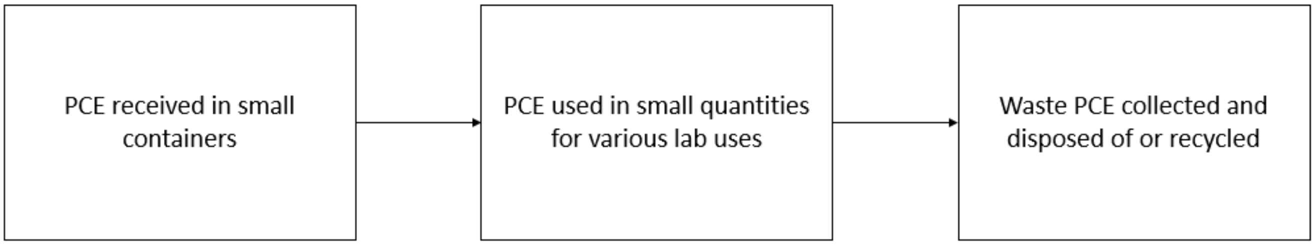

Figure 2-20. General Laboratory Use Process Flow Diagram

2.20.3 Exposure Assessment

2.20.3.1 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 include employees that work at the sites where PCE is used, 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 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.

2.20.3.1 Number of Potentially Exposed Workers

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). The method for estimating number of workers from the Bureau of Labor Statistics' OES data and U.S. Census' SUSB data is detailed in Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census.

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.

2.20.3.2 Occupational Exposure Results

EPA assessed two subcategories of laboratories: 1) university laboratories; and 2) commercial laboratories. EPA assessed exposures at university laboratories using data from OSHA facility inspections (OSHA, 2020). For workers at university labs, EPA constructed a single full-shift sample from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD data did not explicitly state the use of PCE as a lab chemical; rather, EPA assumed the use to be as a lab chemical based on the SIC code for Colleges, Universities, and Professional Schools (OSHA, 2020). EPA assumed this SIC code corresponded to use of PCE in laboratories at a university. OSHA data does not provide job titles or worker activities associated with the sample; therefore, EPA assumed the data were collected on workers and not ONUs. Table 2-75 summarizes the 8-hr TWA data identified for university 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.

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 2-75. Summary of Exposure Monitoring Data for Laboratory Uses of Perchloroethylene

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points
High-End	1.2[a]	0.4	0.3	0.1	1
Central Tendency		0.4	0.3	0.1	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration. Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.

[a] Only one data point was identified for laboratory uses; 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: (OSHA, 2020)

2.20.4 Water Release Assessment

2.20.4.1 Water Release Sources

The primary source of water releases at laboratories is expected to be from disposal of spent PCE reagent. However, not all sites using PCE as a laboratory reagent are expected to dispose of PCE to water. EPA expects some will collect PCE wastes with other hazardous lab materials to be collected and disposed of by a waste contractor as hazardous waste.

2.20.4.2 Water Release Assessment Results

EPA did not identify information from the systematic review process on the number of laboratory sites or the volume of PCE used in laboratory applications to estimate releases of PCE to water from laboratory uses. The SpERC developed by the European Solvent Industry Group for laboratory reagents (European solvents Industry Group, 2019b) estimates a 100% release scenario with 50% of the use volume being released to municipal wastewater, sewer, or water course, and 50% released to air. Therefore, no more than 50% of the use volume is expected to be released to water.

2.21 Waste Handling, Disposal, Treatment, and Recycling

2.21.1 Estimates of Number of Facilities

To determine the number of disposal, treatment, and recycling sites, EPA considered 2016 TRI (U.S. EPA, 2017d), and 2016 DMR (U.S. EPA, 2016b) data. Based on the activities and NAICS codes reported in the 2016 TRI, EPA identified 38 facilities where the primary condition of use is expected to be disposal or recycling of PCE-containing wastes (U.S. EPA, 2017d). In the 2016 DMR data, there are 59 sites for which EPA expects the primary condition of use to be disposal/recycling of PCE wastes based on the reported SIC codes and facility names, three of which are the same as sites identified in TRI (U.S. EPA, 2016b). Based on the DMR and TRI data, EPA assesses a total of 94 sites (38+59 = 97 sites – 3 duplicate sites = 94 sites) for the disposal/recycling of PCE. NAICS codes used to identify disposal/treatment sites are those related to waste disposal including any NAICS code under the 3-digit NAICS code 562000, Waste Management and Remediation Services and NAICS codes excepted to operate cement kilns (e.g., 327310, Cement Manufacturing) which are expected to burn various waste products for fuel.

2.21.2 Process Description

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 or dispose onsite wastes that they themselves generate are assessed in each condition of use assessment in Sections 2.1 through 2.20. Similarly, point source discharges of PCE to surface water are assessed in each condition of use assessment in Sections 2.1 through 2.20 (point source discharges are exempt as solid wastes under RCRA). Wastes of PCE that are generated during a condition of use and sent to a third-party site for treatment, disposal, or recycling may include the following:

- Wastewater: PCE may be contained in wastewater discharged to POTW or other, non-public treatment works for treatment. Industrial wastewater containing PCE discharged to a POTW may be subject to EPA or authorized NPDES state pretreatment programs. The assessment of wastewater discharges to POTWs and non-public treatment works of PCE is included in each of the condition of use assessments in Sections 2.1 through 2.20.

- Solid Wastes: Solid wastes are defined under RCRA as any material that is discarded by being: abandoned; inherently waste-like; a discarded military munition; or recycled in certain ways (certain instances of the generation and legitimate reclamation of secondary materials are exempted as solid wastes under RCRA). Solid wastes may subsequently meet RCRA's definition of hazardous waste by either being listed as a waste at 40 CFR §§ 261.30 to 261.35 or by meeting waste-like characteristics as defined at 40 CFR §§ 261.20 to 261.24. Solid wastes that are hazardous wastes are regulated under the more stringent requirements of Subtitle C of RCRA, whereas non-hazardous solid wastes are regulated under the less stringent requirements of Subtitle D of RCRA.

    - Solid wastes containing PCE may be regulated as a hazardous waste under RCRA waste codes D039 for wastes containing 0.7 mg/L or more of PCE (40 CFR 261.24), F001 for spent halogenated solvents used in degreasing, (40 CFR 261.31), F002 for spent halogenated solvents (40 CFR 261.31), and U210 for discarded commercial chemical products, manufacturing chemical intermediates, off-specification commercial chemical products, container residues, or spill residues. These wastes would be either incinerated in a hazardous waste incinerator or disposed to a hazardous waste landfill.

- Wastes Exempted as Solid Wastes under RCRA: Certain conditions of use of PCE may generate wastes of PCE that are exempted as solid wastes under 40 CFR § 261.4(a). For example, the generation and legitimate reclamation of hazardous secondary materials of PCE may be exempt as a solid waste.

2016 TRI data lists off-site transfers of PCE to land disposal, wastewater treatment, incineration, and recycling facilities (U.S. EPA, 2017d). About 32% of off-site transfers were incinerated, 1% sent to land disposal, less than 1% sent to wastewater treatment, 66% is recycled off-site, and 1% is sent to other or unknown off-site disposal/treatment (U.S. EPA, 2017d). See Figure 2-21.

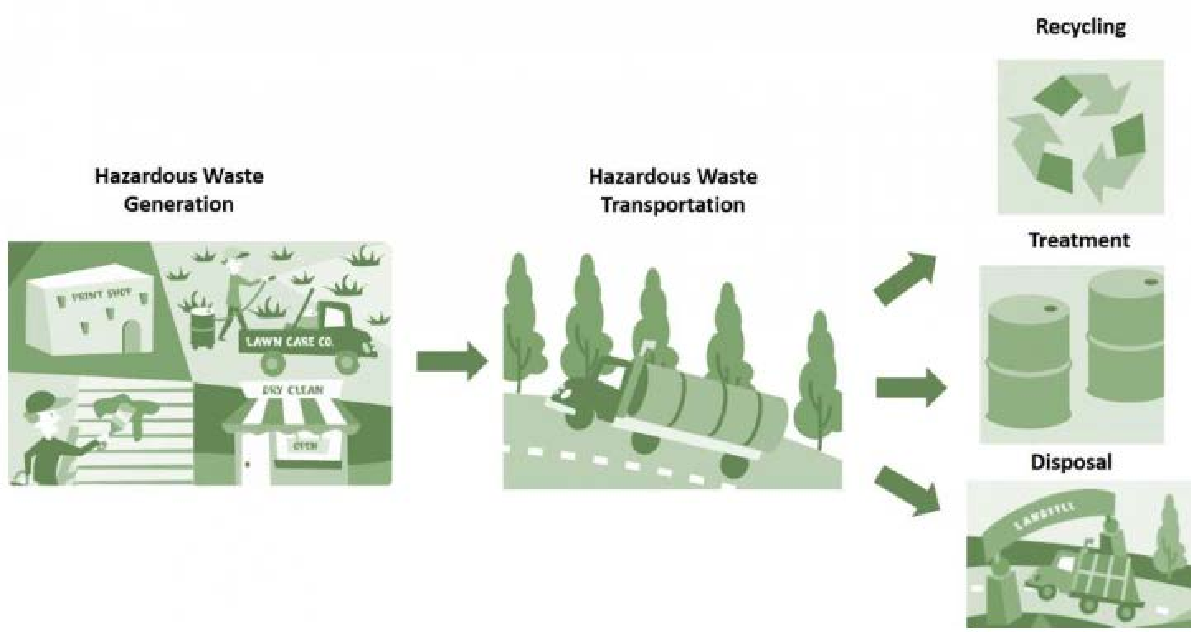

Figure 2-21. Typical Waste Disposal Process
Source: (U.S. EPA, 2017b)

Municipal Waste Incineration

Municipal waste combustors (MWCs) that recover energy are generally located at large facilities comprising an enclosed tipping floor and a deep waste storage pit. Typical large MWCs may range in capacity from 250 to over 1,000 tons per day. At facilities of this scale, waste materials are not generally handled directly by workers. Trucks may dump the waste directly into the pit, or waste may be tipped to the floor and later pushed into the pit by a worker operating a front-end loader. A large grapple from an overhead crane is used to grab waste from the pit and drop it into a hopper, where hydraulic rams feed the material continuously into the combustion unit at a controlled rate. The crane operator also uses the grapple to mix the waste within the pit, in order to provide a fuel consistent in composition and heating value, and to pick out hazardous or problematic waste.

Facilities burning refuse-derived fuel (RDF) conduct on-site sorting, shredding, and inspection of the waste prior to incineration to recover recyclables and remove hazardous waste or other unwanted materials. Sorting is usually an automated process that uses mechanical separation methods, such as trommel screens, disk screens, and magnetic separators. Once processed, the waste material may be transferred to a storage pit, or it may be conveyed directly to the hopper for combustion.

Tipping floor operations may generate dust. Air from the enclosed tipping floor, however, is continuously drawn into the combustion unit via one or more forced air fans to serve as the primary combustion air and minimize odors. Dust and lint present in the air is typically captured in filters or other cleaning devices in order to prevent the clogging of steam coils, which are used to heat the combustion air and help dry higher-moisture inputs[23].

Hazardous Waste Incineration

Commercial scale hazardous waste incinerators are generally two-chamber units, a rotary kiln followed by an afterburner, that accept both solid and liquid waste. Liquid wastes are pumped through pipes and are fed to the unit through nozzles that atomize the liquid for optimal combustion. Solids may be fed to the kiln as loose solids gravity fed to a hopper, or in drums or containers using a conveyor[24,25].

Incoming hazardous waste is usually received by truck or rail, and an inspection is required for all waste received. Receiving areas for liquid waste generally consist of a docking area, pumphouse, and some kind of storage facilities. For solids, conveyor devices are typically used to transport incoming waste.

Smaller scale units that burn municipal solid waste or hazardous waste (such as infectious and hazardous waste incinerators at hospitals) may require more direct handling of the materials by facility personnel. Units that are batch-loaded require the waste to be placed on the grate prior to operation and may involve manually dumping waste from a container or shoveling waste from a container onto the grate. See Figure 2-22 for a typical incineration process.

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[23] J.B. Kitto, Eds., Steam: Its Generation and Use, 40th Edition, Babcock and Wilcox/American Boiler Manufacturers Association, 1992.

[24] Environmental Technology Council's Hazardous Waste Resource Center; http://www.etc.org/advanced-technologies/high-temperature-incineration.aspx

[25] Incineration Services; Heritage; https://www.heritage-enviro.com/services/incineration/

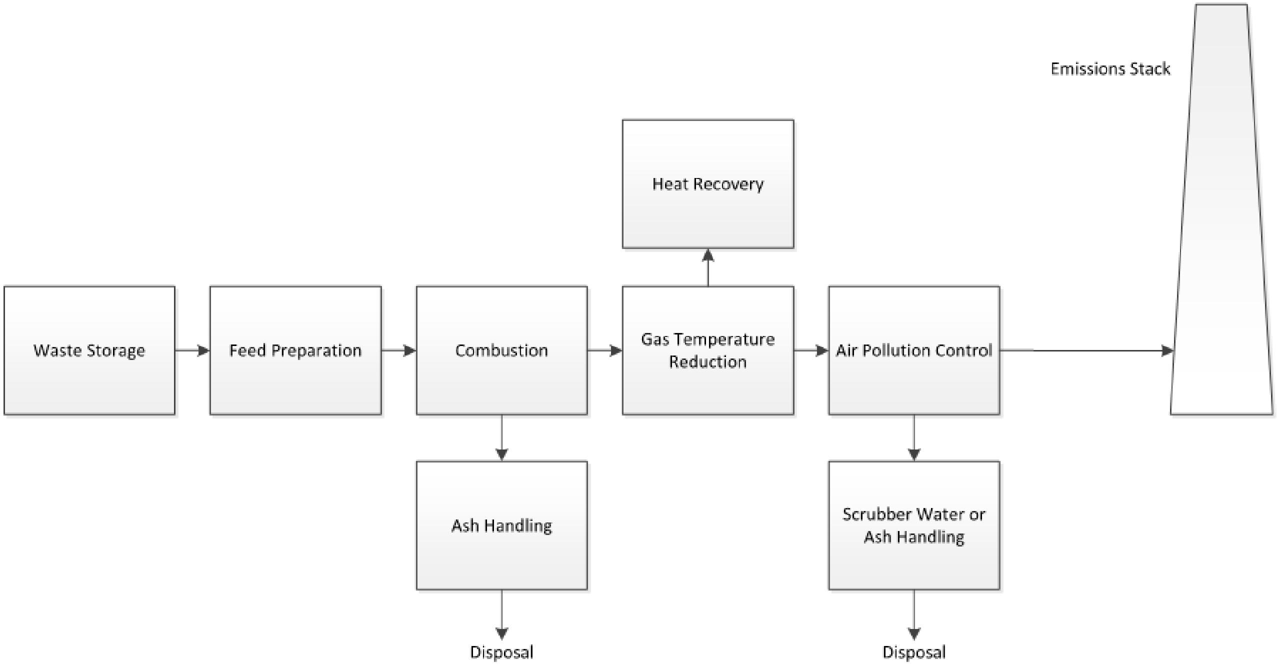

Figure 2-22.Typical Industrial Incineration Process

Municipal Waste Landfill

Municipal solid waste landfills are discrete areas of land or excavated sites that receive household wastes and other types of non-hazardous wastes (e.g. industrial and commercial solid wastes). Standards and requirements for municipal waste landfills include location restrictions, composite liner requirements, leachate collection and removal system, operating practices, groundwater monitoring requirements, closure-and post-closure care requirements, corrective action provisions, and financial assurance. Non-hazardous solid wastes are regulated under RCRA Subtitle D, but state may impose more stringent requirements.

Municipal solid wastes may be first unloaded at waste transfer stations for temporary storage, prior to being transported to the landfill or other treatment or disposal facilities.

Hazardous Waste Landfill

Hazardous waste landfills are excavated or engineered sites specifically designed for the final disposal of non-liquid hazardous wastes. Design standards for these landfills require double liner, double leachate collection and removal systems, leak detection system, run on, runoff and wind dispersal controls, and construction quality assurance program[26]. There are also requirements for closure and post-closure, such as the addition of a final cover over the landfill and continued monitoring and maintenance. These standards and requirements prevent potential contamination of groundwater and nearby surface water resources. Hazardous waste landfills are regulated under Part 264/265, Subpart N.

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[26] https://www.epa.gov/hwpermitting/hazardous-waste-management-facilities-and-units

Solvent Recovery

Waste solvents are generated when it becomes contaminated with suspended and dissolved solids, organics, water, or other substances. Waste solvents can be restored to a condition that permits reuse via solvent reclamation/recycling. The recovery process involves an initial vapor recovery (e.g., condensation, adsorption and absorption) or mechanical separation (e.g., decanting, filtering, draining, setline and centrifuging) step followed by distillation, purification and final packaging. Worker activities are expected to be unloading of waste solvents and loading of reclaimed solvents. Figure 2-23 illustrates a typical solvent recovery process flow diagram (U.S. EPA, 1980).

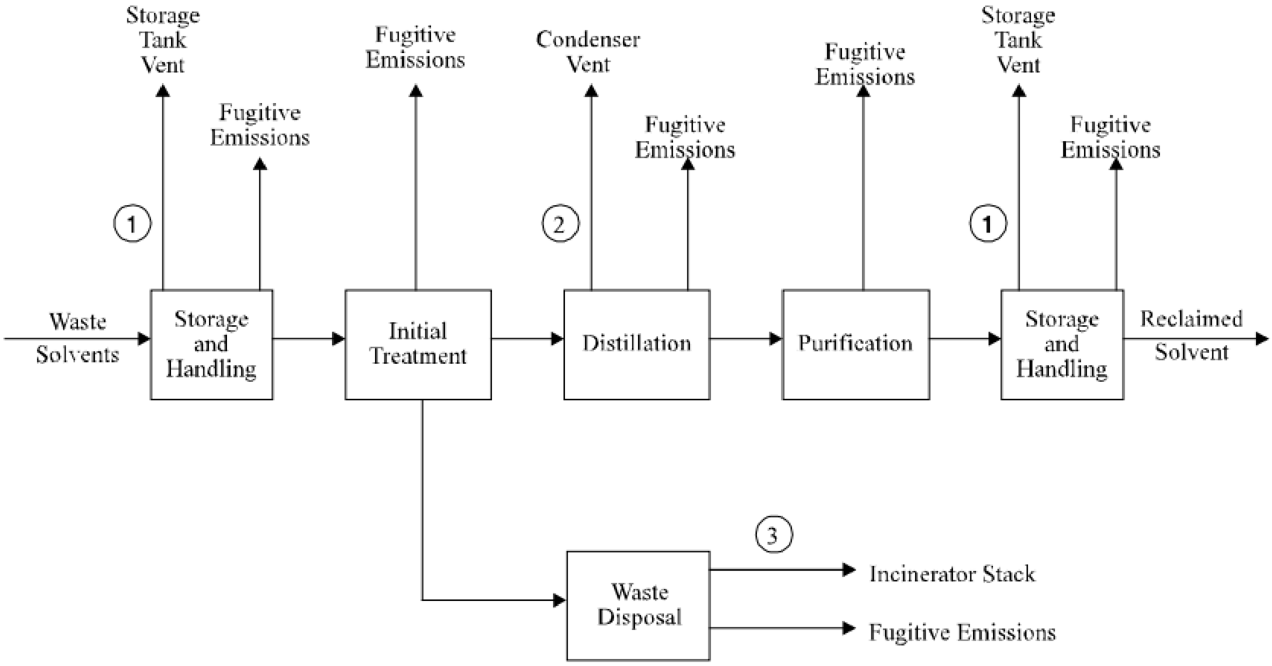

Figure 2-23. General Process Flow Diagram for Solvent Recovery Processes (U.S. EPA, 1980)

2.21.3 Exposure Assessment

2.21.3.1 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 2.3.3.3 for the assessment of worker exposure from chemical unloading activities.

Municipal Waste Incineration

At municipal waste incineration facilities, there may be one or more technicians present on the tipping floor to oversee operations, direct trucks, inspect incoming waste, or perform other tasks as warranted by individual facility practices. These workers may wear protective gear such as gloves, safety glasses, or dust masks. Specific worker protocols are largely up to individual companies, although state or local regulations may require certain worker safety standards be met. Federal operator training requirements pertain more to the operation of the regulated combustion unit rather than operator health and safety.

Workers are potentially exposed via inhalation to vapors while working on the tipping floor. Potentially-exposed workers include workers stationed on the tipping floor, including front-end loader and crane operators, as well as truck drivers. The potential for dermal exposures is minimized by the use of trucks and cranes to handle the wastes.

Hazardous Waste Incineration

More information is needed to determine the potential for worker exposures during hazardous waste incineration and any requirements for personal protective equipment. There is likely a greater potential for worker exposures for smaller scale incinerators that involve more direct handling of the wastes.

Municipal and Hazardous Waste Landfill

At landfills, typical worker activities may include operating refuse vehicles to weigh and unload the waste materials, operating bulldozers to spread and compact wastes, and monitoring, inspecting, and surveying and landfill site[27].

2.21.3.2 Number of Potentially Exposed Workers

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 (U.S. EPA, 2017d) or 2016 DMR (U.S. EPA, 2016b), respectively. The method for estimating number of workers is detailed above in Section 1.4.4 and Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. The employment data from the U.S. Census SUSB and the Bureau of Labor Statistics' OES data are based on NAICS code; therefore, SIC codes reported in the 2016 DMR had to be mapped to a NAICS code to estimate the number of workers. A crosswalk of the SIC codes to the NAICS codes used in the analysis are provided in Table 2-76. In the 2016 DMR there were 27 sites that either did not report a SIC code or reported a SIC for which employment data were not available for the corresponding NAICS code; for these sites, EPA used the average workers and ONUs per site calculated from the other sites with known data.

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[27] http://www.calrecycle.ca.gov/SWfacilities/landfills/needfor/Operations.htm

Table 2-76. Crosswalk of Disposal SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
3273 – Ready-Mixed Concrete	327320 – Ready-Mix Concrete Manufacturing
3295 – Minerals and Earths, Ground or Otherwise Treated	327992 – Ground or Treated Mineral and Earth Manufacturing
4953 – Refuse Systems[a]	562200 – Waste Treatment and Disposal
4959 – Sanitary Services, Not Elsewhere Classified[b]	562900 – Remediation and Other Waste Management Services
7699 – Repair Shops and Related Services, Not Elsewhere Classified[c]	562998 – All Other Miscellaneous Waste Management Services
9511 – Air and Water Resource and Solid Waste Management	924110 – Administration of Air and Water Resource and Solid Waste Management Programs

[a] The SIC code 4953 may map to any of the following NAICS codes: 562211, 562212, 562213 or 562219. There is not enough information in the DMR data to determine the appropriate NAICS code to use; therefore, EPA uses data for the 4-digit NAICS, 562200, rather than a specific 6-digit NAICS.

[b] The SIC code 4959 may map to any of the following NAICS codes: 561710, 561790, 562910 or 562998. Based on the condition of use for the site reporting this SIC code, EPA determined that the NAICS codes 592910 and 592998 most accurately described the site. There is not enough information in the DMR data to determine which is more appropriate; therefore, EPA uses data for the 4-digit NAICS, 562900, rather than a specific 6-digit NAICS.

[c] The SIC code 7699 maps to several NAICS codes primarily related to repair services and not disposal services. After review of the reporting company's website, this site was determined to be primarily engaged in disposal activities; therefore, EPA determined the NAICS codes 562998 most accurately described the site.

Table 2-77 provides a summary of the reported NAICS codes (or NAICS identified in the crosswalk), the number of sites reporting each NAICS code, and the estimated number of workers and ONUs for each NAICS code as well as an overall total for disposal/treatment of PCE wastes. There are approximately 1,600 workers and 700 ONUs potentially exposed during disposal/treatment of PCE wastes.

Table 2-77. Estimated Number of Workers Potentially Exposed to Perchloroethylene During Disposal/Treatment

NAICS Code	Number of Sites	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]	Total Exposed Workers[b]	Total Exposed Occupational Non-Users[b]	Total Exposed
221112	1	6	8	6	8	13
324110	1	170	75	170	75	246
324191	2	20	9	40	18	58
325110	2	64	30	127	60	187
327310	8	22	3	174	27	201
327320	4	5	1	21	3	25
327992	2	17	3	34	7	41
562200	23	6	3	131	75	206
562211	19	9	5	171	98	269
562213	1	13	8	13	8	21
562219	1	3	2	3	2	4
562920	2	2	2	4	3	7
562998	1	1	1	1	1	3
Subtotal for Known SIC/NAICS Data	67	13	6	897	384	1,281
Unknown or No Data	27	26	12	702	311	1,014
Total[c]	94	17	7	1,600	700	2,300

[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 in the relevant NAICS codes. The workers/ONUs per site are then multiplied by the number of sites within that NAICS to get the total exposed. The number of workers/ONUs per site is rounded to the nearest integer. Number of workers and occupational non-users per site for sites with unknown NAICS codes are calculated by averaging the values of the known sites.
[b] Total exposed workers and ONUs for sites with known NAICS are taken directly from the Bureau of Labor Statistics' OES data the U.S. Census' SUSB. For sites with unknown NAICS codes the total workers and ONUs are estimated by multiplying the workers and ONUs per site by the number of sites.
[c] Totals have been rounded to two significant figures. Totals may not add exactly due to rounding.

2.21.3.3 Occupational Exposure Results

EPA assessed exposure from disposal/treatment of PCE using data from OSHA facility inspections (OSHA, 2020). EPA constructed 12 full-shift samples from the OSHA CEHD using the approach described in Section 1.4.5.3. The OSHA CEHD did not provide information on the exact use of PCE; therefore, EPA assessed the use based on the reported SIC code for Refuse Systems (OSHA, 2020). OSHA data does not provide job titles or worker activities associated with the samples; therefore, EPA assumed the data were collected on workers and not ONUs. Table 2-78 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.

Table 2-78. Summary of Exposure Monitoring Data for Disposal/Treatment of Perchloroethylene

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points
High-End	0.1	3.3E-2	2.3E-2	1.2E-2	12
Central Tendency	3.8E-3	1.3E-3	8.7E-4	3.5E-4	

AC = Acute Concentration; ADC = Average Daily Concentration; and LADC = Lifetime Average Daily Concentration.
Equations and parameters for calculation of the AC, ADC, and LADC are described in Appendix B.
Source: (OSHA, 2020)

2.21.4 Water Release Assessment

2.21.4.1 Water Release Sources

Potential sources of water releases at disposal/recycling sites may include the following: aqueous wastes from scrubbers/decanter, trace water settled in storage tanks, and process water generated during the disposal/recycling process.

2.21.4.2 Water Release Assessment Results

EPA assessed water releases using the annual discharge values reported to the 2016 TRI (U.S. EPA, 2017d) and the 2016 DMR (U.S. EPA, 2016b) by the 94 disposal/treatment sites. In the 2016 TRI, four sites reported non-zero indirect discharges to non-POTW WWT, four sites reported indirect discharges to POTW, and all of the sites reported zero direct discharges to surface water. In the 2016 DMR, five sites reported non-zero direct discharges to surface water (indirect discharges not reported in DMR data) and the remaining sites reported no direct discharges.

To estimate the daily release, EPA assumed 250 days/yr of operation as and averaged the annual release over the operating days. Table 2-79 summarizes the water releases from the 2016 TRI and DMR for sites with non-zero discharges.

Table 2-79. Reported Wastewater Discharges of Perchloroethylene from Disposal/Treatment of Perchloroethylene-Containing Wastes

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Clean Harbors Deer Park LLC, La Porte, TX	87	250	0.3	TX0005941	Non-POTW WWT	(U.S. EPA, 2017d)
Clean Harbors El Dorado LLC, El Dorado, AR	9.3	250	3.7E-02	AR0037800	Non-POTW WWT	(U.S. EPA, 2017d)

Site	Annual Release[a] (kg/yr)	Annual Release Days (days/yr)	Daily Release (kg/day)[a]	NPDES Code	Release Media/ Treatment Facility Type	Source
Clean Harbors Recycling Services of Ohio LLC, Hebron, OH	8.6E-03	250	3.4E-05	Not available	POTW	(U.S. EPA, 2017d)
Clean Water Of New York Inc, Staten Island, NY	0.9	250	3.8E-03	NY0200484	Surface Water	(U.S. EPA, 2016b)
Clifford G Higgins Disposal Service Inc SLF, Kingston, NJ	5.2E-02	250	2.1E-04	NJG160946	Surface Water	(U.S. EPA, 2016b)
Durez North Tonawanda Occidental Chemical Corporation, North Tonawanda, NY	1.5E-02	250	5.9E-05	NY0001198	Surface Water	(U.S. EPA, 2016b)
Heritage Thermal Services, East Liverpool, OH	9.1E-05	250	3.6E-07	OH0107298	POTW	(U.S. EPA, 2017d)
Oiltanking Houston Inc, Houston, TX	0.8	250	3.3E-03	TX0091855	Surface Water	(U.S. EPA, 2016b)
Pinewood Site Custodial Trust, Pinewood, SC	0.1	250	5.8E-04	SC0042170	Surface Water	(U.S. EPA, 2016b)
Safety-Kleen Systems Inc, Smithfield, KY	338	250	1.4	KY0098345	Non-POTW WWT	(U.S. EPA, 2017d)
Safety-Kleen Systems Inc, East Chicago, IN	68	250	0.3	Not available	POTW	(U.S. EPA, 2017d)
Tier Environmental LLC, Bedford, OH	30	250	0.1	Not available	POTW	(U.S. EPA, 2017d)
Tradebe Treatment & Recycling LLC, East Chicago, IN	1.4	250	5.4E-03	Not available	Non-POTW WWT	(U.S. EPA, 2017d)

POTW = Publicly-Owned Treatment Works; WWT = Wastewater Treatment

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are calculated from the annual release rate and assuming 250 days of operation per year.

Sources: (U.S. EPA, 2017d, 2016b)

2.22 Dermal Exposure Assessment

Because PCE is a volatile liquid, the dermal absorption of PCE depends on the type and duration of exposure. Where exposure is not 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.

To assess exposure, EPA used the *Dermal Exposure to Volatile Liquids Model* (see Equation 2-3) to calculate the dermal retained dose for both non-occluded and occluded scenarios. The equation modifies the *EPA/OPPT 2-Hand Dermal Exposure to Liquids Model* 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. Default PF values, which vary depending on the type of glove used and the presence of employee training program, are shown in Table 2-80:

Equation 2-3

$$D_{exp} = S \times \frac{(Q_u \times f_{abs})}{PF} \times Y_{derm} \times FT$$

Where:

S is the surface area of contact (cm^2)
Q_u is the quantity remaining on the skin (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)
PF is the glove protection factor (Default: see Table 2-80)

Table 2-80. 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

Table 2-81 presents the estimated dermal 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 work day and that 13 to 19 percent[28] of the applied dose is absorbed through the skin. The exposure estimates are provided for each condition of use, where the conditions of us 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. EPA assesses the following glove use scenarios for Bin 1 conditions of use:
  - No gloves used: Operators in these industrial uses, while working around closed-system equipment, may not wear gloves or may wear gloves for abrasion protection or gripping that are not chemical resistant.
  - Gloves used with a protection factor of 5, 10, and 20: Operators may wear chemical-resistant gloves when taking quality control samples or when connecting and disconnecting hoses during loading/unloading activities. EPA assumes gloves may offer a range of protection, depending on the type of glove and employee training provided.
- **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. EPA assesses the following glove use scenarios for Bin 2 conditions of use:
  - No gloves used: Due to the variety of shop types in these uses the actual use of gloves is uncertain. EPA assumes workers may not wear gloves or may wear gloves for abrasion protection or gripping that are not chemical resistant during routine operations such as adding and removing parts from degreasing equipment.
  - Gloves used with a protection factor of 5, 10, and 20: Workers may wear chemical-resistant gloves when charging and draining degreasing/milling equipment, drumming waste solvent, handling recycled/re-captured maskants, and removing waste sludge. EPA assumes gloves may offer a range of protection, depending on the type of glove and employee training provided.
- **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,

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[28] The absorbed fraction (f_{abs}) is a function of indoor air speed, which differs for industrial and commercial settings.

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. EPA assesses the following glove use scenarios for Bin 3 conditions of use:
    - No gloves used: Actual use of gloves in this use is uncertain. EPA assumes workers may not wear gloves or may wear gloves for abrasion protection or gripping that are not chemical resistant during routine aerosol applications.
    - Gloves used with a protection factor of 5 and 10: Workers may wear chemical-resistant gloves when applying aerosol products. EPA assumes the commercial facilities in Bin 3 do not offer activity-specific training on donning and doffing gloves.
    - Scenarios not assessed: EPA does not assess glove use with protection factors of 20 as EPA assumes chemical-resistant gloves used in these industries would either not be accompanied by training or be accompanied by basic employee training, but not activity-specific training.
- **Bin 4:** Bin 4 covers dry cleaning uses. 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. EPA assesses the following glove use scenarios for Bin 4 conditions of use:
    - No gloves used: Actual use of gloves in this use is uncertain. EPA assumes workers may not wear gloves during routine operations (e.g., spot cleaning).
    - Gloves used with a protection factor of 5 and 10: Workers may wear chemical-resistant gloves when charging and draining solvent to/from machines, removing and disposing sludge, and maintaining equipment. EPA assumes the commercial facilities in Bin 4 do not offer activity-specific training on donning and doffing gloves.
    - Scenarios not assessed: EPA does not assess glove use with protection factors of 20 as EPA assumes chemical-resistant gloves used in these industries would either not be accompanied by training or be accompanied by basic employee training, but not activity-specific training.
- **Bin 5:** Bin 5 covers commercial activities of similar maximum 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. EPA assesses the following glove use scenarios for Bin 5 conditions of use:

  - No gloves used: Actual use of gloves in this use is uncertain. EPA assumes workers may not wear gloves during routine operations (e.g., spot cleaning).
  - Gloves used with a protection factor of 5 and 10: Workers may wear chemical-resistant gloves when charging and draining solvent to/from machines, removing and disposing sludge, and maintaining equipment. EPA assumes the commercial facilities in Bin 5 do not offer activity-specific training on donning and doffing gloves.
  - Scenarios not assessed: EPA does not assess glove use with protection factors of 20 as EPA assumes chemical-resistant gloves used in these industries would either not be accompanied by training or be accompanied by basic employee training, but not activity-specific training.
- **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. EPA assesses the following glove use scenarios for Bin 6 conditions of use:
  - No gloves used: Actual use of gloves in this use is uncertain. EPA assumes workers may not wear gloves during routine operations.
  - Gloves used with a protection factor of 5, 10, and 20: Workers may wear chemical-resistant gloves when unloading the metalworking fluid from containers; transferring fluids to the trough; and performing metal shaping operations. EPA assumes gloves may offer a range of protection, depending on the type of glove and employee training provided.
- **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. EPA assesses the following glove use scenarios for Bin 7 conditions of use:
  - No gloves used: Actual use of gloves in this use is uncertain. EPA assumes workers may not wear gloves or may wear gloves for abrasion protection or gripping that are not chemical resistant during routine operations such as coating/adhesive applications and fabrication steps.
  - Gloves used with a protection factor of 5, 10, and 20 (industrial only): Workers may wear gloves when mixing coating/adhesive, charging products to application equipment (e.g., spray guns, roll applicators, etc.), and cleaning application equipment. Coating/adhesive applications may occur at both industrial and commercial facilities. EPA assumes that

commercial facilities in Bin 6 do not offer activity-specific training on donning and doffing gloves, but that the industrial facilities may offer such training.

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 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 2-81 are equal for multiple bins 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 the risk characterization section of the risk evaluation report. 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.

Table 2-81. Estimated Dermal Acute Retained Dose for Workers in All Conditions of Use

Condition of Use	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)	5.89E-02 (CT) 0.2 (HE)
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)	5.89E-02 (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	0.98	1.8 (CT) 5.3 (HE)	0.4 (CT) 1.1 (HE)	0.2 (CT) 0.5 (HE)	N/A

Condition of Use	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)
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	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)	2.35E-02 (CT) 7.06E-02 (HE)	1.18E-02 (CT) 3.53E-02 (HE)	5.89E-03 (CT) 1.77E-02 (HE)
Adhesives, Sealants, Paints, and Coatings (Industrial)	Bin 7	0.80	0.9 (CT) 2.8 (HE)	0.2 (CT) 0.6 (HE)	9.42E-02 (CT) 0.3 (HE)	4.71E-02 (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

CT = Central Tendency; HE = High-End. Equations and parameters for calculation of dermal exposures are described in Appendix K.

3 Discussion of Uncertainties and Limitations

3.1 Variability

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.

3.2 Uncertainties and Limitations

Uncertainty is "the lack of knowledge about specific variables, parameters, models, or other factors" and can be described qualitatively or quantitatively (U.S. EPA, 2001b). 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. The following sections discuss uncertainties in each of the assessed conditions of use scenarios.

3.2.1 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.

3.2.2 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 be inherently biased. 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 may have used 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 50th and 95th 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.

3.2.3 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.

3.2.3.1 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 judgement 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.

3.2.3.2 EPA AP-42 Loading Model and EPA Mass Balance Inhalation Model

For the incorporation into formulation for non-aerosol formulations assessment, the *EPA AP-42 Loading Model* and the *EPA Mass Balance Inhalation Model* were used to estimate the airborne concentration associated with loading of formulation into drums at industrial facilities. Specific uncertainties associated with these models are described below:

- The model assumes all formulated products are loaded into 55-gallon drums but does not consider the potential for loading products into smaller containers instead of or in addition to drums.
- The model assumes that the process steps associated with drum loading occurs indoors, without engineering controls, and in an open-system environment where vapors freely escape. In the absence of industry-specific information, these assumptions provide for conservative estimates for exposures during this operation. Actual exposures may be less due to various factors including closed-system loading and unloading, the use of vapor recovery systems, or the automation of various process steps.
- The model also does not consider 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.
- 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.

3.2.3.3 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.

3.2.3.4 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.

3.2.3.5 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:

- 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.

3.2.4 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.

3.2.5 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).

3.2.5.1 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.

3.2.5.2 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.

3.2.5.3 Trends in TRI

Figure 3-1 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 3-2 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 3-3 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 3-1.

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.

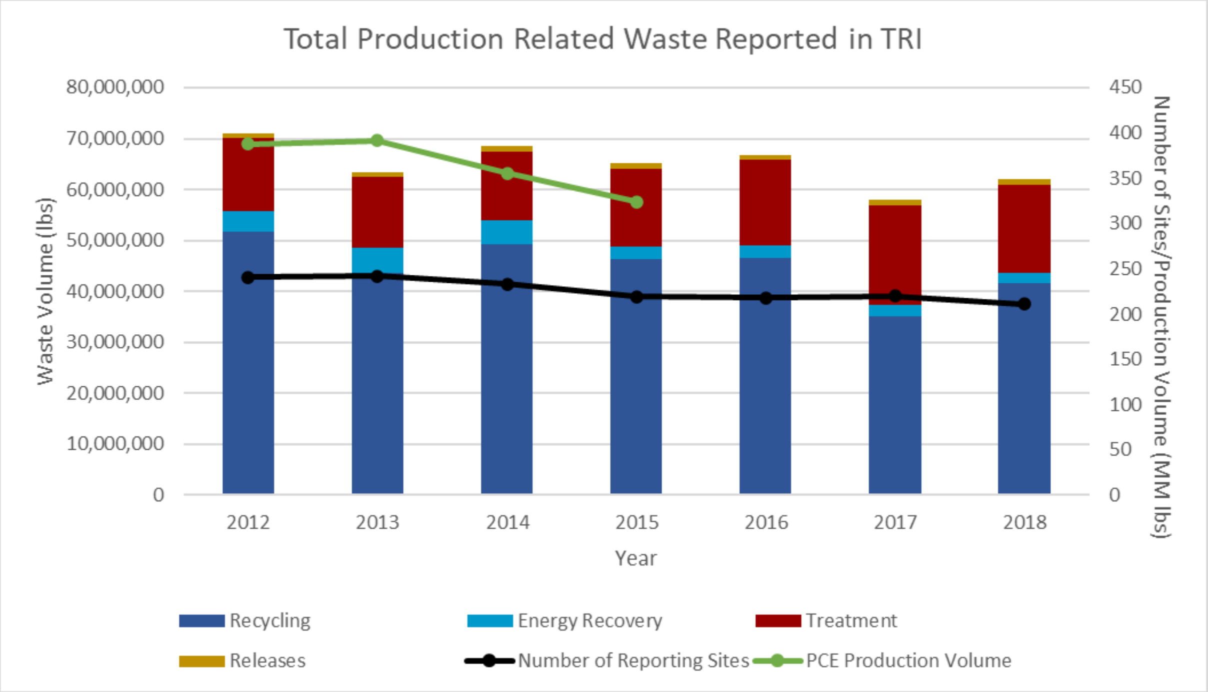

Figure 3-1. Total Production Related Waste Reported in TRI

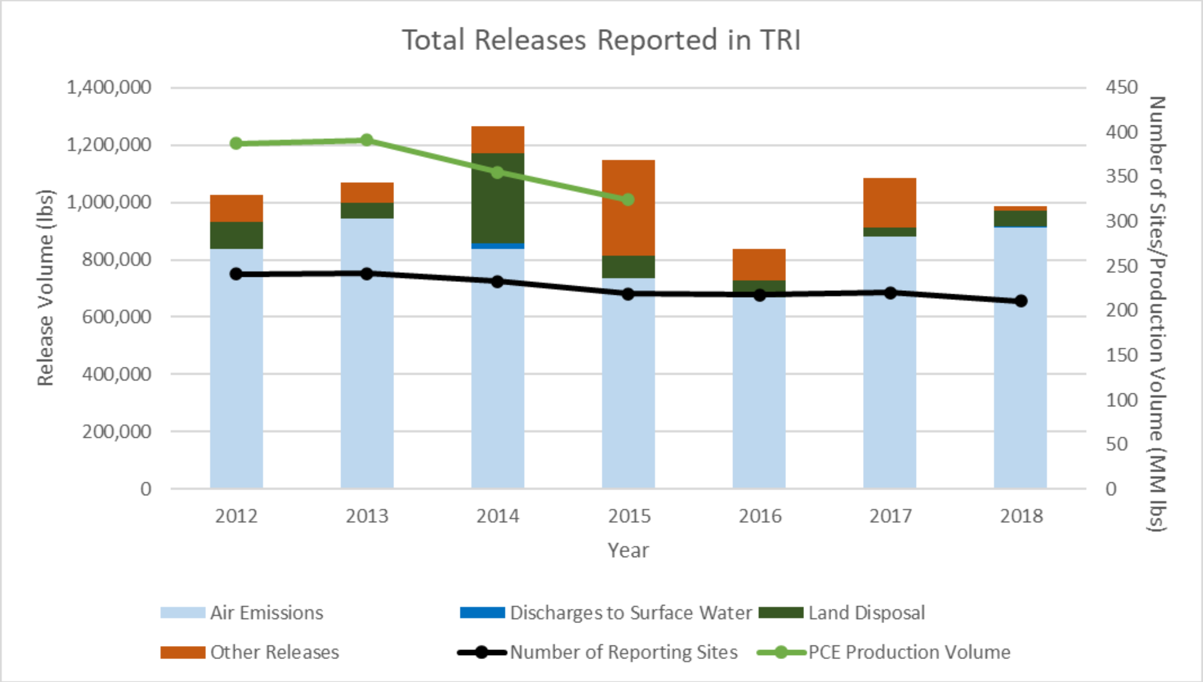

Figure 3-2. Total Releases Reported in TRI[29]

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

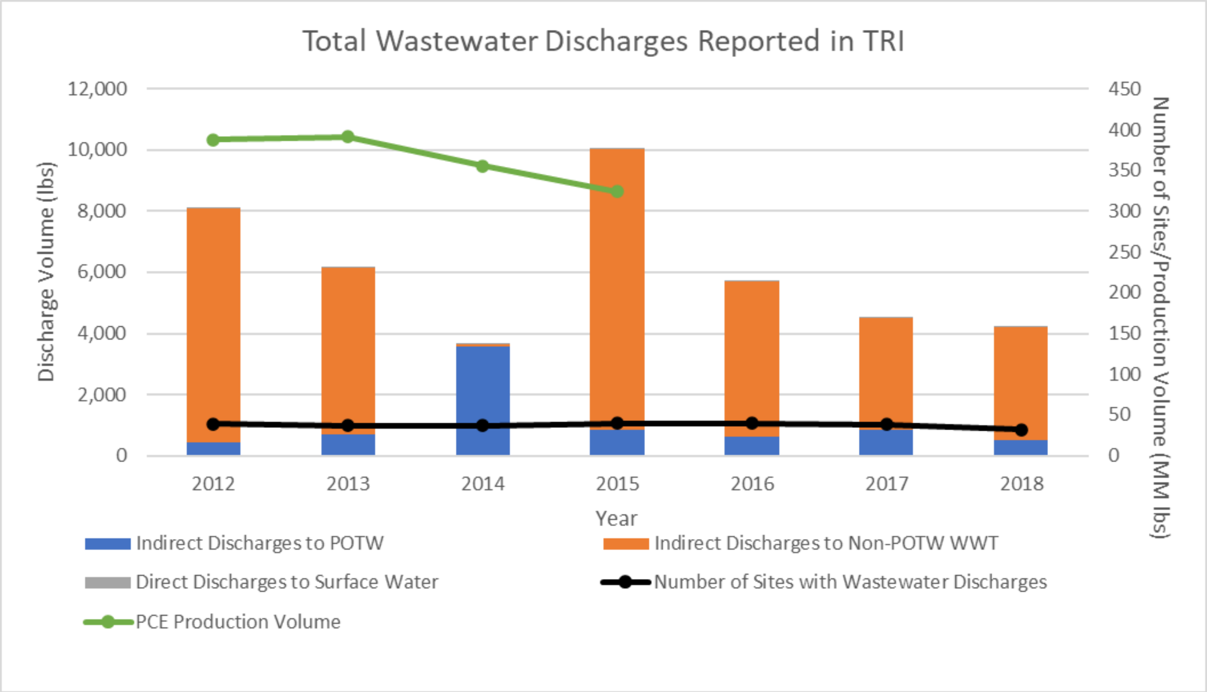


Figure 3-3. Total Wastewater Discharges Reported in TRI

Table 3-1. Results from Linear Regression Analysis of TRI Data

Data	p-Value	R2
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

3.2.5.4 Trends in DMR

Figure 3-4 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 for 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 3-5 shows the same data; however, on a different scale (Figure 3-5 is a “zoom-in” of Figure 3-4 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 3-4. 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 3-2.

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 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 surface water discharges in DMR. The total discharges for 2016 were within the range of expected values for the years analyzed.

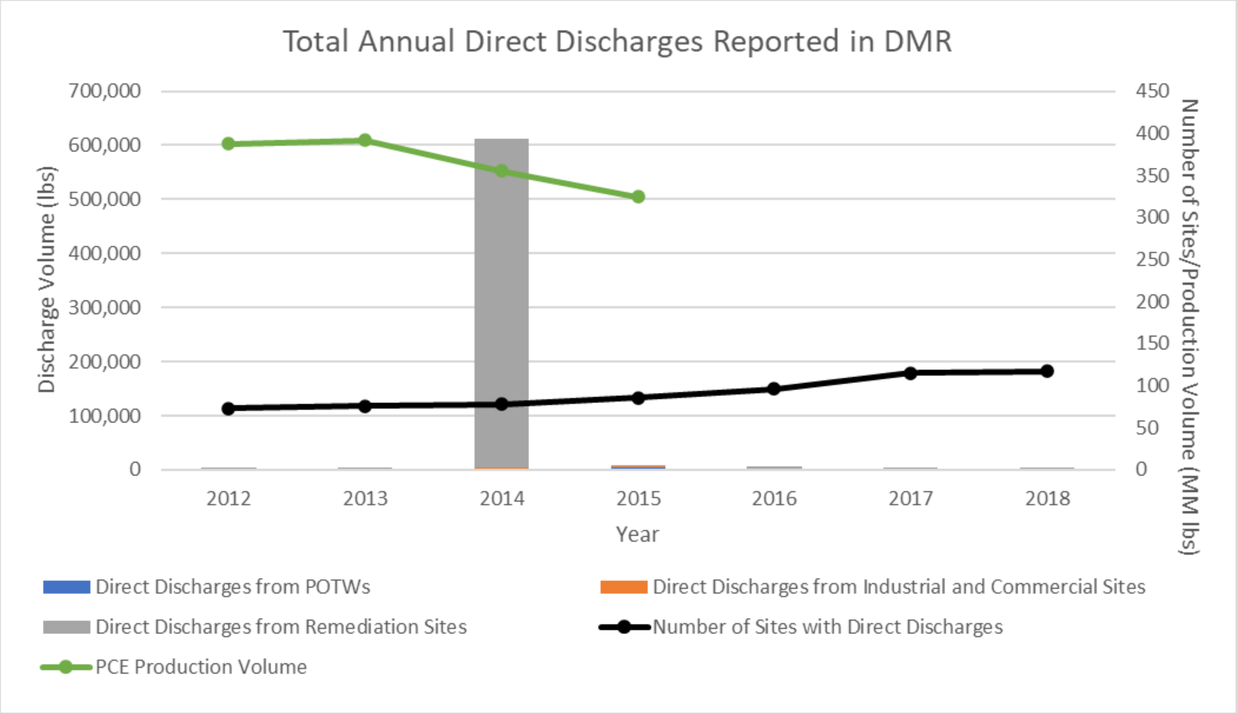
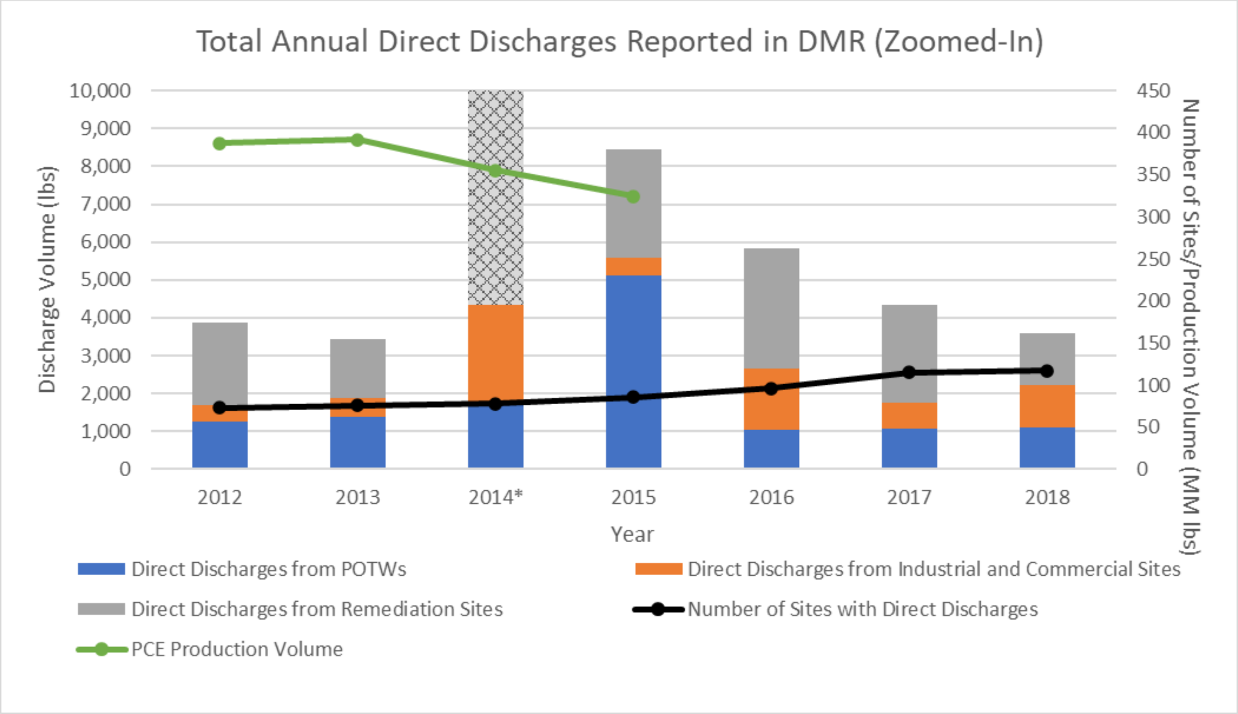


Figure 3-4. Total Annual Direct Discharges Reported in DMR



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

Figure 3-5. Zoom-in of Total Annual Direct Discharges Reported in DMR

Table 3-2. Results from Linear Regression Analysis of DMR Data

Data	p-Value	R2
Direct Discharges from All Sites	0.662	0.041
Direct Discharges from Industrial and Commercial Sites	0.764	0.020

3.2.5.5 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.

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Appendix A Approach for Estimating Number of Workers and Occupational Non-Users

This appendix summarizes the methods that EPA used to estimate the number of workers who are potentially exposed to PCE in each of its conditions of use. The method consists of the following steps:

1. Identify the North American Industry Classification System (NAICS) codes for the industry sectors associated with each condition of use.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics (OES) data (U.S. BLS, 2016).
3. Refine the OES estimates where they are not sufficiently granular by using the U.S. Census Bureau (2015) Statistics of U.S. Businesses (SUSB) data on total employment by 6-digit NAICS.
4. Estimate the percentage of employees likely to be using PCE instead of other chemicals (i.e., the market penetration of PCE in the condition of use).
5. Estimate the number of sites and number of potentially exposed employees per site.
6. Estimate the number of potentially exposed employees within the condition of use.

Step 1: Identifying Affected NAICS Codes

As a first step, EPA identified NAICS industry codes associated with each condition of use. EPA generally identified NAICS industry codes for a condition of use by:

- Querying the U.S. Census Bureau's *NAICS Search* tool using keywords associated with each condition of use to identify NAICS codes with descriptions that match the condition of use.
- Referencing EPA Generic Scenarios (GS's) and Organisation for Economic Co-operation and Development (OECD) Emission Scenario Documents (ESDs) for a condition of use to identify NAICS codes cited by the GS or ESD.
- Reviewing Chemical Data Reporting (CDR) data for the chemical, identifying the industrial sector codes reported for downstream industrial uses, and matching those industrial sector codes to NAICS codes using Table D-2 provided in the CDR reporting instructions.

Each condition of use section in the main body of this report identifies the NAICS codes EPA identified for the respective condition of use.

Step 2: Estimating Total Employment by Industry and Occupation

U.S. BLS (2016) OES data provide employment data for workers in specific industries and occupations. The industries are classified by NAICS codes (identified previously), and occupations are classified by Standard Occupational Classification (SOC) codes.

Among the relevant NAICS codes (identified previously), EPA reviewed the occupation description and identified those occupations (SOC codes) where workers are potentially exposed to PCE. Table_Apx A-1 shows the SOC codes EPA classified as occupations potentially exposed to PCE. These occupations are classified into workers (W) and occupational non-users (O). All other SOC codes are assumed to represent occupations where exposure is unlikely.

Table_Apx A-1. SOCs with Worker and ONU Designations for All Conditions of Use Except Dry Cleaning

SOC	Occupation	Designation
11-9020	Construction Managers	O
17-2000	Engineers	O
17-3000	Drafters, Engineering Technicians, and Mapping Technicians	O
19-2031	Chemists	O
19-4000	Life, Physical, and Social Science Technicians	O
47-1000	Supervisors of Construction and Extraction Workers	O
47-2000	Construction Trades Workers	W
49-1000	Supervisors of Installation, Maintenance, and Repair Workers	O
49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	W
49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	W
49-9010	Control and Valve Installers and Repairers	W
49-9020	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	W
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9060	Precision Instrument and Equipment Repairers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-1000	Supervisors of Production Workers	O
51-2000	Assemblers and Fabricators	W
51-4020	Forming Machine Setters, Operators, and Tenders, Metal and Plastic	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W
51-6030	Sewing Machine Operators	O
51-6040	Shoe and Leather Workers	O
51-6050	Tailors, Dressmakers, and Sewers	O
51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O
51-8020	Stationary Engineers and Boiler Operators	W
51-8090	Miscellaneous Plant and System Operators	W
51-9000	Other Production Occupations	W

W = worker designation
O = ONU designation

For dry cleaning facilities, due to the unique nature of work expected at these facilities and that different workers may be expected to share among activities with higher exposure potential (e.g., unloading the dry cleaning machine, pressing/finishing a dry cleaned load), EPA made different SOC code worker and ONU assignments for this condition of use. Table_Apx A-2 summarizes the SOC codes with worker and ONU designations used for dry cleaning facilities.

Table_Apx A-2. SOCs with Worker and ONU Designations for Dry Cleaning Facilities

SOC	Occupation	Designation
41-2000	Retail Sales Workers	O
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W
51-6030	Sewing Machine Operators	O
51-6040	Shoe and Leather Workers	O
51-6050	Tailors, Dressmakers, and Sewers	O
51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O

W = worker designation
O = ONU designation

After identifying relevant NAICS and SOC codes, EPA used BLS data to determine total employment by industry and by occupation based on the NAICS and SOC combinations. For example, there are 110,640 employees associated with 4-digit NAICS 8123 (*Drycleaning and Laundry Services*) and SOC 51-6010 (*Laundry and Dry-Cleaning Workers*).

Using a combination of NAICS and SOC codes to estimate total employment provides more accurate estimates for the number of workers than using NAICS codes alone. Using only NAICS codes to estimate number of workers typically result in an overestimate, because not all workers employed in that industry sector will be exposed. However, in some cases, BLS only provide employment data at the 4-digit or 5-digit NAICS level; therefore, further refinement of this approach may be needed (see next step).

Step 3: Refining Employment Estimates to Account for lack of NAICS Granularity

The third step in EPA's methodology was to further refine the employment estimates by using total employment data in the U.S. Census Bureau (2015) SUSB. In some cases, BLS OES's occupation-specific data are only available at the 4-digit or 5-digit NAICS level, whereas the SUSB data are available at the 6-digit level (but are not occupation-specific). Identifying specific 6-digit NAICS will ensure that only industries with potential PCE exposure are included. As an example, OES data are available for the 4-digit NAICS 8123 *Drycleaning and Laundry Services*, which includes the following 6-digit NAICS:

- NAICS 812310 Coin-Operated Laundries and Drycleaners;
- NAICS 812320 Drycleaning and Laundry Services (except Coin-Operated);
- NAICS 812331 Linen Supply; and
- NAICS 812332 Industrial Launderers.

In this example, only NAICS 812320 is of interest. The Census data allow EPA to calculate employment in the specific 6-digit NAICS of interest as a percentage of employment in the BLS 4-digit NAICS.

The 6-digit NAICS 812320 comprises 46 percent of total employment under the 4-digit NAICS 8123. This percentage can be multiplied by the occupation-specific employment estimates given in the BLS OES data to further refine our estimates of the number of employees with potential exposure.

Table_Apx A-3 illustrates this granularity adjustment for NAICS 812320.

Table_Apx A-3. Estimated Number of Potentially Exposed Workers and ONUs under NAICS 812320

NAICS	SOC Code	SOC Description	Occupation Designation	Employment by SOC at 4-digit NAICS level	% of Total Employment	Estimated Employment by SOC at 6-digit NAICS level
8123	41-2000	Retail Sales Workers	O	44,500	46.0%	20,459
8123	49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W	1,790	46.0%	823
8123	49-9070	Maintenance and Repair Workers, General	W	3,260	46.0%	1,499
8123	49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W	1,080	46.0%	497
8123	51-6010	Laundry and Dry-Cleaning Workers	W	110,640	46.0%	50,867
8123	51-6020	Pressers, Textile, Garment, and Related Materials	W	40,250	46.0%	18,505
8123	51-6030	Sewing Machine Operators	O	1,660	46.0%	763
8123	51-6040	Shoe and Leather Workers	O	Not Reported for this NAICS Code		
8123	51-6050	Tailors, Dressmakers, and Sewers	O	2,890	46.0%	1,329
8123	51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O	0	46.0%	0
Total Potentially Exposed Employees				**206,070**		**94,740**
Total Workers						**72,190**
Total Occupational Non-Users						**22,551**

Note: numbers may not sum exactly due to rounding.
W = worker
O = occupational non-user
Source: (U.S. BLS, 2016; U.S. Census Bureau, 2015)

Step 4: Estimating the Percentage of Workers Using PCE Instead of Other Chemicals

In the final step, EPA accounted for the market share by applying a factor to the number of workers determined in Step 3. This accounts for the fact that PCE may be only one of multiple chemicals used for the applications of interest. EPA only identified market penetration data for a limited number of conditions of use. In the absence of market penetration data for a given condition of use, EPA assumed PCE may be used at up to all sites and by up to all workers calculated in this method as a bounding estimate. This assumes a market penetration of 100%. Market penetration is discussed for each condition of use in the main body of this report.

Step 5: Estimating the Number of Workers per Site

EPA calculated the number of workers and occupational non-users in each industry/occupation combination using the formula below (granularity adjustment is only applicable where SOC data are not available at the 6-digit NAICS level):

Number of Workers or ONUs in NAICS/SOC (Step 2) × Granularity Adjustment Percentage (Step 3) = Number of Workers or ONUs in the Industry/Occupation Combination

EPA then estimated the total number of establishments by obtaining the number of establishments reported in the U.S. Census Bureau (2015) SUSB data at the 6-digit NAICS level.

EPA then summed the number of workers and occupational non-users over all occupations within a NAICS code and divided these sums by the number of establishments in the NAICS code to calculate the average number of workers and occupational non-users per site.

Step 6: Estimating the Number of Workers and Sites for a Condition of Use

EPA estimated the number of workers and occupational non-users potentially exposed to PCE and the number of sites that use PCE in a given condition of use through the following steps:

6.A. Obtaining the total number of establishments by:
   i. Obtaining the number of establishments from SUSB (U.S. Census Bureau, 2015) at the 6-digit NAICS level (Step 5) for each NAICS code in the condition of use and summing these values; or
   ii. Obtaining the number of establishments from the Toxics Release Inventory (TRI), Discharge Monitoring Report (DMR) data, National Emissions Inventory (NEI), or literature for the condition of use.

6.B. Estimating the number of establishments that use PCE by taking the total number of establishments from Step 6.A and multiplying it by the market penetration factor from Step 4.

6.C. Estimating the number of workers and occupational non-users potentially exposed to PCE by taking the number of establishments calculated in Step 6.B and multiplying it by the average number of workers and occupational non-users per site from Step 5.

Appendix B Equations for Calculating Acute and Chronic (Non-Cancer and Cancer) Inhalation Exposures

This report assesses PCE exposures to workers in occupational settings, presented as 8-hr time weighted average (TWA). The 8-hr TWA exposures are then used to calculate acute exposure (AC), average daily concentration (ADC) for chronic, non-cancer risks, and lifetime average daily concentration (LADC) for chronic, cancer risks.

Acute workplace exposures are assumed to be equal to the contaminant concentration in air (8-hr TWA), per Equation_Apx B-1.

Equation_Apx B-1

$$AC = \frac{C \times ED}{AT_{acute}}$$

Where:

AC = acute exposure concentration
C = contaminant concentration in air (TWA)
ED = exposure duration (hr/day)
AT_{acute} = acute averaging time (hr)

ADC and LADC are used to estimate workplace exposures for non-cancer and cancer risks, respectively. These exposures are estimated as follows:

Equation_Apx B-2

$$\mathrm{ADC\ or\ LADC} = \frac{\mathrm{C \times ED \times EF \times WY}}{\mathrm{AT\ or\ AT_c}}$$

Equation_Apx B-3

$$\mathrm{AT} = \mathrm{WY} \times 365\,\frac{\mathrm{day}}{\mathrm{yr}} \times 24\,\frac{\mathrm{hr}}{\mathrm{day}}$$

Equation_Apx B-4

$$\mathrm{AT_C} = \mathrm{LT} \times 365\,\frac{\mathrm{day}}{\mathrm{yr}} \times 24\,\frac{\mathrm{hr}}{\mathrm{day}}$$

Where:

ADC = Average daily concentration used for chronic non-cancer risk calculations
LADC = Lifetime average daily concentration used for chronic cancer risk calculations
ED = Exposure duration (hr/day)
EF = Exposure frequency (day/yr)
WY = Working years per lifetime (yr)
AT = Averaging time (hr) for chronic, non-cancer risk
AT_C = Averaging time (hr) for cancer risk
AWD = Annual working days (day/yr)
f = Fractional working days with exposure (unitless)
LT = Lifetime years (yr) for cancer risk

The parameter values in Table_Apx B-1 are used to calculate each of the above acute or chronic exposure estimates. Where exposure is calculated using probabilistic modeling, the AC, ADC, and LADC calculations are integrated into the Monte Carlo simulation. Where multiple values are provided for ED and EF, it indicates that EPA may have used different values for different conditions of use. The rationale for these differences are described below in this section.

Table_Apx B-1. Parameter Values for Calculating Inhalation Exposure Estimates

Parameter Name	Symbol	Value	Unit
Exposure Duration	ED	8 or 12	hr/day
Exposure Frequency	EF	250 258 (50th percentile) to 293 (95th percentile) (dry cleaning only) 125 to 150 (DoD – oil analysis only) 30 to 36 (DoD – water pipe repair only)	days/yr
Working years	WY	31 (50th percentile) 40 (95th percentile)	years
Lifetime Years, cancer	LT	78	years
Averaging Time, non-cancer	AT	271,560 (central tendency)[a] 350,400 (high-end)[b]	hr
Averaging Time, cancer	AT_c	683,280	hr

[a] Calculated using the 50th percentile value for working years (WY)
[b] Calculated using the 95th percentile value for working years (WY)

Exposure Duration (ED)

EPA generally uses an exposure duration of 8 hours per day for averaging full-shift exposures with two notable exceptions: manufacturing and results from the Dry Cleaning Multi-Zone Inhalation Exposure Model. In the manufacturing data there were both 8-hr TWA and 12-hr TWA monitoring data. EPA used an ED of 8 hours for the 8-hr TWA data and 12 hours for the 12-hr TWA data. For dry cleaning, the monitoring data were generally 8-hr TWAs; therefore, EPA used an ED of 8 hours. However, EPA assumes dry cleaners may operate up to 12 hours per day; therefore, when modeling dry cleaning exposures using the multi-zone model, EPA modeled assuming an ED of 12 hours.

Exposure Frequency (EF)

EPA generally uses an exposure frequency of 250 days per year with three notable exceptions: OES with 12-hr shifts, dry cleaning and DoD uses. For OES with 12-hr shifts, EPA assumed employees would work the same number of hours per year as an 8-hr shift employee (2,000 hrs at 250 days/yr) which resulted an estimate of 167 days/yr for 12-hr shift employees. EPA assumed dry cleaners may operate between five and six days per week and 50 to 52 weeks per year resulting in a range of 250 to 312 annual working days per year (AWD). Taking into account fractional days exposed (f) resulted in an exposure frequency (EF) of 258 at the 50th percentile and 293 at the 95th percentile. For the two DoD uses, information was provided indicating process frequencies of two to three times per week (oil analysis) and two to three times per month (water pipe repair). EPA used the maximum frequency for high-end estimates and the midpoint frequency for central tendency estimates. For the oil analysis use this resulted in 125 days/yr at the central tendency and 150 days/yr at the high-end. For the water pipe repair, this resulted in 30 days/yr at the central tendency and 36 days/yr at the high-end.

EF is expressed as the number of days per year a worker is exposed to the chemical being assessed. In some cases, it may be reasonable to assume a worker is exposed to the chemical on each working day. In other cases, it may be more appropriate to estimate a worker's exposure to the chemical occurs during a subset of the worker's annual working days. The relationship between exposure frequency and annual working days can be described mathematically as follows:

Equation_Apx B-5

$$EF = f \times AWD$$

Where:

EF = exposure frequency, the number of days per year a worker is exposed to the chemical (day/yr)
f = fractional number of annual working days during which a worker is exposed to the chemical (unitless)
AWD = annual working days, the number of days per year a worker works (day/yr)

U.S. BLS (2016) provides data on the total number of hours worked and total number of employees by each industry NAICS code. These data are available from the 3- to 6-digit NAICS level (where 3-digit NAICS are less granular and 6-digit NAICS are the most granular). Dividing the total, annual hours worked by the number of employees yields the average number of hours worked per employee per year for each NAICS.

EPA has identified approximately 140 NAICS codes applicable to the multiple conditions of use for the ten chemicals undergoing risk evaluation. For each NAICS code of interest, EPA looked up the average hours worked per employee per year at the most granular NAICS level available (i.e., 4-digit, 5-digit, or 6-digit). EPA converted the working hours per employee to working days per year per employee assuming employees work an average of eight hours per day. The average number of days per year worked, or AWD, ranges from 169 to 282 days per year, with a 50th percentile value of 250 days per year. EPA repeated this analysis for all NAICS codes at the 4-digit level. The average AWD for all 4-digit NAICS codes ranges from 111 to 282 days per year, with a 50th percentile value of 228 days per year. 250 days per year is approximately the 75th percentile. In the absence of industry- and PCE-specific data, EPA assumes the parameter *f* is equal to one for all conditions of use except dry cleaning.

Dry cleaning used a uniform distribution from 0.8 to 1 for *f*. The 0.8 value was derived from the observation that the weighted average of 200 day/yr worked (from BLS/Census) is 80% of the standard assumption that a full-time worker works 250 day/yr. The maximum of 1 is appropriate as dry cleaners may be family owned and operated and some workers may work as much as every operating day.

Working Years (WY)

EPA has developed a triangular distribution for working years. EPA has defined the parameters of the triangular distribution as follows:

- Minimum value: BLS CPS tenure data with current employer as a low-end estimate of the number of lifetime working years: 10.4 years;
- Mode value: The 50th percentile tenure data with all employers from SIPP as a mode value for the number of lifetime working years: 36 years; and
- Maximum value: The maximum average tenure data with all employers from SIPP as a high-end estimate on the number of lifetime working years: 44 years.

This triangular distribution has a 50th percentile value of 31 years and a 95th percentile value of 40 years. EPA uses these values for central tendency and high-end ADC and LADC calculations, respectively.

The U.S. BLS (2014) provides information on employee tenure with *current employer* obtained from the Current Population Survey (CPS). CPS is a monthly sample survey of about 60,000 households that provides information on the labor force status of the civilian non-institutional population age 16 and over; CPS data are released every two years. The data are available by demographics and by generic industry sectors but are not available by NAICS codes.

The U.S. Census Bureau (2019a) Survey of Income and Program Participation (SIPP) provides information on *lifetime tenure with all employers*. SIPP is a household survey that collects data on income, labor force participation, social program participation and eligibility, and general demographic characteristics through a continuous series of national panel surveys of between 14,000 and 52,000 households (U.S. Census Bureau, 2019b). EPA analyzed the 2008 SIPP Panel Wave 1, a panel that began in 2008 and covers the interview months of September 2008 through December 2008 (U.S. Census Bureau, 2019a, b). For this panel, lifetime tenure data are available by Census Industry Codes, which can be cross-walked with NAICS codes.

SIPP data include fields for the industry in which each surveyed, employed individual works (TJBIND1), worker age (TAGE), and years of work experience *with all employers* over the surveyed individual's lifetime.[30] Census household surveys use different industry codes than the NAICS codes used in its firm surveys, so these were converted to NAICS using a published crosswalk (U.S. Census Bureau, 2013). EPA calculated the average tenure for the following age groups: 1) workers age 50 and older; 2) workers age 60 and older; and 3) workers of all ages employed at time of survey. EPA used

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[30] To calculate the number of years of work experience EPA took the difference between the year first worked (TMAKMNYR) and the current data year (i.e., 2008). EPA then subtracted any intervening months when not working (ETIMEOFF).

tenure data for age group “50 and older” to determine the high-end lifetime working years, because the sample size in this age group is often substantially higher than the sample size for age group “60 and older”. For some industries, the number of workers surveyed, or the *sample size*, was too small to provide a reliable representation of the worker tenure in that industry. Therefore, EPA excluded data where the sample size is less than five from our analysis.

Table_Apx B-2 summarizes the average tenure for workers age 50 and older from SIPP data. Although the tenure may differ for any given industry sector, there is no significant variability between the 50th and 95th percentile values of average tenure across manufacturing and non-manufacturing sectors.

Table_Apx B-2. Overview of Average Worker Tenure from U.S. Census SIPP (Age Group 50+)

Industry Sectors	Working Years			
	Average	50th Percentile	95th Percentile	Maximum
All industry sectors relevant to the 10 chemicals undergoing risk evaluation	35.9	36	39	44
Manufacturing sectors (NAICS 31-33)	35.7	36	39	40
Non-manufacturing sectors (NAICS 42-81)	36.1	36	39	44

Source: (U.S. Census Bureau, 2019a)
Note: Industries where sample size is less than five are excluded from this analysis.

BLS CPS data provides the median years of tenure that wage and salary workers had been with their current employer. Table_Apx B-3 presents CPS data for all demographics (men and women) by age group from 2008 to 2012. To estimate the low-end value on number of working years, EPA uses the most recent (2014) CPS data for workers age 55 to 64 years, which indicates a median tenure of 10.4 years with their current employer. The use of this low-end value represents a scenario where workers are only exposed to the chemical of interest for a portion of their lifetime working years, as they may change jobs or move from one industry to another throughout their career.

Table_Apx B-3. Median Years of Tenure with Current Employer by Age Group

Age	January 2008	January 2010	January 2012	January 2014
16 years and over	4.1	4.4	4.6	4.6
16 to 17 years	0.7	0.7	0.7	0.7
18 to 19 years	0.8	1.0	0.8	0.8
20 to 24 years	1.3	1.5	1.3	1.3
25 years and over	5.1	5.2	5.4	5.5
25 to 34 years	2.7	3.1	3.2	3.0
35 to 44 years	4.9	5.1	5.3	5.2
45 to 54 years	7.6	7.8	7.8	7.9
55 to 64 years	9.9	10.0	10.3	10.4
65 years and over	10.2	9.9	10.3	10.3

Source: (U.S. BLS, 2014)

Lifetime Years (LT)

EPA assumes a lifetime of 78 years for all worker demographics.

Appendix C Sample Calculations for Calculating Acute and Chronic (Non-Cancer and Cancer) Inhalation Exposures

Sample calculations for high-end and central tendency acute and chronic (non-cancer and cancer) exposure concentrations for one condition of use, manufacturing, are demonstrated below. The explanation of the equations and parameters used is provided in Appendix B.

C.1 Example High-End AC, ADC, and LADC Calculations

Calculate AC_{HE}:

$$AC_{HE} = \frac{C_{HE} \times ED}{AT_{acute}}$$

$$AC_{HE} = \frac{2.61\ ppm \times 8\ hr/day}{24\ hr/day} = 0.87\ ppm$$

Calculate ADC_{HE}:

$$ADC_{HE} = \frac{C_{HE} \times ED \times EF \times WY}{AT}$$

$$ADC_{HE} = \frac{2.61\ ppm \times 8\frac{hr}{day} \times 250\frac{days}{year} \times 40\ years}{40\ years \times 365\frac{days}{yr} \times 24\frac{hr}{day}} = 0.60\ ppm$$

Calculate $LADC_{HE}$:

$$LADC_{HE} = \frac{C_{HE} \times ED \times EF \times WY}{AT_c}$$

$$LADC_{HE} = \frac{2.61\ ppm \times 8\frac{hr}{day} \times 250\frac{days}{year} \times 40\ years}{78\ years \times 365\frac{days}{year} \times 24\ hr/day} = 0.31\ ppm$$

C.2 Example Central Tendency AC, ADC, and LADC Calculations

Calculate AC_{CT}:

$$AC_{CT} = \frac{C_{CT} \times ED}{AT_{acute}}$$

$$AC_{CT} = \frac{0.03\ ppm \times 8\ hr/day}{24\ hr/day} = 0.01\ ppm$$

Calculate ADC_{CT}:

$$ADC_{CT} = \frac{C_{CT} \times ED \times EF \times WY}{AT}$$

$$ADC_{CT} = \frac{0.03\ ppm \times 8\,\frac{hr}{day} \times 250\,\frac{days}{year} \times 31\ years}{31\ years \times 365\,\frac{days}{yr} \times 24\,\frac{hr}{day}} = 0.01\ ppm$$

Calculate $LADC_{CT}$:

$$LADC_{CT} = \frac{C_{CT} \times ED \times EF \times WY}{AT_c}$$

$$LADC_{CT} = \frac{0.03\ ppm \times 8\,\frac{hr}{day} \times 250\,\frac{days}{year} \times 31\ years}{78\ years \times 365\,\frac{days}{year} \times 24\ hr/day} = 2.95 \times 10^{-3}\ ppm$$

Appendix D Approach for Estimating Water Releases from Manufacturing Sites Using Effluent Guidelines

This appendix presents a methodology for estimating water releases of PCE from manufacturing sites using effluent guidelines (EGs). This method uses the maximum daily and maximum average monthly concentrations allowed under the Organic Chemicals, Plastics and Synthetic Fibers (OCPSF) Effluent Guidelines and Standards (U.S. EPA, 1987). EGs are national regulatory standards set forth by EPA for wastewater discharges to surface water and municipal sewage treatment plants. The OCPSF EG applies to facilities classified under the following SIC codes:

- 2821—Plastic Materials, Synthetic Resins, and Nonvulcanizable Elastomers;
- 2823—Cellulosic Man-Made Fibers;
- 2865—Cyclic Crudes and Intermediates, Dyes, and Organic Pigments; and
- 2869—Industrial Organic Chemicals, Not Elsewhere Classified.

Manufacturers of PCE would typically be classified under SIC code 2869; therefore, the requirements of the OCPSF EG are assumed to apply to manufacturing sites. Subparts I, J, and K of the OCPSF EG set limits for the concentration of PCE in wastewater effluent for industrial facilities that are direct discharge point sources using end-of-pipe biological treatment, direct discharge point sources that do not use end-of-pipe biological treatment, and indirect discharge point sources, respectively (U.S. EPA, 1987). Direct dischargers are facilities that discharge effluent directly to surface waters and indirect dischargers are facilities that discharge effluent to publicly-owned treatment works (POTW). The OCPSF limits for PCE in each of the Subparts are provided in Table_Apx D-1.

Table_Apx D-1. Summary of OCPSF Effluent Guidelines for Perchloroethylene

OCPSF Subpart	Maximum for Any One Day (µg/L)	Maximum for Any Monthly Average (µg/L)	Basis
Subpart I – Direct Discharge Point Sources That Use End-of-Pipe Biological Treatment	56	22	BAT effluent limitations and NSPS
Subpart J – Direct Discharge Point Sources That Do Not Use End-of-Pipe Biological Treatment	164	52	BAT effluent limitations and NSPS
Subpart K – Indirect Discharge Point Sources	164	52	Pretreatment Standards for Existing Sources (PSES) and Pretreatment Standards for New Sources (PSNS)

BAT = Best Available Technology Economically Achievable; NSPS = New Source Performance Standards; PSES = Pretreatment Standards for Existing Sources; PSNS = Pretreatment Standards for New Sources.
Source: (U.S. EPA, 1987)

To estimate daily releases from the EG, EPA used Equation_Apx D-1 to estimate daily releases and Equation_Apx D-2 to estimate annual releases using the parameters in Table_Apx D-2. The prevalence of end-of-pipe biological treatment is unknown; therefore, EPA used the discharge limits for direct discharge point sources that do not use end-of-pipe biological treatment (Subpart J) and indirect discharge point sources (Subpart K). EPA estimated a central tendency daily release using the limit for the maximum monthly average (52 µg/L) from Subparts J and K, a high-end daily release using the limit for the maximum for any one day (164 µg/L) from Subparts J and K, and an annual release using the maximum monthly average from Subparts J and K.

Equation_Apx D-1

$$DR = \frac{DL \times PW \times PV}{1{,}000{,}000{,}000 \times OD}$$

Equation_Apx D-2

$$AR = \frac{DL \times PW \times PV}{1{,}000{,}000{,}000}$$

Table_Apx D-2. Default Parameters for Estimating Water Releases of Perchloroethylene from Manufacturing Sites

Parameter	Parameter Description	Default Value	Unit
DR	Daily release rate	Calculated from equation	kg/site-day
DL	Discharge limit[a]	Max Daily: 164 Average Daily: 52 Annual: 52	µg/L
PW	Produced water[b]	10	L/kg
PV	Annual PCE production volume	Site-specific	kg/site-yr
OD	Operating Days[c]	350	days/yr
AR	Annual release rate	Calculated from equation	kg/site-yr

[a] Discharge limits are based on the maximum discharge limits allowed in the OCPSF EG, which correspond to the discharge limits for direct discharge point sources with no biological end-of-pipe treatment (Subpart J) and indirect discharge points sources (Subpart K) (citation for 40 C.F.R. 414). There is no “average” daily discharge limit set by the EGs; therefore, EPA assumed that the average daily discharge concentration would be equal to the maximum monthly average discharge limit.

[b] The amount of produced water per kilogram of PCE produced is based on the SpERC developed by the European Solvent Industry Group for the manufacture of a substance, which estimates 10 m^3 of wastewater generated per metric ton of substance produced and converted to 10 L/kg (European Solvents Industry Group, 2012).

[c] Due to large throughput, manufacturing sites are assumed to operate seven days per week and 50 weeks per year with two weeks per year for shutdown activities.

EPA did not identify PCE-specific information on the amount of wastewater produced per day. The Specific Environmental Release Category (SpERC) developed by the European Solvent Industry Group for the manufacture of a substance estimates 10 m^3 of wastewater generated per metric ton of substance produced (equivalent to 10 L water/kg of substance produced) (European Solvents Industry Group, 2012). In lieu of PCE-specific information, EPA estimated wastewater flow using the SpERC specified wastewater production volume and the annual PCE production rates for each facility. Table_Apx D-3 provides estimated daily production volume and wastewater flow for each facility that EPA used the EG to assess water releases.

Table_Apx D-3. Summary of Facility Perchloroethylene Production Volumes and Wastewater Flow Rates

Site	Annual Production Volume (kg/site-yr)	Annual Operating Days (days/yr)	Daily Production Volume (kg/site-day)	Daily Wastewater Flow (L/site-day)
Axiall Corporation, Westlake, LA[a]	20,743,859	350	59,268	592,682
Greenchem, West Palm Beach, FL[a]	20,743,859	350	59,268	592,682
Solvents & Chemicals, Pearland, TX[b]	59,626	350	170	1,704
Univar USA Inc, Redmond, WA[a]	20,743,859	350	59,268	592,682

[a] The 2015 annual production volumes in the 2016 CDR for these sites was either claimed as CBI or withheld. EPA estimate the production volume by subtracting known site production volumes from the national production volume and averaging the result over all the sites with CBI or withheld production volumes and converting from pounds to kilograms.
[b] Annual production volume for this site is based on the 2015 production volume reported in the 2016 CDR and converting from pounds to kilograms.

EPA estimated both a maximum daily release and an average daily release using the OCPSF EG limits for PCE for maximum on any one day and maximum for any monthly average, respectively. Prevalence of end-of-pipe biological treatment at PCE manufacturing sites is unknown; therefore, EPA used limits for direct discharges with no end-of-pipe biological treatment and indirect dischargers as conservative. EPA estimated annual releases from the average daily release and assuming 350 days/yr of operation.

Example max daily, average daily, and annual water release calculations for PCE at manufacturing sites based on the estimated production volume for Axiall Corporation (45,732,418 lbs/yr or 20,743,859 kg/yr)[31]:

$$Max\ DR = \frac{164\,\frac{\mu g}{L} \times 10\,\frac{L}{kg} \times 20{,}743{,}859\,\frac{kg}{yr}}{1{,}000{,}000{,}000\,\frac{\mu g}{kg} \times 350\,\frac{days}{yr}} = 0.10\,\frac{kg}{day}$$

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[31] This estimated production volume is equal to the estimated production volume assessed for Greeenchem and Univar USA Inc.

$$Average\ DR = \frac{52\,\frac{\mu g}{L} \times 10\,\frac{L}{kg} \times 20{,}743{,}859\,\frac{kg}{yr}}{1{,}000{,}000{,}000\,\frac{\mu g}{kg} \times 350\,\frac{days}{yr}} = 0.03\ \frac{kg}{day}$$

$$AR = \frac{52\,\frac{\mu g}{L} \times 10\,\frac{L}{kg} \times 20{,}743{,}859\,\frac{kg}{yr}}{1{,}000{,}000{,}000\,\frac{\mu g}{kg}} = 10.79\,\frac{kg}{yr}$$

Appendix E Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model Approach and Parameters

This appendix presents the modeling approach and model equations used in the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model. The model was developed through review of relevant literature and consideration of existing EPA exposure models. The model approach is a generic inhalation exposure assessment at industrial facilities that is applicable for any volatile chemical with the following conditions of use:

- Manufacture (loading of chemicals into containers);
- Processing as a reactant/intermediate (unloading of chemicals);
- Processing into formulation, mixture, or reaction products;
- Import (repackaging); and
- Other similar conditions of use at industrial facilities (e.g., industrial processing aid).

As an example, PCE at a manufacturing facility is expected to be packaged and loaded into a container before distributing to another industrial processing or use site (e.g., formulation sites, sites using PCE as an intermediate, and sites using PCE as a processing aid). At the industrial processing or use site, PCE is then unloaded from the container into a process vessel before being incorporated into a mixture, used as a chemical intermediate, or otherwise processed/used. For the model, EPA assumes PCE is unloaded into tank trucks and railcars and transported and distributed in bulk. EPA also assumes the chemical is handled as a pure substance (100 percent concentration).

Because PCE is volatile (vapor pressure above 0.01 torr at room temperature), fugitive emissions may occur when PCE is loaded into or unloaded from a tank truck or railcar. Sources of these emissions include:

- Displacement of saturated air containing PCE as the container/truck is filled with liquid;
- Emissions of saturated air containing PCE that remains in the loading arm, transfer hose, and related equipment; and
- Emissions from equipment leaks from processing units such as pumps, seals and valves.

These emissions result in subsequent exposure to workers involved in the transfer activity. The following subsections address these emission sources.

E.1 Displacement of Saturated Air Inside Tank Trucks and Railcars

For screening-level assessments, EPA typically uses the *EPA/OAQPS AP-42 Loading Model* to conservatively assess exposure during container unloading activities (U.S. EPA, 2015b). The model estimates release to air from the displacement of air containing chemical vapor as a container/vessel is filled with liquid (U.S. EPA, 2015b). The model assumes the unloading activity displaces an air volume equal to the size of the container, and that displaced air is either 50 percent or 100 percent saturated with chemical vapor (U.S. EPA, 2015b).

Process units at facilities that manufacture PCE as a primary product; use PCE as a reactant or manufacture PCE as a product or co-product; or are located at a plant that is a major source of hazardous air pollutants (HAPs) as defined in section 112(a) of the Clean Air Act are required to install and operate a vapor capture system and control device (or vapor balancing system) for loading/unloading operations (U.S. EPA, 1994c). Therefore, EPA expects the majority of industrial facilities to use a vapor balance system to minimize fugitive emissions when loading and unloading tank trucks and railcars. As such, vapor losses from displacement of air is likely mitigated by the use of such systems. Actual fugitive emissions are likely limited to any saturated vapor that remain in the hose, loading arm, or related equipment after being disconnected from the truck or railcar. This emission source is addressed in the next subsection.

E.2 Emissions of Saturated Air that Remain in Transfer Hoses/Loading Arm

After loading is complete, transfer hoses and/or loading arms are disconnected from tank trucks and railcars. Saturated air containing the chemical of interest that remains in transfer equipment may be released to air, presenting a source of fugitive emissions. The quantity of PCE released will depend on concentration in the vapor and the volume of vapor in the loading arm/hose/piping.

Table_Apx E-1 presents the dimensions for several types of loading systems according to an OPW Engineered Systems catalog (OPW Engineered Systems, 2014). OPW Engineered Systems (2014) specializes in the engineering, designing, and manufacturing of systems for loading and unloading a wide range of materials including petroleum products, liquefied gases, asphalt, solvents, and hazardous and corrosive chemicals. These systems include loading systems, swivel joints, instrumentation, quick and dry-disconnect systems, and safety breakaways. Based on the design dimensions, the table presents the calculated total volume of loading arm/system and assumes the volume of vapor containing PCE equals the volume of the loading arm/system.

Based on comments from HSIA (2017), halogenated solvents, such as PCE, are expected to be delivered in either tank trailers or tank cars. Therefore, EPA modeled the central tendency scenario as tank truck loading/unloading. EPA modeled the high-end scenario as railcar loading/unloading since railcars are larger and more likely to use longer transfer arms (and thus represent a higher exposure potential than tank trucks). To estimate the high-end transfer arm volume, EPA calculated the 95th percentile of the OPW Engineered Systems loading arms volumetric data resulting in a high-end value of 17.7 gallons. For the central tendency tank truck scenario, EPA assumed a 2-inch diameter, 12-ft long transfer hose. This hose has a volume of 2.0 gallons.

Once the volume is known, the emission rate, E_T (g/s), can be calculated as follows:

Equation_Apx E-1

$$E_T = \frac{f \times MW \times 3{,}786.4 \times V_h \times X \times VP}{t_{disconnect} \times T \times R \times 3{,}600 \times 760}$$

Default values for Equation_Apx E-1 can be found in Table_Apx E-2.

Table_Apx E-1. Example Dimensions and Volume of Loading Arm/Transfer System

OPW Engineered Systems Transfer Arm	Length of Loading Arm/Connection (in)[a]				Volume, V_h (gal)[b]			
	2-inch	3-inch	4-inch	6-inch	2-inch	3-inch	4-inch	6-inch
Unsupported Boom-Type Bottom Loader	149.875	158.5	165.25	191.75	2.0	4.9	9.0	23.5
“A” Frame Loader M-32-F	153.75	159.75	164.5	NA	2.1	4.9	8.9	NA
“A” Frame Hose Loader AFH-32-F	180.75	192.75	197.5	NA	2.5	5.9	10.7	NA
CWH Series Counterweighted Hose Loader	NA	NA	309	NA	NA	NA	16.8	NA
Spring Balanced Hose Loader SRH-32-F	204.75	216.75	221.5	NA	2.8	6.6	12.0	NA
Spring Balanced Hose Loader LRH-32-F	NA	270	277.625	NA	NA	8.3	15.1	NA
Top Loading Single Arm Fixed Reach	201.75	207.75	212.5	NA	2.7	6.4	11.6	NA
Top Loading Scissor Type Arm	197.875	206.5	213.25	NA	2.7	6.3	11.6	NA
Supported Boom Arm B-32-F	327.375	335	341.5	NA	4.5	10.3	18.6	NA
Unsupported Boom Arm GT-32-F	215.875	224.5	231.25	NA	2.9	6.9	12.6	NA
Slide Sleeve Arm A-32F	279	292.5	305.125	NA	3.8	9.0	16.6	NA
Hose without Transfer Arm								
Hose (EPA judgment)	120	--	--	--	1.6	--	--	--

[a] Total length includes length of piping, connections, and fittings.
[b] Calculated based on dimension of the transfer hose/connection, $V_h = \pi r^2 L$ (converted from cubic inch to gallons).
Source: (OPW Engineered Systems, 2014)

Table_Apx E-2. Default Values for Calculating Emissions Rate of Perchloroethylene from Transfer/Loading Arm

Parameter	Parameter Description	Default Value	Unit
E_T	Emission rate of chemical from transfer/loading system	Calculated from model equation	g/s
f	Saturation factor[a]	1	dimensionless
MW	Molecular weight of the chemical	165.833	g/mol
V_h	Volume of transfer hose	See Table_Apx E-1	gallons
r	Fill rate[a]	2 (tank truck) 1 (railcar)	containers/hr
$t_{disconnect}$	Time to disconnect hose/couplers (escape of saturated vapor from disconnected hose or transfer arm into air)	0.25	hr
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of the pure chemical	18.5	torr
T	Temperature	298	K
R	Universal gas constant	82.05	atm-cm3/gmol-K

[a] Saturation factor and fill rate values are based on established EPA release and inhalation exposure assessment methodologies (U.S. EPA, 2015b).

E.3 Emissions from Leaks

During loading/unloading activities, emissions may also occur from equipment leaks from valves, pumps, and seals. Per EPA's *Chapter 5: Petroleum Industry* of AP-42 (U.S. EPA, 2015a) and EPA's *Protocol for Equipment Leak Emission Estimates* (U.S. EPA, 1995), the following equation can be used to estimate emission rate E_L, calculated as the sum of average emissions from each process unit:

Equation_Apx E-2

$$E_L = \sum (F_A \times WF_{TOC} \times N) \times \frac{1,000}{3,600}$$

Parameters for calculating equipment leaks using Equation_Apx E-2 can be found in Table_Apx E-3.

Table_Apx E-3. Parameters for Calculating Emission Rate of Perchloroethylene from Equipment Leaks

Parameter	Parameter Description	Default Value	Unit
E_L	Emission rate of chemical from equipment leaks	Calculated from model equation	g/s
F_A	Applicable average emission factor for the equipment type	See Table_Apx E-4	kg/hr-source
WF_{TOC}	Average weight fraction of chemical in the stream	1	dimensionless
N	Number of pieces of equipment of the applicable equipment type in the stream	See Table_Apx E-4	Source

To estimate emission leaks using this modeling approach, EPA modeled a central tendency loading rack scenario using tank truck loading/unloading and a high-end loading rack scenario using railcar loading/unloading as discussed in Appendix E.2. EPA used engineering judgment to estimate the type and number of equipment associated with the loading rack in the immediate vicinity of the loading operation. EPA assumes at least one worker will be near the loading rack during the entire duration of the loading operation.

Table_Apx E-4 presents the average emission factor for each equipment type, based on the synthetic organic chemical manufacturing industry (SOCMI) emission factors as provided by EPA's 1995 Protocol (U.S. EPA, 1995), and the likely number of pieces of each equipment used for each chemical loading/unloading activity, based on EPA's judgment. Note these emission factors are for emission rates of total organic compound emission and are assumed to be applicable to PCE. In addition, these factors are most valid for estimating emissions from a population of equipment and are not intended to be used to estimate emissions for an individual piece of equipment over a short period of time.

Table_Apx E-4. Default Values for F_A and N

Equipment Type	Service	SOCMI Emission Factor, F_A (kg/hr-source)[a]	Number of Equipment, N (central tendency)	Number of Equipment, N (high-end)
Valves	Gas Light liquid Heavy liquid	0.00597 0.00403 0.00023	3 (gas) 5 (light liquid) --	3 (gas) 10 (light liquid) --
Pump seals[b]	Light liquid Heavy liquid	0.0199 0.00862	--	--
Compressor seals	Gas	0.228	--	--
Pressure relief valves	Gas	0.104	1	1
Connectors	All	0.00183	2	3
Open-ended lines	All	0.0017	--	--
Sampling connections	All	0.015	2	3

[a] SOCMI average emission factors for total organic compounds from EPA’s 1995 Protocol (U.S. EPA, 1995). “Light liquid” is defined as “material in a liquid state in which the sum of the concentration of individual constituents with a vapor pressure over 0.3 kilopascals (kPa) at 20 °C is greater than or equal to 20 weight percent”. “Heavy liquid” is defined as “not in gas/vapor service or light liquid service.” Since PCE has a vapor pressure of 18.5 mmHg (2.47 kPa) at 25 °C, EPA modeled PCE liquid as a light liquid.

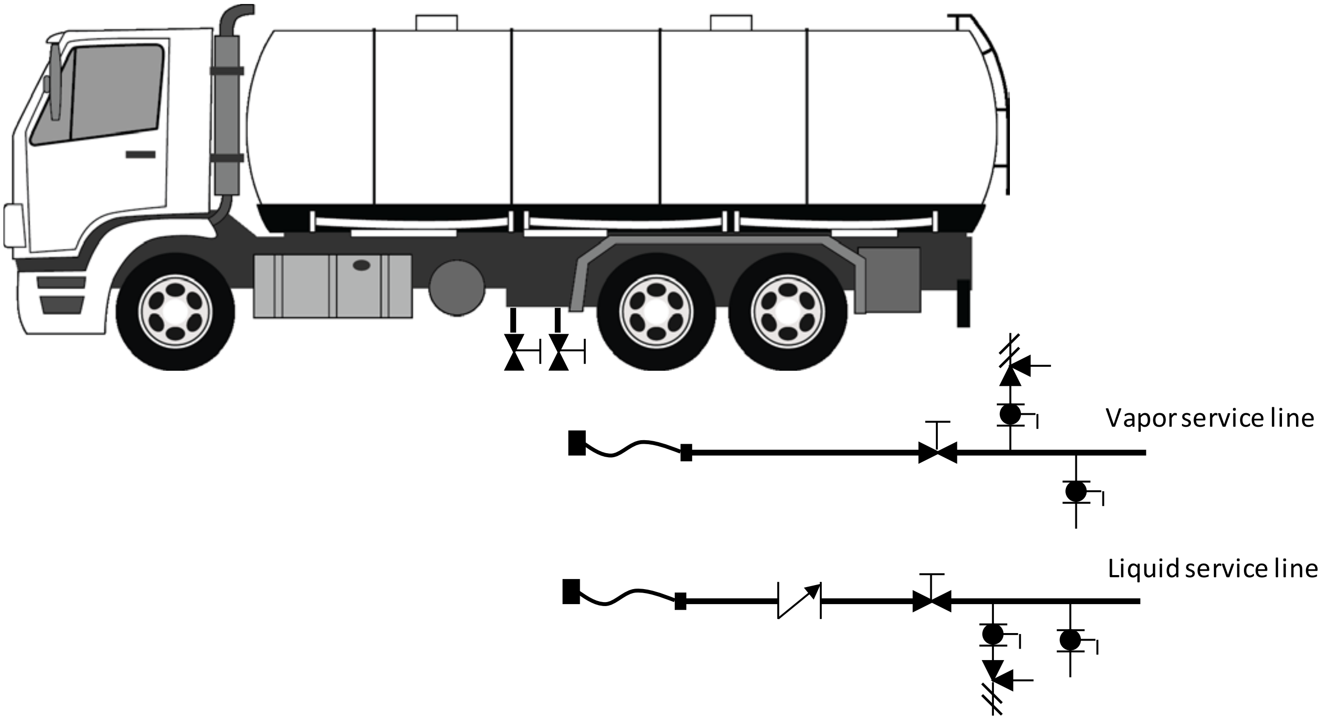
[b] The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

Source: (U.S. EPA, 1995)

EPA assumed the following equipment are used in loading racks for the loading/unloading of tank trucks and railcars. Figure_Apx E-1 illustrates an example tank truck and unloading rack equipment.

- Tank Truck Loading/Unloading:
  - Liquid Service:
    - Four valves (modeled as valves in light liquid service)
    - One safety relief valve (modeled as valve in light liquid service)
    - One bleed valve or sampling connection
    - One hose connector
  - Vapor Service:
    - Three valves (modeled as valves in gas service)
    - One pressure relief valve
    - One bleed valve (modeled as a sampling connection)
    - One hose connector
- Railcar Loading/Unloading
  - Liquid Service: EPA assumed, for the high-end scenario, two parallel liquid service lines, each using the same equipment as assumed for tank trucks. Therefore, a total of:
    - Eight valves (modeled as valves in light liquid service)
    - Two safety relief valves (modeled as valve in light liquid service)
    - Two bleed valves or sampling connections

        - Two transfer arm connectors
    - Vapor Service: EPA assumed a single line in vapor service with the same equipment as assumed for tank trucks.
        - Three valves (modeled as valves in gas service)
        - One pressure relief valve
        - One bleed valve (modeled as a sampling connection)
        - One transfer arm connector



Figure_Apx E-1. Illustration of Transfer Lines Used During Tank Truck Unloading and Associated Equipment Assumed by EPA

E.4 Exposure Estimates

The vapor generation rate, G, or the total emission rate over time, can be calculated by aggregating emissions from all sources:

- During the transfer period, emissions are only due to leaks, with emission rate $G = E_L$.
- After transfer, during the disconnection of the hose(s), emissions are due to both leaks and escape of saturated vapor from the hose/transfer arm with emission rate $G = E_T + E_L$.

The vapor generation rate can then be used with the *EPA/OPPT Mass Balance Inhalation Model* to estimate worker exposure during loading/unloading activities (U.S. EPA, 2015b). The *EPA/OPPT Mass Balance Inhalation Model* estimates the exposure concentration using Equation_Apx E-3 and the default parameters found in Table_Apx E-5 (U.S. EPA, 2015b). Table_Apx E-6 presents exposure estimates for PCE using this approach. These estimates assume one unloading/loading event per day and PCE is loaded/unloaded at 100% concentration. The loading operation occurs in an outdoor area with minimal structure, with wind speeds of 9 mph (central tendency) or 5 mph (high-end).

Equation_Apx E-3

$$C_m = \frac{C_v}{V_m}$$

Table_Apx E-5. Parameters for Calculating Exposure Concentration Using the EPA/OPPT Mass Balance Model

Parameter	Parameter Description	Default Value	Unit
C_m	Mass concentration of chemical in air	Calculated from model equation	mg/m^3
C_v	Volumetric concentration of chemical in air	Calculated as the lesser of: $\frac{170{,}000 \times T \times G}{MW \times Q \times k}$ or $\frac{1{,}000{,}000 \times X \times VP}{760}$	ppm
T	Temperature of air	298	K
G	Vapor generation rate	E_L during transfer period E_T+E_L after transfer/during disconnection of hose/transfer arm	g/s
MW	Molecular weight of the chemical	165.833	g/mol
Q	Outdoor ventilation rate	237,600 (central tendency) $26{,}400 \times \left(60 \times \frac{vz}{5280}\right)$ (high-end)	ft^3/min
vz	Air speed	440	ft/min
k	Mixing factor	0.5	dimensionless
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of the pure chemical	18.5	torr
V_m	Molar volume	24.45 @ 25°C, 1 atm	L/mol

EPA also calculated acute and 8-hr TWA exposures as shown in Equation_Apx E-4 and Equation_Apx E-5, respectively. The acute TWA exposure is the weighted average exposure during the entire exposure duration per shift, accounting for the number of loading/unloading events per shift. The 8-hr TWA exposure is the weighted average exposure during an entire 8-hr shift, assuming zero exposures during the remainder of the shift. EPA assumed one container is loaded/unloaded per shift: one tank truck per shift for the central tendency scenario and one railcar per shift for the high-end scenario.

Equation_Apx E-4

$$Acute\ TWA = \frac{\left(C_{m(leak\ only)} \times (h_{event} - t_{disconnect}) + \left(C_{m(leak\ and\ hose)} \times t_{disconnect}\right)\right) \times N_{cont}}{h_{shift}}$$

Equation_Apx E-5

$$8 - hr\ TWA = \frac{\left(C_{m(leak\ only)} \times (h_{event} - t_{disconnect}) + \left(C_{m(leak\ and\ hose)} \times t_{disconnect}\right)\right) \times N_{cont}}{8}$$

Where:

$C_{m(leak\ only)}$ = Airborne concentration (mass-based) due to leaks during unloading while hose connected (mg/m^3)

$C_{m(leak\ and\ hose)}$ = Airborne concentration (mass-based) due to leaks and displaced air during hose disconnection (mg/m^3)

h_{event} = Exposure duration of each loading/unloading event (hr/event); calculated as the inverse of the fill rate, *r*: 0.5 hr/event for tank trucks and 1 hr/event for railcars

h_{shift} = Exposure duration during the shift (hr/shift); calculated as $h_{event} \times N_{cont}$: 0.5 hr/shift for tank trucks and 1 hr/shift for railcars

$t_{disconnect}$ = Time duration to disconnect hoses/couplers (during which saturated vapor escapes from hose into air) (hr/event)

N_{cont} = Number of containers loaded/unloaded per shift (event/shift); assumed one tank truck per shift for central tendency scenario and one railcar per shift for high-end scenario

Table_Apx E-6. Calculated Emission Rates and Resulting Exposures from the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model for Perchloroethylene

Scenario	E_L (g/s)	E_T (g/s)	$E_L + E_T$ (g/s)	C_m (leaks only) (mg/m^3)	C_m (leaks and hose vapor) (mg/m^3)	Acute TWA (mg/m^3) [a]	8-hr TWA (mg/m^3)	Acute TWA (ppm)[a]	8-hr TWA (ppm)
Central Tendency	0.049	0.001	0.050	0.85	0.88	0.86	0.054	0.13	0.01
High-End	0.059	0.012	0.071	1.85	2.24	1.95	0.24	0.29	0.04

[a] Acute TWA exposure is a 0.5-hr TWA exposure for the central tendency scenario and a 1-hr TWA exposure for the high-end scenario.

Appendix F Drum Loading and Unloading Release and Inhalation Exposure Model Approach and Parameters

This appendix presents the approach for central tendency and high-end inhalation exposure estimation for the loading of formulated-products containing PCE into 55-gallon drums. This approach applies a stochastic modeling approach to the *EPA/OAQPS AP-42 Loading Model*, which estimates air releases during container loading and unloading, and the *EPA/OPPT Mass Balance Model*, which estimates inhalation exposures resulting from air releases (U.S. EPA, 2015b).

This approach is intended to assess air releases and associated inhalation exposures associated with indoor container loading scenarios at industrial and commercial facilities. Inhalation exposure to chemical vapors is a function of the chemical's physical properties, ventilation rate of the container loading area, type of loading method, and other model parameters. While physical properties are fixed for a chemical, some model parameters, such as ventilation rate (Q), mixing factor (k), and vapor saturation factor (f), are expected to vary from one facility to another. This approach addresses variability for these parameters using a Monte Carlo simulation.

An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data or engineering judgment to address the variability in ventilation rate (Q), mixing factor (k), vapor saturation factor (f), and exposed working years per lifetime (WY). A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0 (Palisade, Ithaca, New York). The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed 100,000 iterations of the model to capture the range of possible input values, including values with low probability of occurrence.

From the distribution resulting from the Monte Carlo simulation, EPA selected the 95th and 50th percentile values to represent a high-end exposure and central tendency exposure level respectively. The statistics were calculated directly in @Risk. The following subsections detail the model design equations and parameters used for Inhalation exposure estimates.

F.1 Model Design Equations

The *EPA/OPPT Mass Balance Model* includes the following equations for estimating mass concentration of the chemical vapor in air (mg/m^3):

Equation_Apx F-1

$$C_m = \frac{C_v \times MW}{V_m}$$

Where:

C_m = Mass concentration of chemical vapor in air (mg/m^3)
Cv = Volumetric concentration of chemical vapor in air (ppm)
MW = Molecular Weight of chemical (g/mol)

V_m = Molar volume (L/mol)

Equation_Apx F-2

$$C_v = \frac{170{,}000 \times T \times G}{MW \times Q \times k}$$

Where:

T = Temperature (K)
G = Average vapor generation rate (g/s)
MW = Molecular weight of chemical (g/mol)
Q = Ventilation rate (ft^3/min)
K = Mixing factor (Dimensionless)

The average vapor generation rate needed for the *EPA/OPPT Mass Balance Model* is calculated from the following *EPA/OAQPS AP-42 Loading Model:*

Equation_Apx F-3

$$G = \frac{f \times MW \times (3{,}785.4 \times V_c) \times r \times X \times \frac{VP}{760}}{3{,}600 \times T \times R}$$

Where:

G = Average vapor generation rate (g/s)
f = Saturation factor (Dimensionless)
MW = Molecular weight of chemical (g/mol)
V_c = Container volume (gallon)
r = Container loading/unloading rate (number of containers/hr)
X = Vapor pressure correction factor (Dimensionless), assumed equal to weight fraction of component
VP = Vapor pressure (at temperature, T) (mmHg)
T = Temperature (K)
R = Universal gas constant (atm-cm^3/mol-K)

Mass concentration of the chemical vapor in air (C_m) calculated from Equation_Apx F-1 and the time spent loading containers each day ($t_{loading}$) are then used in the following equation to estimate the 8-hr TWA concentration used for estimating acute exposure concentrations (AC), average daily concentrations (ADC) used for chronic non-cancer risk calculations (ADC) and lifetime average daily concentration (LADC) used for chronic cancer risk calculations:

Equation_Apx F-4

$$8 - hr\ TWA = \frac{C_m \times t_{loading}}{8\ hr}$$

To determine the amount of time spent each day loading containers, the model uses the following equations:

Equation_Apx F-5

$$t_{loading} = \frac{N_{cd}}{r}$$

Where:

$t_{loading}$ = Loading duration (hrs)
N_{cd} = Number of containers loaded per site per day (containers/site-day)
r = Container fill rate (drum/hr)

Equation_Apx F-6

$$N_{cd} = \frac{N_{cy}}{OD}$$

Where:

N_{cy} = Number of containers per site per year (containers/site-yr)
OD = Operating days (days/yr)

Equation_Apx F-7

$$N_{cy} = \frac{PV}{V_{c-lb} \times wtfrac \times N_{sites}}$$

Where:

PV = Production volume for the condition of use (lb/yr)
V_{c-lb} = Volume of container in pounds (lb/container)
$wtfrac$ = weight fraction of PCE in the formulation (unitless)
N_{sites} = Number of sites for the condition of use

F.2 Model Parameters

Table_Apx F-1 summarizes the model parameters and their values for the *EPA/OAQPS AP-42 Loading Model* and the *EPA/OPPT Mass Balance Model*. Each parameter is discussed in detail the following the subsections.

Table_Apx F-1. Summary of Parameter Values and Distributions Used in the Inhalation Exposure Model

Input Parameter	Symbol	Unit	Constant Model Parameter Values	Variable Model Parameter Values				Rationale/Basis
				Lower Bound	Upper Bound	Mode	Distribution Type	
EPA/OAQPS AP-42 Loading Model								
Saturation factor	f	dimensionless	—	0.5	1.45	0.5	Triangular	See Section F.2.1
Molecular weight of the chemical	MW	g/mol	165.833	—	—	—	—	Physical Property
Volume of container	V_c	gallons	55	—	—	—	—	See Section F.2.2
Fill rate	r	containers/hr	20	—	—	—	—	See Section F.2.3
Vapor pressure correction factor	X	dimensionless	—	Equal to x_i	Equal to x_i	Equal to x_i	Uniform	See Section F.2.4
Vapor pressure of the pure chemical	VP	torr	18.5	—	—	—	—	Physical Property
Temperature	T	K	298	—	—	—	—	Process Parameter
Universal gas constant	R	atm-cm^3/gmol-K	82.05	—	—	—	—	Physical Constant
Mol fraction of chemical	x_i	dimensionless	—	Equal to wtfrac	Equal to wtfrac	Equal to wtfrac	Uniform	See Section F.2.4
EPA/OPPT Mass Balance Inhalation Model								
Ventilation rate (indoor)	Q	ft^3/min	—	500	10,000	3,000	Triangular	See Section F.2.5
Mixing factor	k	dimensionless	—	0.1	1	0.5	Triangular	See Section F.2.6
Molar volume	V_m	L/mol	24.46	—	—	—	—	Physical Constant

Input Parameter	Symbol	Unit	Constant Model Parameter Values	Variable Model Parameter Values				Rationale/Basis
				Lower Bound	Upper Bound	Mode	Distribution Type	
Other Parameters								
Weight fraction of chemical in dry cleaning and degreasing formulation	wtfrac	dimensionless	1	—	—	—	—	See Section F.2.7
Weight fraction of chemical in miscellaneous formulations	wtfrac	dimensionless	—	0.3	0.8	—	Uniform	See Section F.2.7
Lb per drum	V_{c_lb}	lb/container	744.95	—	—	—	—	See Section F.2.2
Production volume for dry cleaning	PV	lb/yr	32,424,074	—	—	—	—	See Section F.2.8
Production volume for degreasing	PV	lb/yr	22,696,852	—	—	—	—	See Section F.2.8
Production volume for miscellaneous formulations	PV	lb/yr	9,727,222	—	—	—	—	See Section F.2.8
Number of sites for dry cleaning solvent formulation	N_{sites}	# of sites	5	—	—	—	—	See Section F.2.9
Number of sites for degreasing solvent formulation	N_{sites}	# of sites	19	—	—	—	—	See Section F.2.9
Number of sites for miscellaneous product formulation	N_{sites}	# of sites	15	—	—	—	—	See Section F.2.9
Operating days	OD	day/yr	300	—	—	—	—	See Section F.2.10
Exposure Frequency	EF	day/yr	250	—	—	—	—	See Section F.2.11
Exposure Duration	ED	hr/day	8	—	—	—	—	See Section F.2.12

F.2.1 Saturation Factor

The *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments*, *Volume 1* [CEB Manual] (U.S. EPA, 1991a) indicates that during splash filling the saturation concentration was reached or exceeded by misting with a maximum saturation factor of 1.45. The CEB manual indicates that generation rate for bottom filling was expected to be about 0.5 (U.S. EPA, 1991a). The underlying distribution of this parameter is not known; therefore, EPA assigned triangular distributions, since triangular distribution requires least assumptions and is completely defined by range and mode of a parameter. Because a mode was not provided for this parameter, EPA assigned a mode value of 0.5 for bottom filling as bottom filling minimizes volatilization (U.S. EPA, 1991a). This value also corresponds to the typical value provided in the ChemSTEER User Guide (U.S. EPA, 2015b) for the *EPA/OAQPS AP-42 Loading Model* for drums.

F.2.2 Volume of Container

EPA assumed formulated products were loaded into 55-gallon drums. It is possible that some formulated products, such as coatings and adhesives, may be loaded into smaller containers (e.g., pails) for smaller commercial and consumer applications; however, EPA does not have information to estimate the volume packaged into drums versus smaller containers. Therefore, EPA assessed the entire throughput as packaged into drums to give the most protective worker exposure estimates.

This value was then converted to lbs. using the density of PCE. This assumes that the density of the formulated product will be similar to that of PCE. This may result in error when estimating number of containers where the actual density of the formulation differs significantly from that of PCE.

F.2.3 Fill Rate

The ChemSTEER User Guide (U.S. EPA, 2015b) provides a typical fill rate of 20 containers per hour for 55-gallon drums.

F.2.4 Vapor Pressure Correction Factor and Mole Fraction

The ChemSTEER User Guide (U.S. EPA, 2015b) assumes Raoult's Law such that the vapor pressure correction factor may be set equal to the mole fraction of PCE in the formulation. Due to the wide variety of formulations PCE may be used in, the mole fraction of PCE in each product could not be determined. Therefore, EPA assumed that the mole fraction is equal to the weight fraction of PCE in the formulation (see Section F.2.7). This assumption is not expected to result in significant error in formulations where the molecular weight (MW) of PCE is very similar to that of the other components. However, if the MW of PCE differs significantly from the MW of the other components it may result in error when estimating the vapor generation rate and corresponding exposure. If the MW of PCE is significantly lower than the MW of other components then the mol fraction, correction factor and resulting vapor generation and exposure will be overestimated. If the MW of PCE is significantly higher than the other components the mol fraction, correction factor, and resulting vapor generation and exposure will be underestimated.

F.2.5 Ventilation Rate

The CEB Manual (U.S. EPA, 1991a) indicates general ventilation rates in industry range from 500 to 10,000 ft^3/min, with a typical value of 3,000 ft^3/min. The underlying distribution of this parameter is not known; therefore, EPA assigned triangular distributions, since triangular distribution requires least assumptions and is completely defined by range and mode of a parameter. EPA assumed the mode is equal to the typical value provided by the CEB Manual (U.S. EPA, 1991a).

F.2.6 Mixing Factor

The CEB Manual (U.S. EPA, 1991a) indicates mixing factors may range from 0.1 to 1, with 1 representing ideal mixing. The CEB Manual references the 1988 ACGIH Ventilation Handbook which suggests the following factors and descriptions: 0.67 to 1 for best mixing; 0.5 to 0.67 for good mixing; 0.2 to 0.5 for fair mixing; and 0.1 to 0.2 for poor mixing. The underlying distribution of this parameter is not known; therefore, EPA assigned triangular distributions, since triangular distribution requires least assumptions and is completely defined by range and mode of a parameter. The mode for this distribution was not provided; therefore, EPA assigned a mode value of 0.5 based on the typical value provided in the ChemSTEER User Guide (U.S. EPA, 2015b) for the *EPA/OPPT Mass Balance Inhalation Model*.

F.2.7 Weight Fraction of Chemical

The weight fraction of PCE in the product varies depending on specific product being formulated. For formulation, EPA considered three types of formulations: 1) degreasing solvents, 2) dry cleaning solvents, and 3) miscellaneous products. Miscellaneous products include coatings, adhesives, metalworking fluids, and other niche use PCE-based products. These three categories were selected based on the availability (or lack thereof) of market data. For example, market data from HSIA (2008) estimated 7% of the production volume of PCE is used in degreasing, 10% is used in dry cleaning, and 3% is for “miscellaneous” uses. More specific market data for the third “miscellaneous” group were not available; therefore, EPA could not divide the PCE production volume amongst the product types to develop exposure estimates for each product type.

For degreasing and dry cleaning solvents EPA assumed the PCE weight fraction to be 100%. Typically, the only materials expected to be added to degreasing and dry cleaning solvents are stabilizers used to prevent decomposition during storage and use (European Chlorinated Solvents Association, 2011). PCE generally requires less stabilizers than other chlorinated solvents with weight fractions of stabilizers expected to be less than 0.5% in degreasing solvents, and less than 0.05% in dry cleaning solvents. (European Chlorinated Solvents Association, 2011). Therefore, the assumption of 100% PCE in the model is not expected to significantly impact exposure results.

For miscellaneous products, the concentration of PCE can vary greatly depending on the product being formulated. For modeling purposes, EPA assessed used a uniform distribution of 30 to 80% PCE in the formulated product based on the expected concentrations of solvents in organic solvent-borne coatings estimated by the OECD ESD (Oecd, 2009b). This range was used as it is expected to encompass the range of compositions for the majority of PCE-based products in this category (e.g., per the OECD ESD (Oecd, 2009a) typical organic solvent concentrations in adhesives is estimated to be between 60 to 75% which falls within the range used in the model). While it is possible that some of the products contain PCE concentrations outside this range, the error from this is expected to be small as, based on the reported NAICS codes, 10 of the 15 formulation sites assessed in this category are either coatings (including maskants) or adhesive formulation sites (see Section F.2.9).

F.2.8 Production Volume

HSIA (2008) estimated 7% of the production volume of PCE is used in degreasing, 10% is used in dry cleaning, and 3% is for “miscellaneous” uses. More specific market data for the third “miscellaneous” group were not available; therefore, EPA could not divide the PCE production volume amongst the product types to develop exposure estimates for each product type. Based on the 2016 CDR (U.S. EPA, 2016d), the national production volume of PCE in 2015 was 324,240,744 lbs. resulting in the following PCE production volumes used in each category:

- Degreasing – 22,696,852 lbs.;
- Dry Cleaning – 32,424,074 lbs.; and
- Miscellaneous – 9,727,222 lbs.

F.2.9 Number of Sites

Formulation sites were determined based on SIC codes reported by sites in the 2016 DMR (U.S. EPA, 2016b) and activities and NAICS codes reported by sites in the 2016 TRI (U.S. EPA, 2017d). This resulted in a total of 39 formulation sites. Each site was than categorized as a degreasing solvent formulation site, dry cleaning solvent formulation site, or a miscellaneous product formulation site for use in modeling. Sites were categorizes based on reported NAICS codes (or SIC codes mapped to NAICS codes) as follows:

- Degreasing solvent formulation NAICS codes:
    - 324110 – Petroleum Refineries[32]; and
    - 325998 – All Other Miscellaneous Chemical Product and Preparation Manufacturing[33].
- Dry cleaning solvent formulation NAICS codes:
    - 325611 – Soap and Other Detergent Manufacturing;
    - 325612 – Polish and Other Sanitation Good Manufacturing; and
    - 325613 – Surface Active Agent Manufacturing.
- Miscellaneous formulation NAICS codes:
    - All NAICS codes reported not listed above.

The categorization resulted in 19 formulation sites for degreasing solvents, 5 for dry cleaning solvents, and 15 for miscellaneous products.

F.2.10 Operating Days

EPA assumed 300 days/yr of operation as given in the SpERC developed by the European Solvent Industry Group for the formulation and (re)packing of substances and mixtures (European Solvents Industry Group, 2019a). EPA uses 300 days per year rather than 350 (7 days/wk, 50 wks/yr) because it is likely that formulation sites make multiple products not all of which will contain PCE. Drum loading of PCE-based products is only expected to occur on days were PCE-containing products are produced.

F.2.11 Exposure Frequency

When calculating ADC and LADC, EPA uses an exposure frequency of 250 days/yr. This assumes workers work five days per week 50 weeks per year, with two weeks off.

F.2.12 Exposure Duration

EPA assumes workers work a total of eight hours per day.

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[32] EPA does not typically expect petroleum refineries to formulate degreasing solvents; however, the one site reporting this NAICS code to the 2016 TRI also reported as an importer to the 2016 CDR and reported its entire import volume as used on-site and reported formulation of solvents for cleaning and degreasing.

[33] This NAICS codes may also include sites manufacturing aerosol products; therefore, the total number of sites for formulating degreasing solvents may be overestimated.

Appendix G Vapor Degreasing and Cold Cleaning Near-Field/Far-Field Inhalation Exposure Models Approach and Parameters

This appendix presents the modeling approach and model equations used in the following models:

- Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model;
- Web Degreasing Near-Field/Far-Field Inhalation Exposure Model; and
- Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model.

The models were developed through review of the literature and consideration of existing EPA/OPPT exposure models. These models use a near-field/far-field approach (Aiha, 2009), 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 occupational non-users are exposed at concentrations in the far-field.

The model uses the following parameters to estimate exposure concentrations in the near-field and far-field:

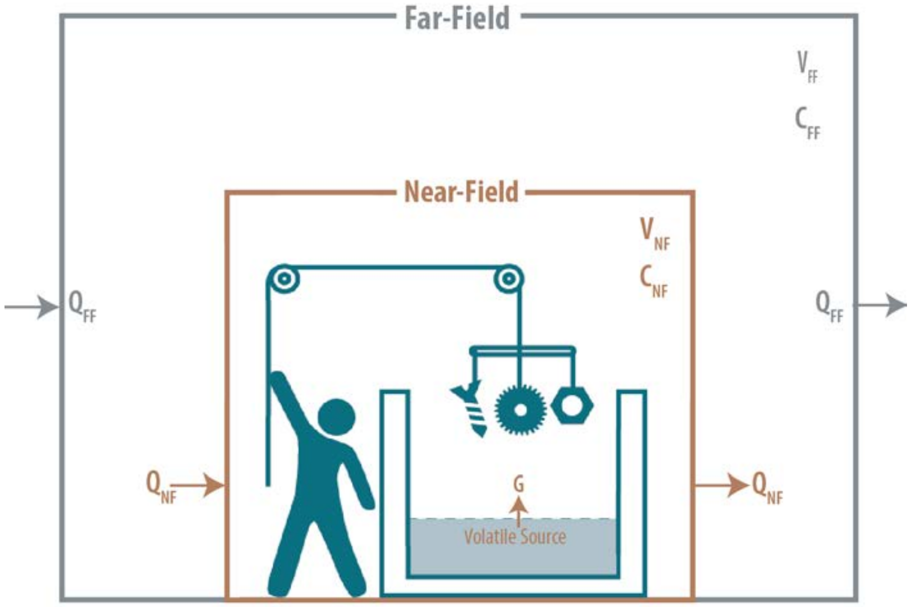
- Far-field size;
- Near-field size;
- Air exchange rate;
- Indoor air speed;
- Exposure duration;
- Vapor generation rate; and
- Operating hours per day.

An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 100,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence).

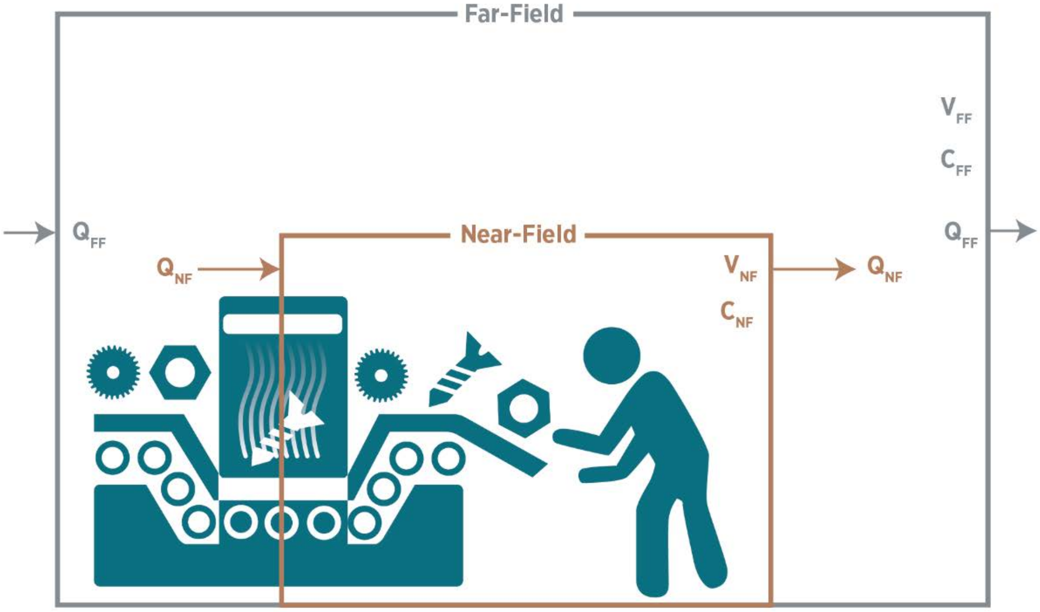
Model results from the Monte Carlo simulation are presented as 95th and 50th percentile values. The statistics were calculated directly in @Risk. The 95th percentile value was selected to represent high-end exposure level, whereas the 50th percentile value was selected to represent typical exposure level. The following subsections detail the model design equations and parameters for vapor degreasing and cold cleaning models.

G.1 Model Design Equations

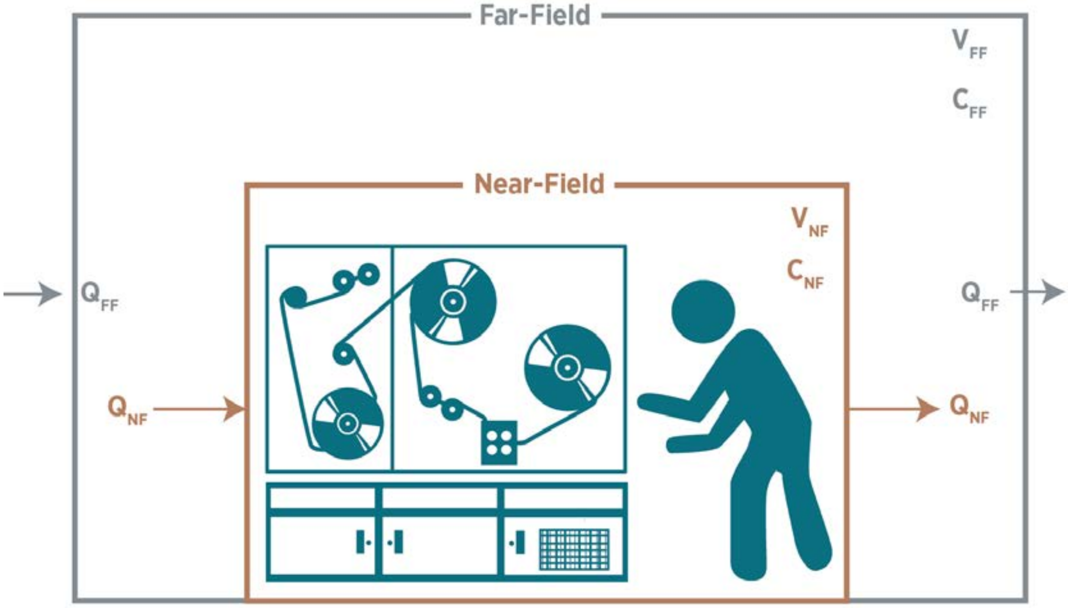
Figure_Apx G-1 through Figure_Apx G-3 illustrate the near-field/far-field modeling approach as it was applied by EPA to each vapor degreasing and cold cleaning model. As the figures show, volatile PCE vapors evaporate into the near-field, resulting in worker exposures at a PCE concentration C_{NF}. The concentration is directly proportional to the evaporation rate of PCE, G, into the near-field, whose volume is denoted by V_{NF}. The ventilation rate for the near-field zone (Q_{NF}) determines how quickly PCE dissipates into the far-field, resulting in occupational non-user exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outside air.



Figure_Apx G-1. The Near-Field/Far-Field Model as Applied to the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model



Figure_Apx G-2. The Near-Field/Far-Field Model as Applied to the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model



Figure_Apx G-3. The Near-Field/Far-Field Model as Applied to the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model

The model design equations are presented below in Equation_Apx G-1 through Equation_Apx G-16. Note the design equations are the same for each of the models discussed in this appendix.

Near-Field Mass Balance

Equation_Apx G-1

$$V_{NF}\frac{dC_{NF}}{dt} = C_{FF}Q_{NF} - C_{NF}Q_{NF} + G$$

Far-Field Mass Balance

Equation_Apx G-2

$$V_{FF}\frac{dC_{FF}}{dt} = C_{NF}Q_{NF} - C_{FF}Q_{NF} - C_{FF}Q_{FF}$$

Where:

V_{NF} = near-field volume;
V_{FF} = far-field volume;
Q_{NF} = near-field ventilation rate;
Q_{FF} = far-field ventilation rate;
C_{NF} = average near-field concentration;
C_{FF} = average far-field concentration;
G = average vapor generation rate; and
t = elapsed time.

Both of the previous equations can be solved for the time-varying concentrations in the near-field and far-field as follows (Aiha, 2009):

Equation_Apx G-3

$$C_{NF} = G\left(k_1 + k_2e^{\lambda_1 t} - k_3e^{\lambda_2 t}\right)$$

Equation_Apx G-4

$$C_{FF} = G\left(\frac{1}{Q_{FF}} + k_4e^{\lambda_1 t} - k_5e^{\lambda_2 t}\right)$$

Where:

Equation_Apx G-5

$$k_1 = \frac{1}{\left(\frac{Q_{NF}}{Q_{NF} + Q_{FF}}\right)Q_{FF}}$$

Equation_Apx G-6

$$k_2 = \frac{Q_{NF}Q_{FF} + \lambda_2 V_{NF}(Q_{NF} + Q_{FF})}{Q_{NF}Q_{FF}V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx G-7

$$k_3 = \frac{Q_{NF}Q_{FF} + \lambda_1 V_{NF}(Q_{NF} + Q_{FF})}{Q_{NF}Q_{FF}V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx G-8

$$k_4 = \left(\frac{\lambda_1 V_{NF} + Q_{NF}}{Q_{NF}}\right)k_2$$

Equation_Apx G-9

$$k_5 = \left(\frac{\lambda_2 V_{NF} + Q_{NF}}{Q_{NF}}\right) k_3$$

Equation_Apx G-10

$$\lambda_1 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) + \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

Equation_Apx G-11

$$\lambda_2 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) - \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

EPA calculated the hourly TWA concentrations in the near-field and far-field using Equation_Apx G-12 and Equation_Apx G-13, respectively. Note that the numerator and denominator of Equation_Apx G-12 and Equation_Apx G-13 use two different sets of time parameters. The numerator is based on operating times for the scenario (e.g., 13 hours for conveyorized degreasers, 24 hours for web degreasers, and 1 to 24 hours for cold cleaning, see Section G.2) while the denominator is fixed to an average time span, t_avg, of eight hours (since EPA is interested in calculating 8-hr TWA exposures). Mathematically, the numerator and denominator must reflect the same amount of time. This is indeed the case since the numerator assumes exposures are zero for any hours not within the operating time. Therefore, mathematically speaking, both the numerator and the denominator reflect eight hours regardless of the values selected for t_1 and t_2.

Equation_Apx G-12

$$C_{NF,TWA} = \frac{\int_{t_1}^{t_2} C_{NF}dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(k_1 + k_2 e^{\lambda_1 t} - k_3 e^{\lambda_2 t}\right)dt}{t_{avg}} =$$

$$\frac{G\left(k_1 t_2 + \frac{k_2 e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_3 e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(k_1 t_1 + \frac{k_2 e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_3 e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

Equation_Apx G-13

$$C_{FF,TWA} = \frac{\int_{t_1}^{t_2} C_{FF}dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(\frac{1}{Q_{FF}} + k_4 e^{\lambda_1 t} - k_5 e^{\lambda_2 t}\right)dt}{t_{avg}} =$$

$$\frac{G\left(\frac{t_2}{Q_{FF}} + \frac{k_4 e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_5 e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(\frac{t_1}{Q_{FF}} + \frac{k_4 e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_5 e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

To calculate the mass transfer to and from the near-field, the free surface area, FSA, is defined to be the surface area through which mass transfer can occur. Note that the FSA is not equal to the surface area of the entire near-field. EPA defined the near-field zone to be a rectangular box resting on the floor; therefore, no mass transfer can occur through the near-field box's floor. FSA is calculated in Equation_Apx G-14, below:

Equation_Apx G-14

$$FSA = 2(L_{NF}H_{NF}) + 2(W_{NF}H_{NF}) + (L_{NF}W_{NF})$$

Where: L_{NF}, W_{NF}, and H_{NF} are the length, width, and height of the near-field, respectively. The near-field ventilation rate, Q_{NF}, is calculated in Equation_Apx G-15 from the near-field indoor wind speed, v_{NF}, and FSA, assuming half of FSA is available for mass transfer into the near-field and half of FSA is available for mass transfer out of the near-field:

Equation_Apx G-15

$$Q_{NF} = \frac{1}{2} v_{NF} FSA$$

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx G-16:

Equation_Apx G-16

$$Q_{FF} = V_{FF} AER$$

Using the model inputs described in Section G.2, EPA estimated PCE inhalation exposures for workers in the near-field and for occupational non-users in the far-field. EPA then conducted the Monte Carlo simulations using @Risk (Version 7.0.0). The simulations applied 100,000 iterations and the Latin Hypercube sampling method for each model.

G.2 Model Parameters

Table_Apx G-1 through Table_Apx G-3 summarize the model parameters and their values for each of the models discussed in this Appendix. Each parameter is discussed in detail in the following subsections.

Table_Apx G-1. Summary of Parameter Values and Distributions Used in the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	ft^3	—	—	10,594	70,629	17,657	Triangular	See Section G.2.1
Air exchange rate	AER	hr^{-1}	—	—	2	20	3.5	Triangular	See Section G.2.2
Near-field indoor wind speed	v_{NF}	ft/hr	—	—	—	23,882	—	Lognormal	See Section G.2.3
		cm/s	—	—	—	202.2	—	Lognormal	
Near-field length	L_{NF}	ft	10	—	—	—	—	Constant Value	See Section G.2.4
Near-field width	W_{NF}	ft	10	—	—	—	—	Constant Value	
Near-field height	H_{NF}	ft	6	—	—	—	—	Constant Value	
Starting time	t_1	hr	0	—	—	—	—	Constant Value	Constant
Exposure Duration	t_2	hr	8	—	—	—	—	Constant Value	See Section G.2.5
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	See Section G.2.6
Vapor generation rate	G	mg/hr	—	—	1.85E+06	1.85E+06	—	Discrete	See Section G.2.7
		lb/hr	—	—	4.083	4.083	—	Discrete	
Operating hours per day	OH	hr/day	13	—	—	—	—	Discrete	See Section G.2.8

Table_Apx G-2. Summary of Parameter Values and Distributions Used in the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	ft^3	—	—	10,594	70,629	17,657	Triangular	See Section G.2.1
Air exchange rate	AER	hr^{-1}	—	—	2	20	3.5	Triangular	See Section G.2.2
Near-field indoor wind speed	v_{NF}	ft/hr	—	—	—	23,882	—	Lognormal	See Section G.2.3
		cm/s	—	—	—	202.2	—	Lognormal	
Near-field length	L_{NF}	ft	10	—	—	—	—	Constant Value	See Section G.2.4
Near-field width	W_{NF}	ft	10	—	—	—	—	Constant Value	
Near-field height	H_{NF}	ft	6	—	—	—	—	Constant Value	
Starting time	t_1	hr	0	—	—	—	—	Constant Value	Constant.
Exposure Duration	t_2	hr	8	—	—	—	—	Constant Value	See Section G.2.5
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	See Section G.2.6
Vapor generation rate	G	mg/hr	—	—	9.09E+03	2.24E+04	—	Discrete	See Section G.2.7
		lb/hr	—	—	0.020	0.049	—	Discrete	
Operating hours per day	OH	hr/day	24	—	—	—	—	Discrete	See Section G.2.8

Table_Apx G-3. Summary of Parameter Values and Distributions Used in the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	ft^3	—	—	10,594	70,629	17,657	Triangular	See Section G.2.1
Air exchange rate	AER	hr^{-1}	—	—	2	20	3.5	Triangular	See Section G.2.2
Near-field indoor wind speed	v_{NF}	ft/hr	—	—	—	23,882	—	Lognormal	See Section G.2.3
		cm/s	—	—	—	202.2	—	Lognormal	
Near-field length	L_{NF}	ft	10	—	—	—	—	Constant Value	See Section G.2.4
Near-field width	W_{NF}	ft	10	—	—	—	—	Constant Value	
Near-field height	H_{NF}	ft	6	—	—	—	—	Constant Value	
Starting time	t_1	hr	0	—	—	—	—	Constant Value	Constant.
Exposure Duration	t_2	hr	—	—	1	8	—	Discrete	See Section G.2.5
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	See Section G.2.6
Vapor generation rate	G	mg/hr	—	—	5.13E-02	5.63E+04	—	Discrete	See Section G.2.7
		lb/hr	—	—	1.13E-07	0.12	—	Discrete	
Operating hours per day	OH	hr/day	—	—	1	24	—	Discrete	See Section G.2.8

G.2.1 Far-Field Volume

EPA used the same far-field volume distribution for each of the models discussed. The far-field volume is based on information obtained from von Grote (2003)) that indicated volumes at German metal degreasing facilities can vary from 300 to several thousand cubic meters. They noted that smaller volumes are more typical and assumed 400 and 600 m^3 (14,126 and 21,189 ft^3) in their exposure models (Von Grote, 2003). These are the highest and lowest values EPA identified in the literature; therefore, EPA assumes a triangular distribution bound from 300 m^3 (10,594 ft^3) to 2,000 m^3 (70,629 ft^3) with a mode of 500 m^3 (the midpoint of 400 and 600 m^3) (17,657 ft^3).

G.2.2 Air Exchange Rate

EPA used the same air exchange rate distribution for each of the models discussed. The air exchange rate is based on data from Hellweg (2009) and information received from a peer reviewer during the development of the 2014 *TSCA Work Plan Chemical Risk Assessment Trichloroethylene: Degreasing, Spot Cleaning and Arts & Crafts Uses* (Scg, 2013). Hellweg (2009) reported that average air exchange rates for occupational settings using mechanical ventilation systems vary from 3 to 20 hr^{-1}. The risk assessment peer reviewer comments indicated that values around 2 to 5 hr^{-1} are likely (Scg, 2013), in agreement with the low end reported by Hellweg (2009). Therefore, EPA used a triangular distribution with the mode equal to 3.5 hr^{-1}, the midpoint of the range provided by the risk assessment peer reviewer (3.5 is the midpoint of the range 2 to 5 hr^{-1}), with a minimum of 2 hr^{-1}, per the risk assessment peer reviewer (Scg, 2013) and a maximum of 20 hr^{-1} per Hellweg (2009).

G.2.3 Near-Field Indoor Air Speed

Baldwin (1998) measured indoor air speeds across a variety of occupational settings in the United Kingdom. Fifty-five work areas were surveyed across a variety of workplaces.

EPA analyzed the air speed data from Baldwin (1998) and categorized the air speed surveys into settings representative of industrial facilities and representative of commercial facilities. EPA fit separate distributions for these industrial and commercial settings and used the industrial distribution for facilities performing vapor degreasing and/or cold cleaning.

EPA fit a lognormal distribution for both data sets as consistent with the authors observations that the air speed measurements within a surveyed location were lognormally distributed and the population of the mean air speeds among all surveys were lognormally distributed. Since lognormal distributions are bound by zero and positive infinity, EPA truncated the distribution at the largest observed value among all of the survey mean air speeds from Baldwin (1998).

EPA fit the air speed surveys representative of industrial facilities to a lognormal distribution with the following parameter values: mean of 22.414 cm/s and standard deviation of 19.958 cm/s. In the model, the lognormal distribution is truncated at a maximum allowed value of 202.2 cm/s (largest surveyed mean air speed observed in Baldwin (1998)) to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

Baldwin (1998) only presented the mean air speed of each survey. The authors did not present the individual measurements within each survey. Therefore, these distributions represent a distribution of mean air speeds and not a distribution of spatially variable air speeds within a single workplace setting. However, a mean air speed (averaged over a work area) is the required input for the model.

G.2.4 Near-Field Volume

EPA assumed a near-field of constant dimensions of 10 ft x 10 ft x 6 ft resulting in a total volume of 600 ft^3.

G.2.5 Exposure Duration

EPA assumed the maximum exposure duration for each model is equal to the entire work-shift (eight hours). Therefore, if the degreaser/cold cleaning machine operating time was greater than eight hours, then exposure duration was set equal to eight hours. If the operating time was less than eight hours, then exposure duration was set equal to the degreaser/cold cleaning machine operating time (see Section G.2.8 for discussion of operating hours).

G.2.6 Averaging Time

EPA was interested in estimating 8-hr TWAs for use in risk calculations; therefore, a constant averaging time of eight hours was used for each of the models.

G.2.7 Vapor Generation Rate

For the vapor generation rate from each machine type (conveyorized, web, and cold), EPA used a discrete distribution based on the annual unit emission rates reported in the 2014 NEI (U.S. EPA, 2016a). Annual unit emission rates were converted to hourly unit emission rates by dividing the annual reported emissions by the reported annual operating hours (see Section G.2.8). Reported annual emissions in NEI without accompanying reported annual operating hours were not included in the analysis. Emission rates reported as zero were also excluded as it is unclear if this is before or after vapor controls used by the site and if the vapor controls used would control emissions into the work area (thus reducing exposure) or only control emissions to the environment (which would not affect worker exposures). Table_Apx G-4 summarizes the data available in the 2014 NEI for the relevant machine types.

Table_Apx G-4. Summary of Perchloroethylene Vapor Degreasing and Cold Cleaning Data from the 2014 NEI

Unit Type	Total Units	Units with Zero Emissions	Units without Accompanying Operating Hours	Units Used in Analysis
Conveyorized Degreasers	1	0	0	1
Web Degreasers	10	0	0	10
Cold Cleaning Machines	34	6	2	26

Source: (U.S. EPA, 2016a)

Table_Apx G-5 through Table_Apx G-7 summarize the distribution of hourly unit emissions for each machine type calculated from the annual emission in the 2014 NEI. It should be noted that the emission rate for conveyorized degreasing is based on a single unit emission rate and it is unclear how representative this emission rate is of a “typical” conveyorized degreaser.

Table_Apx G-5. Distribution of Perchloroethylene Conveyorized Degreasing Unit Emissions

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
1	4.08	1.0000

Table_Apx G-6. Distribution of Perchloroethylene Web Degreasing Unit Emissions

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
1	0.0495	0.1000
1	0.0495	0.1000
1	0.0495	0.1000
1	0.0495	0.1000
1	0.0330	0.1000
1	0.0330	0.1000
4	0.0200	0.4000

Table_Apx G-7. Distribution of Perchloroethylene Cold Cleaning Unit Emissions

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
1	0.124	0.0385
1	0.085	0.0385
1	0.022	0.0385
1	1.17E-02	0.0385
1	4.02E-03	0.0385
1	8.03E-04	0.0385
1	4.01E-04	0.0385
1	2.67E-04	0.0385
1	2.66E-04	0.0385
1	2.30E-04	0.0385
1	2.01E-04	0.0385
1	2.01E-04	0.0385
1	1.34E-04	0.0385
1	9.13E-05	0.0385
1	9.13E-05	0.0385
1	9.13E-05	0.0385
1	9.13E-05	0.0385
1	9.13E-05	0.0385
1	2.77E-05	0.0385
1	2.28E-05	0.0385
1	2.17E-05	0.0385
1	1.83E-05	0.0385
1	1.49E-06	0.0385
1	2.98E-07	0.0385
1	2.98E-07	0.0385
1	1.13E-07	0.0385

G.2.8 Operating Hours

For the operating hours of each machine type (conveyorized, web, and cold), EPA used a discrete distribution based on the daily operating hours reported in the 2014 NEI. It should be noted that not all units had an accompanying reported daily operating hours; therefore, the distribution for the operating hours per day is based on a subset of the reported units. Table_Apx G-8 through Table_Apx G-10 summarize the distribution of operating hours per day for each machine type. It should be noted that the operating hours for conveyorized degreasers is based on a single unit operating time and it is unclear how representative this is of a "typical" conveyorized degreaser.

Table_Apx G-8. Distribution of Perchloroethylene Conveyorized Degreasing Operating Hours

Count of Occurrences	Operating Hours (hr/day)	Fractional Probability
1	13	1.0000

Table_Apx G-9. Distribution of Perchloroethylene Web Degreasing Operating Hours

Count of Occurrences	Operating Hours (hr/day)	Fractional Probability
7	24	1.0000

Table_Apx G-10. Distribution of Perchloroethylene Cold Cleaning Operating Hours

Count of Occurrences	Operating Hours (hr/day)	Fractional Probability
19	24	0.7037
7	8	0.2593
1	1	0.0370

Appendix H Brake Servicing Near-Field/Far-Field Inhalation Exposure Model Approach and Parameters

This appendix presents the modeling approach and model equations used in the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. The model was developed through review of the literature and consideration of existing EPA/OPPT exposure models. This model uses a near-field/far-field approach (Aiha, 2009), where an aerosol application located inside the near-field generates a mist of droplets, and indoor air movements lead to the convection of the droplets between the near-field and far-field. Workers are assumed to be exposed to PCE droplet concentrations in the near-field, while occupational non-users are exposed at concentrations in the far-field.

The model uses the following parameters to estimate exposure concentrations in the near-field and far-field:

- Far-field size;
- Near-field size;
- Air exchange rate;
- Indoor air speed;
- Concentration of PCE in the aerosol formulation;
- Amount of degreaser used per brake job;
- Number of degreaser applications per brake job;
- Time duration of brake job;
- Operating hours per week; and
- Number of jobs per work shift.

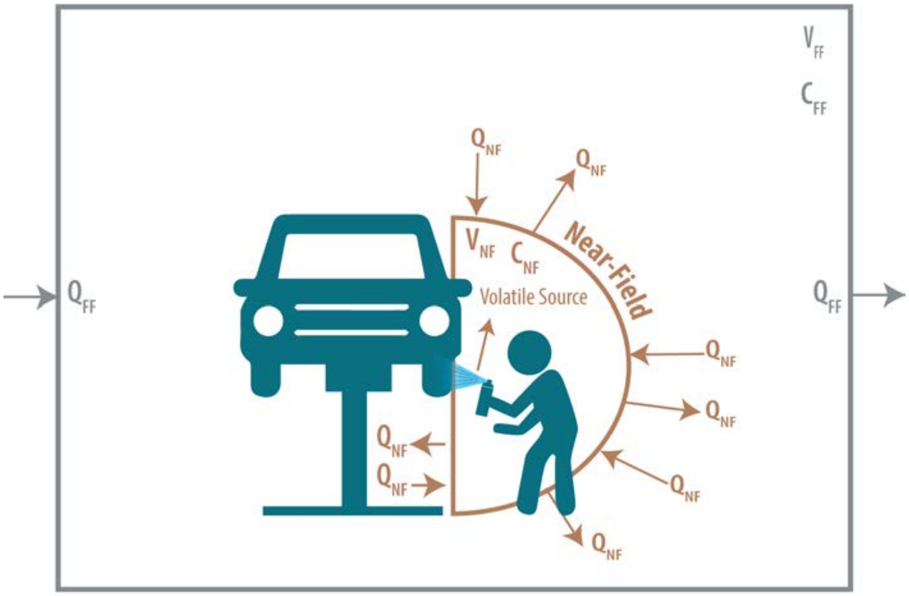
An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 100,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence).

Model results from the Monte Carlo simulation are presented as 95th and 50th percentile values. The statistics were calculated directly in @Risk. The 95th percentile value was selected to represent high-end exposure level, whereas the 50th percentile value was selected to represent central tendency exposure level. The following subsections detail the model design equations and parameters for the brake servicing model.

H.1 Model Design Equations

In brake servicing, the vehicle is raised on an automobile lift to a comfortable working height to allow the worker (mechanic) to remove the wheel and access the brake system. Brake servicing can include inspections, adjustments, brake pad replacements, and rotor resurfacing. These service types often involve disassembly, replacement or repair, and reassembly of the brake system. Automotive brake cleaners are used to remove oil, grease, brake fluid, brake pad dust, or dirt. Mechanics may occasionally use brake cleaners, engine degreasers, carburetor cleaners, and general purpose degreasers interchangeably (Carb, 2000). Automotive brake cleaners can come in aerosol or liquid form (Carb, 2000): this model estimates exposures from aerosol brake cleaners (degreasers).

Figure_Apx H-1 illustrates the near-field/far-field modeling approach as it was applied by EPA to brake servicing using an aerosol degreaser. The application of the aerosol degreaser immediately generates a mist of droplets in the near-field, resulting in worker exposures at a PCE concentration C_{NF}. The concentration is directly proportional to the amount of aerosol degreaser applied by the worker, who is standing in the near-field-zone (i.e., the working zone). The volume of this zone is denoted by V_{NF}. The ventilation rate for the near-field zone (Q_{NF}) determines how quickly PCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outside air.



Figure_Apx H-1. The Near-Field/Far-Field Model as Applied to the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model

In brake servicing using an aerosol degreaser, aerosol degreaser droplets enter the near-field in non-steady "bursts," where each burst results in a sudden rise in the near-field concentration. The near-field and far-field concentrations then decay with time until the next burst causes a new rise in near-field concentration. Based on site data from automotive maintenance and repair shops obtained by CARB (Carb, 2000) for brake cleaning activities and as explained in Appendix H.2.5 and H.2.9, the model assumes a worker will perform an average of 11 applications of the degreaser product per brake job with five minutes between each application and that a worker may perform one to four brake jobs per day each taking one hour to complete. EPA modeled two scenarios: one where the brake jobs occurred back-to-back and one where brake jobs occurred one hour apart. In both scenarios, EPA assumed the worker does not perform a brake job, and does not use the aerosol degreaser, during the first hour of the day.

EPA denoted the top of each five-minute period for each hour of the day (e.g., 8:00 am, 8:05 am, 8:10 am, etc.) as $t_{m,n}$. Here, m has the values of 0, 1, 2, 3, 4, 5, 6, and 7 to indicate the top of each hour of the day (e.g., 8 am, 9 am, etc.) and n has the values of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 to indicate the top of each five-minute period within the hour. No aerosol degreaser is used, and no exposures occur, during the first hour of the day, $t_{0,0}$ to $t_{0,11}$ (e.g., 8 am to 9 am). Then, in both scenarios, the worker begins the first brake job during the second hour, $t_{1,0}$ (e.g., 9 am to 10 am). The worker applies the aerosol degreaser at the top of the second 5-minute period and each subsequent 5-minute period during the hour-long brake job (e.g., 9:05 am, 9:10 am,…9:55 am). In the first scenario, the brake jobs are performed back-to-back, if performing more than one brake job on the given day. Therefore, the second brake job begins at the top of the third hour (e.g., 10 am), and the worker applies the aerosol degreaser at the top of the second 5-minute period and each subsequent 5-minute period (e.g., 10:05 am, 10:10 am,…10:55 am). In the second scenario, the brake jobs are performed every other hour, if performing more than one brake job on the given day. Therefore, the second brake job begins at the top of the fourth hour (e.g., 11 am), and the worker applies the aerosol degreaser at the top of the second 5-minute period and each subsequent 5-minute period (e.g., 11:05 am, 11:10 am,…11:55 am).

In the first scenario, after the worker performs the last brake job, the workers and occupational non-users (ONUs) continue to be exposed as the airborne concentrations decay during the final three to six hours until the end of the day (e.g., 4 pm). In the second scenario, after the worker performs each brake job, the workers and ONUs continue to be exposed as the airborne concentrations decay during the time in which no brake jobs are occurring and then again when the next brake job is initiated. In both scenarios, the workers and ONUs are no longer exposed once they leave work.

Based on data from CARB (Carb, 2000), EPA assumes each brake job requires one 14.4-oz can of aerosol brake cleaner as described in further detail below. The model determines the application rate of PCE using the weight fraction of PCE in the aerosol product. EPA uses a uniform distribution of weight fractions for PCE based on facility data for the aerosol products in use (Carb, 2000).

The model design equations are presented below in Equation_Apx H-1 through Equation_Apx H-14.

Near-Field Mass Balance

Equation_Apx H-1

$$V_{NF}\frac{dC_{NF}}{dt} = C_{FF}Q_{NF} - C_{NF}Q_{NF}$$

Far-Field Mass Balance

Equation_Apx H-2

$$V_{FF}\frac{dC_{FF}}{dt} = C_{NF}Q_{NF} - C_{FF}Q_{NF} - C_{FF}Q_{FF}$$

Where:

V_{NF} = near-field volume;
V_{FF} = far-field volume;
Q_{NF} = near-field ventilation rate;
Q_{FF} = far-field ventilation rate;
C_{NF} = average near-field concentration;
C_{FF} = average far-field concentration; and

t = elapsed time.

Solving Equation_Apx H-1 and Equation_Apx H-2 in terms of the time-varying concentrations in the near-field and far-field yields Equation_Apx H-3 and Equation_Apx H-4, which EPA applied to each of the 12 five-minute increments during each hour of the day. For each five-minute increment, EPA calculated the initial near-field concentration at the top of the period ($t_{m,n}$), accounting for both the burst of PCE from the degreaser application (if the five-minute increment is during a brake job) and the residual near-field concentration remaining after the previous five-minute increment ($t_{m,n-1}$; except during the first hour and $t_{m,0}$ of the first brake job, in which case there would be no residual PCE from a previous application). The initial far-field concentration is equal to the residual far-field concentration remaining after the previous five-minute increment. EPA then calculated the decayed concentration in the near-field and far-field at the end of the five-minute period, just before the degreaser application at the top of the next period ($t_{m,n+1}$). EPA then calculated a 5-minute TWA exposure for the near-field and far-field, representative of the worker's and ONUs' exposures to the airborne concentrations during each five-minute increment using Equation_Apx H-13 and Equation_Apx H-14. The *k* coefficients (Equation_Apx H-5 through Equation_Apx H-8) are a function of the initial near-field and far-field concentrations, and therefore are re-calculated at the top of each five-minute period. In the equations below, where the subscript "m, n-1" is used, if the value of n-1 is less than zero, the value at "m-1, 11" is used and where the subscript "m, n+1" is used, if the value of n+1 is greater than 11, the value at "m+1, 0" is used.

Equation_Apx H-3

$$C_{NF,t_{m,n+1}} = \left(k_{1,t_{m,n}} e^{\lambda_1 t} + k_{2,t_{m,n}} e^{\lambda_2 t}\right)$$

Equation_Apx H-4

$$C_{FF,t_{m,n+1}} = \left(k_{3,t_{m,n}} e^{\lambda_1 t} - k_{4,t_{m,n}} e^{\lambda_2 t}\right)$$

Equation_Apx H-5

$$k_{1,t_{m,n}} = \frac{Q_{NF}\left(C_{FF,0}(t_{m,n}) - C_{NF,0}(t_{m,n})\right) - \lambda_2 V_{NF} C_{NF,0}(t_{m,n})}{V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx H-6

$$k_{2,t_{m,n}} = \frac{Q_{NF}\left(C_{NF,0}(t_{m,n}) - C_{FF,0}\,(t_{m,n})\right) + \lambda_1 V_{NF} C_{NF,0}(t_{m,n})}{V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx H-7

$$k_{3,t_{m,n}} = \frac{(Q_{NF} + \lambda_1 V_{NF})(Q_{NF}\left(C_{FF,0}(t_{m,n}) - C_{NF,0}(t_{m,n})\right) - \lambda_2 V_{NF} C_{NF,0}(t_{m,n}))}{Q_{NF} V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx H-8

$$k_{4,t_{m,n}} = \frac{(Q_{NF} + \lambda_2 V_{NF})(Q_{NF}\left(C_{NF,0}(t_{m,n}) - C_{FF,0}(t_{m,n})\right) + \lambda_1 V_{NF} C_{NF,0}(t_{m,n}))}{Q_{NF} V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx H-9

$$\lambda_1 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) + \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

Equation_Apx H-10

$$\lambda_2 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) - \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

Equation_Apx H-11

$$C_{NF,o}\left(t_{m,n}\right) = \begin{cases} 0, \;\; m = 0 \\ \dfrac{Amt}{V_{NF}}\left(1{,}000\,\dfrac{mg}{g}\right) + C_{NF}\left(t_{m,n-1}\right), \;\; n > 0 \; for\ all\ m\ where\ brake\ job\ occurs \end{cases}$$

Equation_Apx H-12

$$C_{FF,o}\left(t_{m,n}\right) = \begin{cases} 0, \;\; m = 0 \\ C_{FF}\left(t_{m,n-1}\right), \;\; for\ all\ n\ where\ m > 0 \end{cases}$$

Equation_Apx H-13

$$C_{NF,\text{ 5-min TWA, }t_{m,n}} = \frac{\left(\dfrac{k_{1,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_2} + \dfrac{k_{2,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_2}\right) - \left(\dfrac{k_{1,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_1} + \dfrac{k_{2,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_1}\right)}{t_2 - t_1}$$

Equation_Apx H-14

$$C_{FF,\text{ 5-min TWA, }t_{m,n}} = \frac{\left(\dfrac{k_{3,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_2} + \dfrac{k_{4,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_2}\right) - \left(\dfrac{k_{3,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_1} + \dfrac{k_{4,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_1}\right)}{t_2 - t_1}$$

After calculating all near-field/far-field 5-minute TWA exposures (i.e., $C_{NF,\text{ 5-min TWA, }t_{m,n}}$ and $C_{FF,\text{ 5-min TWA, }t_{m,n}}$) for each five-minute period of the work day, EPA calculated the near-field/far-field 8-hour TWA concentration and 1-hour TWA concentrations following the equations below:

Equation_Apx H-15

$$C_{NF,\text{ 8-hr }TWA} = \frac{\sum_{m=0}^{7}\sum_{n=0}^{11}\left[C_{NF,\text{5-min }TWA,t_{m,n}} \times 0.0833\ hr\right]}{8\ hr}$$

Equation_Apx H-16

$$C_{NF,\text{ 8-hr }TWA} = \frac{\sum_{m=0}^{7}\sum_{n=0}^{11}\left[C_{FF,\text{5-min }TWA,t_{m,n}} \times 0.0833\ hr\right]}{8\ hr}$$

Equation_Apx H-17

$$C_{NF,\text{1-hr}\,TWA} = \frac{\sum_{n=0}^{11}\left[C_{NF,\text{5-min}\,TWA,t_{m,n}} \times 0.0833\ hr\right]}{1\ hr}$$

Equation_Apx H-18

$$C_{FF,\text{1-hr}\,TWA} = \frac{\sum_{n=0}^{11}\left[C_{FF,\text{5-min}\,TWA,t_{m,n}} \times 0.0833\ hr\right]}{1\ hr}$$

EPA calculated rolling 1-hour TWA's throughout the workday and the model reports the maximum calculated 1-hour TWA.

To calculate the mass transfer to and from the near-field, the free surface area (FSA) is defined to be the surface area through which mass transfer can occur. The FSA is not equal to the surface area of the entire near-field. EPA defined the near-field zone to be a hemisphere with its major axis oriented vertically, against the vehicle, and aligned through the center of the wheel (see Figure_Apx H-1). The top half of the circular cross-section rests against, and is blocked by, the vehicle and is not available for mass transfer. The FSA is calculated as the entire surface area of the hemisphere's curved surface and half of the hemisphere's circular surface per Equation_Apx H-19, below:

Equation_Apx H-19

$$FSA = \left(\frac{1}{2} \times 4\pi R_{NF}^2\right) + \left(\frac{1}{2} \times \pi R_{NF}^2\right)$$

Where: R_{NF} is the radius of the near-field

The near-field ventilation rate, Q_{NF}, is calculated in Equation_Apx H-20 from the indoor wind speed, v_{NF}, and FSA, assuming half of the FSA is available for mass transfer into the near-field and half of the FSA is available for mass transfer out of the near-field:

Equation_Apx H-20

$$Q_{NF} = \frac{1}{2} v_{NF} FSA$$

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx H-21:

Equation_Apx H-21

$$Q_{FF} = V_{FF} AER$$

Using the model inputs described in Appendix H.2, EPA estimated PCE inhalation exposures for workers in the near-field and for occupational non-users in the far-field. EPA then conducted the Monte Carlo simulations using @Risk (Version 7.0.0). The simulations applied 100,000 iterations and the Latin Hypercube sampling method.

H.2 Model Parameters

Table_Apx H-1 summarizes the model parameters and their values for the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. Each parameter is discussed in detail in the following subsections.

Table_Apx H-1. Summary of Parameter Values and Distributions Used in the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	m^3	—	—	206	70,679	3,769	Triangular	Distribution based on data collected by CARB (Carb, 2000).
Air exchange rate	AER	hr^{-1}	—	—	1	20	3.5	Triangular	Demou (2009) identifies typical AERs of 1 hr^{-1} and 3 to 20 hr^{-1} for occupational settings without and with mechanical ventilation systems, respectively. Hellweg (2009) identifies average AERs for occupational settings utilizing mechanical ventilation systems to be between 3 and 20 hr^{-1}. Golsteijn (2014) indicates a characteristic AER of 4 hr^{-1}. Peer reviewers of EPA's 2013 TCE draft risk assessment commented that values around 2 to 5 hr^{-1} may be more likely (Scg, 2013), in agreement with Golsteijn (2014) . A triangular distribution is used with the mode equal to the midpoint of the range provided by the peer reviewer (3.5 is the midpoint of the range 2 to 5 hr^{-1}).
Near-field indoor wind speed	v_{NF}	ft/hr	—	—	0	23,882	—	Lognormal	Lognormal distribution fit to commercial-type workplace data from Baldwin (1998).
		cm/s	—	—	0	202.2	—	Lognormal	
Near-field radius	R_{NF}	m	1.5	—	—	—	—	Constant Value	Constant.
Starting time for each	t_1	hr	0	—	—	—	—	Constant Value	Constant.

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
application period									
End time for each application period	t_2	hr	0.0833	—	—	—	—	Constant Value	Assumes aerosol degreaser is applied in 5-minute increments during brake job.
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	Constant.
PCE weight fraction	wtfrac	wt frac	—	—	0.20	0.99	—	Discrete	Discrete distribution of PCE-based aerosol product formulations based on survey results from CARB (Carb, 2000). Where the weight fraction of PCE in the formulation was given as a range, EPA assumed a uniform distribution within the reported range for the PCE concentration in the product.
Degreaser Used per Brake Job	W_d	oz/ job	14.4	—	—	—	—	Constant Value	Based on data from CARB (Carb, 2000).
Number of Applications per Job	N_A	Applications/ job	11	—	—	—	—	Constant Value	Calculated from the average of the number of applications per brake and number of brakes per job.
Amount Used per Application	Amt	g PCE/ application	—	—	7.4	36.7	—	Calculated	Calculated from wtfrac, W_d, and N_A.
Operating hours per week	OHpW	hr/week	—	—	40	122.5	—	Lognormal	Lognormal distribution fit to the operating hours per week observed in CARB (Carb, 2000) site visits.

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Number of Brake Jobs per Work Shift	N_J	jobs/site-shift	—	—	1	4	—	—	Calculated from the average number of brake jobs per site per year, OHpW, and assuming 52 operating weeks per year and 8 hours per work shift.

H.2.1 Far-Field Volume

The far-field volume is based on information obtained from CARB (Carb, 2000) from site visits of 137 automotive maintenance and repair shops in California. CARB (2000) indicated that shop volumes at the visited sites ranged from 200 to 70,679 m^3 with an average shop volume of 3,769 m^3. Based on this data EPA assumed a triangular distribution bound from 200 m^3 to 70,679 m^3 with a mode of 3,769 m^3 (the average of the data from CARB (2000)).

CARB measured the physical dimensions of the portion of the facility where brake service work was performed at the visited facilities. CARB did not consider other areas of the facility, such as customer waiting areas and adjacent storage rooms, if they were separated by a normally closed door. If the door was normally open, then CARB did consider those areas as part of the measured portion where brake servicing emissions could occur (Carb, 2000) . CARB's methodology for measuring the physical dimensions of the visited facilities provides the appropriate physical dimensions needed to represent the far-field volume in EPA's model. Therefore, CARB's reported facility volume data are appropriate for EPA's modeling purposes.

H.2.2 Air Exchange Rate

The air exchange rate (AER) is based on data from Demou (2009), Hellweg (2009), Golsteijn (2014), and information received from a peer reviewer during the development of the 2014 TSCA Work Plan Chemical Risk Assessment Trichloroethylene: Degreasing, Spot Cleaning and Arts & Crafts Uses (Scg, 2013). Demou (2009) identifies typical AERs of 1 hr^{-1} and 3 to 20 hr^{-1} for occupational settings without and with mechanical ventilation systems, respectively. Similarly, Hellweg (2009) identifies average AERs for occupational settings using mechanical ventilation systems to vary from 3 to 20 hr^{-1}. Golsteijn (2014) indicates a characteristic AER of 4 hr^{-1}. The risk assessment peer reviewer comments indicated that values around 2 to 5 hr^{-1} are likely (Scg, 2013), in agreement with Golsteijn (2014) and the low end reported by Demou (2009) and Hellweg (2009). Therefore, EPA used a triangular distribution with the mode equal to 3.5 hr^{-1}, the midpoint of the range provided by the risk assessment peer reviewer (3.5 is the midpoint of the range 2 to 5 hr^{-1}), with a minimum of 1 hr^{-1}, per Demou (2009) and a maximum of 20 hr^{-1} per Demou (2009) and Hellweg (2009).

H.2.3 Near-Field Indoor Air Speed

Baldwin (1998) measured indoor air speeds across a variety of occupational settings in the United Kingdom. Fifty-five work areas were surveyed across a variety of workplaces.

EPA analyzed the air speed data from Baldwin (1998) and categorized the air speed surveys into settings representative of industrial facilities and representative of commercial facilities. EPA fit separate distributions for these industrial and commercial settings and used the commercial distribution for facilities performing aerosol degreasing.

EPA fit a lognormal distribution for both data sets as consistent with the authors observations that the air speed measurements within a surveyed location were lognormally distributed and the population of the mean air speeds among all surveys were lognormally distributed. Since lognormal distributions are bound by zero and positive infinity, EPA truncated the distribution at the largest observed value among all of the survey mean air speeds from Baldwin (1998).

EPA fit the air speed surveys representative of commercial facilities to a lognormal distribution with the following parameter values: mean of 10.853 cm/s and standard deviation of 7.883 cm/s. In the model, the lognormal distribution is truncated at a maximum allowed value of 202.2 cm/s (largest surveyed mean air speed observed in Baldwin (1998) to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

Baldwin (1998) only presented the mean air speed of each survey. The authors did not present the individual measurements within each survey. Therefore, these distributions represent a distribution of mean air speeds and not a distribution of spatially-variable air speeds within a single workplace setting. However, a mean air speed (averaged over a work area) is the required input for the model.

H.2.4 Near-Field Volume

EPA defined the near-field zone to be a hemisphere with its major axis oriented vertically, against the vehicle, and aligned through the center of the wheel (see Figure_Apx H-1). The near-field volume is calculated per Equation_Apx H-22. EPA defined a near-field radius (R_{NF}) of 1.5 meters, approximately 4.9 feet, as an estimate of the working height of the wheel, as measured from the floor to the center of the wheel.

Equation_Apx H-22

$$V_{NF} = \frac{1}{2} \times \frac{4}{3} \pi R_{NF}^3$$

H.2.5 Application Time

EPA assumed an average of 11 brake cleaner applications per brake job (see Appendix H.2.9). CARB observed, from their site visits, that the visited facilities did not perform more than one brake job in any given hour (Carb, 2000). Therefore, EPA assumed a brake job takes one hour to perform. Using an assumed average of 11 brake cleaner applications per brake job and one hour to perform a brake job, EPA calculates an average brake cleaner application frequency of once every five minutes (0.0833 hr). EPA models an average brake job of having no brake cleaner application during its first five minutes and then one brake cleaner application per each subsequent 5-minute period during the one-hour brake job.

H.2.6 Averaging Time

EPA was interested in estimating 8-hr TWAs for use in risk calculations; therefore, a constant averaging time of eight hours was used.

H.2.7 Perchloroethylene Weight Fraction

CARB (2000) collected information on PCE concentrations from safety data sheets (SDS) of PCE-based aerosol products used at 54 automotive maintenance and repair facilities. EPA used a discrete distribution to model the PCE weight fraction based on the number of occurrences of each formulation type. In some instances, the concentration of PCE was reported as a range. For these formulation types, EPA used a uniform distribution to model the PCE weight fraction within the formulation type. Table_Apx H-2 provides a summary of the reported PCE weight fractions in the SDS's and the number of occurrences of each formulation type, and the fractional probability of each formulation type.

Table_Apx H-2. Summary of Perchloroethylene-Based Aerosol Degreaser Formulations

Formulation Type ID Assigned by EPA for Use in the Model	Perchloroethylene Weight Fraction	Number of Occurrences	Fractional Probability
1000	0.65-0.94	29	0.5370
1100	0.99	2	0.0370
1200	0.90	1	0.0185
1300	0.70-0.94	2	0.0370
1400	0.25-0.85	1	0.0185
1500	0.90-0.99	2	0.0370
1600	0.65-0.75	1	0.0185
1700	0.89	1	0.0185
1800	0.60-0.99	2	0.0370
1900	0.20-0.50	1	0.0185
2000	0.55	9	0.1667
2100	0.85	1	0.0185
2200	0.98	2	0.0370
	Total	**54**	1.0000

H.2.8 Volume of Degreaser Used per Brake Job

CARB (2000) assumed that brake jobs require 14.4 oz of aerosol product. EPA did not identify other information to estimate the volume of aerosol product per job; therefore, EPA used a constant volume of 14.4 oz per brake job based on CARB (2000).

H.2.9 Number of Applications per Brake Job

Workers typically apply the brake cleaner before, during, and after brake disassembly. Workers may also apply the brake cleaner after brake reassembly as a final cleaning process (Carb, 2000). Therefore, EPA assumed a worker applies a brake cleaner three or four times per wheel. Since a brake job can be performed on either one axle or two axles (Carb, 2000), EPA assumed a brake job may involve either two or four wheels. Therefore, the number of brake cleaner (aerosol degreaser) applications per brake job can range from six (3 applications/brake x 2 brakes) to 16 (4 applications/brake x 4 brakes). EPA assumed a constant number of applications per brake job based on the midpoint of this range of 11 applications per brake job.

H.2.10 Amount of Perchloroethylene Used per Application

EPA calculated the amount of perchloroethylene used per application using Equation_Apx H-23. The calculated mass of perchloroethylene used per application ranges from 7.4 to 36.7 grams.

Equation_Apx H-23

$$Amt = \frac{W_d \times wtfrac \times 28.3495 \frac{g}{oz}}{N_A}$$

Where:

Amt = Amount of PCE used per application (g/application);
W_d = Weight of degreaser used per brake job (oz/job);
Wtfrac = Weight fraction of PCE in aerosol degreaser (unitless); and
N_A = Number of degreaser applications per brake job (applications/job).

H.2.11 Operating Hours per Week

CARB (2000) collected weekly operating hour data for 54 automotive maintenance and repair facilities. The surveyed facilities included service stations (fuel retail stations), general automotive shops, car dealerships, brake repair shops, and vehicle fleet maintenance facilities. The weekly operating hours of the surveyed facilities ranged from 40 to 122.5 hr/week. EPA fit a lognormal distribution to the surveyed weekly operating hour data. The resulting lognormal distribution has a mean of 16.943 and standard deviation of 13.813, which set the shape of the lognormal distribution. EPA shifted the distribution to the right such that its minimum value is 40 hr/week and set a truncation of 122.5 hr/week (the truncation is set as 82.5 hr/week relative to the left shift of 40 hr/week).

H.2.12 Number of Brake Jobs per Work Shift

CARB (2000) visited 137 automotive maintenance and repair shops and collected data on the number of brake jobs performed annually at each facility. CARB calculated an average of 936 brake jobs performed per facility per year. EPA calculated the number of brake jobs per work shift using the average number of jobs per site per year, the operating hours per week, and assuming 52 weeks of operation per year and eight hours per work shift using Equation_Apx H-24 and rounding to the nearest integer. The calculated number of brake jobs per work shift ranges from one to four.

Equation_Apx H-24

$$N_J = \frac{936 \frac{jobs}{\text{site-year}} \times 8 \frac{hours}{shift}}{52 \frac{weeks}{yr} \times OHpW}$$

Where:

N_J = Number of brake jobs per work shift (jobs/site-shift); and
OHpW = Operating hours per week (hr/week).

Appendix I Dry Cleaning Multi-Zone Inhalation Exposure Model Approach and Parameters

This appendix presents the modeling approach and model equations used in the Dry Cleaning Multi-Zone Inhalation Exposure Model. The model was developed through review of relevant literature and consideration of existing EPA exposure models. This model uses a near-field/far-field approach (Aiha, 2009), 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 occupational non-users are exposed at concentrations in the far-field. Because there are multiple activities with potential PCE exposure at a dry cleaner, a multi-zone modeling approach is used to account for PCE vapor generation from multiple sources. The model considers the following three worker activities:

- **Spot cleaning of stains on both dirty and clean garments:** On receiving a garment, dry cleaners inspect for stains or spots they can remove as much of as possible before cleaning the garment in a dry cleaning machine. Spot cleaning may also occur after dry cleaning if the stains or spots were not adequately removed. Spot cleaning occurs on a spotting board and can involve the use of a spotting agent containing various solvents, such as PCE. Workers are exposed to PCE when applying it via squeeze bottles, hand-held spray bottles, or even from spray guns connected to pressurized tanks. Once applied, the worker may come into further contact with the PCE if using a brush, spatula, pressurized air or steam, or their fingers to scrape or flush away the stain (Young, 2012; Niosh, 1997a). For modeling, EPA assumed the near-field is a rectangular volume covering the body of a worker.
- **Unloading garments from dry cleaning machines:** At the end of each dry cleaning cycle, dry cleaning workers manually open the machine door to retrieve cleaned garments. During this activity, workers are exposed to PCE vapors remaining in the dry cleaning machine cylinder. For modeling, EPA assumed that the near-field consists of a hemispherical area surrounding the machine door, and that the entire cylinder volume of air containing PCE exchanges with the workplace air, resulting in a "spike" in PCE concentration in the near-field, C_D, during each unloading event. This concentration is directly proportional to the amount of residual PCE in the cylinder when the door is opened. The near-field concentration then decays with time until the next unloading event occurs.
- **Finishing and pressing:** The cleaned garments taken out of the cylinder after each dry clean cycle contain residual solvents and are not completely dried (Von Grote, 2003). The residual solvents are continuously emitted into the workplace during pressing and finishing, where workers manually place the cleaned garments on the pressing machine to be steamed and ironed. EPA assumed any residual solvent is entirely evaporated during pressing, resulting in an increase in the near-field PCE concentration during this activity. Workers are exposed to PCE vapors while standing in vicinity of the press machine. Because this activity is typically performed while standing, EPA assumed the near-field to be a rectangular volume covering the upper body of the worker.

The model uses the following parameters to estimate exposure concentrations in the near-field and far-field:

- Far-field size;

- Near-field size;
- Air exchange rate;
- Indoor air speed;
- Exposure duration;
- Concentration of solvent in the drum after the dry cleaning cycle;
- Residual solvent adhered to garments after dry cleaning;
- Spot cleaning use rate; and
- Operating hours per day.

An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Professional Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 10,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence). Note: this is fewer iterations than used for the near-field/far-field models described in other appendices as the multi-zone model takes significantly longer to run and 10,000 iterations allowed the simulation to be complete in a reasonable amount of time while still capturing the variability of each parameter.

Model results from the Monte Carlo simulation are presented as 95th and 50th percentile values. The statistics were calculated directly in @Risk[34]. The 95th percentile value was selected to represent high-end exposure level, whereas the 50th percentile value was selected to represent central tendency exposure level. The following subsections detail the model design equations and parameters for the dry cleaning model.

I.1 Model Design Equations

Figure_Apx I-1 illustrates the near-field/far-field modeling approach as it was applied by EPA to the Dry Cleaning Multi-Zone Inhalation Exposure Model. As the figure shows, PCE vapor is generated in each of the three near-fields, resulting in worker exposures at concentrations C_S, C_D, and C_F. The volume of each zone is denoted by V_S, V_D, and V_F. The ventilation rate for the near-field zone (Q_S, Q_D, Q_F) determines how quickly PCE dissipates into the far-field (i.e., the facility space surrounding the near-fields), resulting in occupational non-user exposures to PCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the PCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly PCE dissipates out of the surrounding space and into the outside air.

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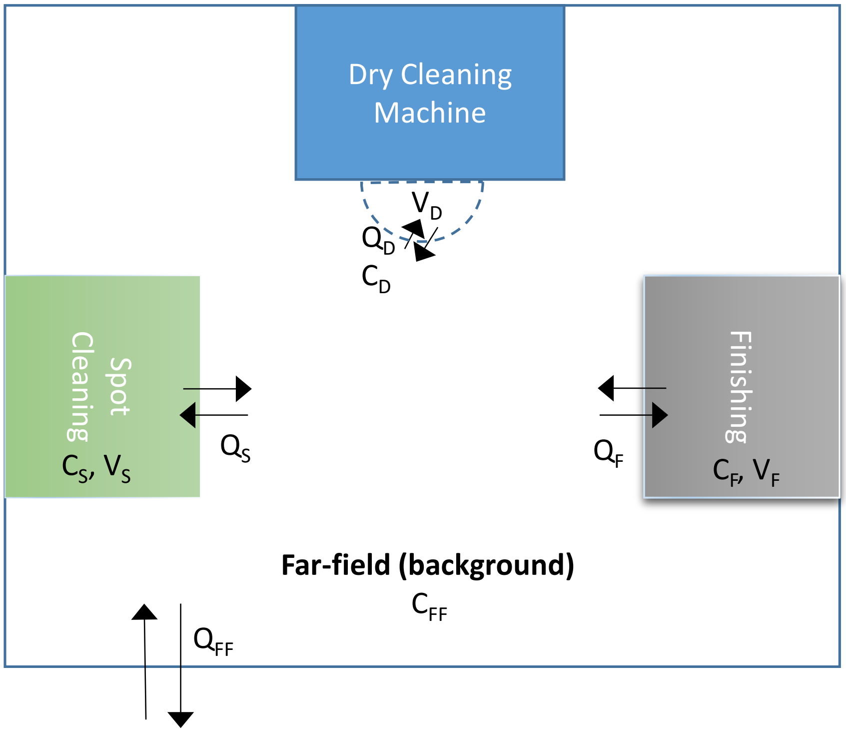
[34] *@Risk*; Palisade; https://www.palisade.com/risk/



Figure_Apx I-1. Illustration of the Dry Cleaning Multi-Zone Inhalation Exposure Model

The model design equations are presented below in Equation_Apx I-1 through Equation_Apx I-15.

<u>Near-Field Mass Balance for Spot Cleaning (Multi-Zone)</u>

Equation_Apx I-1

$$V_S \frac{dC_S}{dt} = C_{FF}Q_S - C_SQ_S + G_S$$

<u>Near-Field Mass Balance for Finishing (Multi-Zone)</u>

Equation_Apx I-2

$$V_F \frac{dC_F}{dt} = C_{FF}Q_F - C_FQ_F + G_F$$

<u>Near-Field Mass Balance for Dry Cleaning Machine (Multi-Zone)</u>

Equation_Apx I-3

$$V_D \frac{dC_D}{dt} = C_{FF}Q_D - C_DQ_D$$

<u>Far-Field Mass Balance</u>

Equation_Apx I-4

$$V_{FF} \frac{dC_{FF}}{dt} = C_SQ_S + C_FQ_F + C_DQ_D - C_{FF}Q_S - C_{FF}Q_F - C_{FF}Q_D - C_{FF}Q_{FF}$$

Where:

V_S = near-field volume for spot cleaning;
V_F = near-field volume for finishing;

V_D = near-field volume for unloading dry cleaning machine;
V_{FF} = far-field volume;
Q_S = near-field ventilation rate for spot cleaning;
Q_F = near-field ventilation rate for finishing;
Q_D = near-field ventilation rate for dry cleaning machine;
Q_{FF} = far-field ventilation rate;
C_S = average near-field concentration for spot cleaning;
C_F = average near-field concentration for finishing;
C_D = average near-field concentration for dry cleaning machine;
C_{FF} = average far-field concentration;
G_S = average vapor generation rate for spot cleaning;
G_F = average vapor generation rate for finishing; and
t = elapsed time.

To calculate the mass transfer to and from the near-field, the free surface area, FSA, is defined to be the surface area through which mass transfer can occur. Note that the FSA may not be equal to the surface area of the entire near-field.

For spot-cleaning, EPA defined the near-field zone to be a rectangular box resting on the floor; therefore, no mass transfer can occur through the near-field box's floor. FSA is calculated using Equation_Apx I-5:

Equation_Apx I-5

$$FSA_S = 2(L_S H_S) + 2(W_S H_S) + (L_S W_S)$$

For finishing, EPA defined the near-field zone to be a rectangular box resting on the floor; therefore, no mass transfer can occur through the near-field box's floor. FSA is calculated using Equation_Apx I-6:

Equation_Apx I-6

$$FSA_F = 2(L_{NF} H_{NF}) + 2(W_{NF} H_{NF}) + (L_{NF} W_{NF})$$

For dry cleaning, EPA defined the near-field zone to be a hemispheric area projecting from the door of the dry cleaning machine, calculated as Equation_Apx I-7:

Equation_Apx I-7

$$FSA_D = 2\pi r_D^2$$

Where:

FSA_S = free surface area for spot cleaning;
FSA_F = free surface area for finishing;
FSA_D = free surface area for dry cleaning machine;
L_S = near-field length for spot cleaning;
H_S = near-field height for spot cleaning;
W_S = near-field width for spot cleaning;
L_F = near-field length for finishing;
H_F = near-field height for finishing;
W_F = near-field width for finishing; and

r_D = radius of the dry cleaning machine door opening.

The near-field ventilation rates, Q_S, Q_D, and Q_F are calculated from the near-field indoor wind speed, ν_{NF}, and FSA, using Equation_Apx I-8 through Equation_Apx I-10, assuming half of FSA is available for mass transfer into the near-field and half of FSA is available for mass transfer out of the near-field. The near-field indoor wind speed is assumed to be the same across all three near fields:

Equation_Apx I-8

$$Q_S = \frac{1}{2} v_{NF} FSA_S$$

Equation_Apx I-9

$$Q_F = \frac{1}{2} v_{NF} FSA_F$$

Equation_Apx I-10

$$Q_D = \frac{1}{2} V_{NF} FSA_D$$

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx I-11:

Equation_Apx I-11

$$Q_{FF} = V_{FF} AER$$

The model results in the following four, coupled ordinary differential equations (ODEs) given in Equation_Apx I-12 through Equation_Apx I-15:

Equation_Apx I-12

$$\frac{dC_S}{dt} = -\frac{Q_S}{V_S} C_S + \frac{Q_S}{V_S} C_{FF} + \frac{G_S}{V_S}$$

Equation_Apx I-13

$$\frac{dC_F}{dt} = -\frac{Q_F}{V_F} C_F + \frac{Q_F}{V_F} C_{FF} + \frac{G_F}{V_F}$$

Equation_Apx I-14

$$\frac{dC_D}{dt} = -\frac{Q_D}{V_D} C_D + \frac{Q_D}{V_D} C_{FF}$$

Equation_Apx I-15

$$\frac{dC_{FF}}{dt} = \frac{Q_S}{V_{FF}} C_S + \frac{Q_F}{V_{FF}} C_F + \frac{Q_D}{V_{FF}} C_D - \frac{Q_S + Q_F + Q_D + Q_{FF}}{V_{FF}} C_{FF}$$

When solving coupled ODEs, it is common to transform the equations into a standard mathematical format. This standard mathematical format allows one to more easily identify appropriate solution methodologies from standard mathematical references. EPA transformed these four ODEs into the following format in Equation_Apx I-16 through Equation_Apx I-19:

Equation_Apx I-16

$$y_1' = a_{11}y_1 + a_{14}y_4 + g_1$$

Equation_Apx I-17

$$y_2' = a_{22}y_2 + a_{24}y_4 + g_2$$

Equation_Apx I-18

$$y_3' = a_{33}y_3 + a_{34}y_4$$

Equation_Apx I-19

$$y_4' = a_{41}y_1 + a_{42}y_2 + a_{43}y_3 + a_{44}y_4$$

Where:

$$\frac{dC_S}{dt} = y_1'$$

$$\frac{dC_F}{dt} = y_2'$$

$$\frac{dC_D}{dt} = y_3'$$

$$\frac{dC_{FF}}{dt} = y_4'$$

And:

$$C_S = y_1 \qquad C_F = y_2 \qquad C_D = y_3 \qquad C_{FF} = y_4$$

$$-\frac{Q_S}{V_S} = a_{11} \qquad -\frac{Q_F}{V_F} = a_{22} \qquad -\frac{Q_D}{V_D} = a_{33}$$

$$\frac{Q_S}{V_S} = a_{14} \qquad \frac{Q_F}{V_F} = a_{24} \qquad \frac{Q_D}{V_D} = a_{34}$$

$$\frac{Q_S}{V_{FF}} = a_{41} \qquad \frac{Q_F}{V_{FF}} = a_{42} \qquad \frac{Q_D}{V_{FF}} = a_{43} \qquad -\frac{Q_S+Q_F+Q_D+Q_{FF}}{V_{FF}} = a_{44}$$

$$\frac{G_S}{V_S} = g_1 \qquad \frac{G_F}{V_F} = g_2$$

These ordinary differential equations can be solved using a numerical integration method. EPA used the fourth-order Runge-Kutta method (RK4). RK4 numerically integrates a system of coupled ordinary differential equations from time step *n* to *n+1* with a constant time step size of *h* using the following equations (shown for generic variables y_1, y_2, y_3, and y_4 as a function of *t*).

Equation_Apx I-20

$$\frac{dy_1}{dt} = f_1(t, y_1, y_2, y_3, y_4)$$

Equation_Apx I-21

$$\frac{dy_2}{dt} = f_2(t, y_1, y_2, y_3, y_4)$$

Equation_Apx I-22

$$\frac{dy_3}{dt} = f_3(t, y_1, y_2, y_3, y_4)$$

Equation_Apx I-23

$$\frac{dy_4}{dt} = f_4(t, y_1, y_2, y_3, y_4)$$

Where, for each ODE *j* = 1, 2, 3, 4 (where 1 = spot cleaning, 2 = finishing, 3 = dry cleaning machine, and 4 = far field):

Equation_Apx I-24

$$k_1^j = f_j(t, y_1, y_2, y_3, y_4)$$

Equation_Apx I-25

$$k_2^j = f_j(t + \frac{1}{2}h, y_1 + \frac{1}{2}k_1^1h, y_2 + \frac{1}{2}k_1^2h, y_3 + \frac{1}{2}k_1^3h, y_4 + \frac{1}{2}k_1^4h)$$

Equation_Apx I-26

$$k_3^j = f_j(t + \frac{1}{2}h, y_1 + \frac{1}{2}k_2^1h, y_2 + \frac{1}{2}k_2^2h, y_3 + \frac{1}{2}k_2^3h, y_4 + \frac{1}{2}k_2^4h)$$

Equation_Apx I-27

$$k_4^j = f_j(t + h, y_1 + k_3^1h, y_2 + k_3^2h, y_3 + k_3^3h, y_4 + k_3^4h)$$

Equation_Apx I-28

$$y_j^{n+1} = y_j^n + \frac{1}{6}h(k_1^j + 2k_2^j + 2k_3^j + k_4^j)$$

RK4 is an *explicit* integration method, meaning it solves for the dependent variables at step *n+1* explicitly using the dependent variables at step *n*. RK4 is a fourth-order method, which means the local truncation error at a single integration step is on the order of h^5, while the total global error is on the order of h^4.

The choice of step size *h* is such to allow a successful integration of the system of differential equations. If parameter values are chosen such that the differential equation coefficients (the *a* terms in Equation_Apx I-16 through Equation_Apx I-19) are sufficiently large, the differential equations may become *stiff*. Stiff differential equations would require sufficiently small time step sizes to allow their integration. Stiffness can be difficult to predict. If stiffness is encountered, meaning if the solution diverges to unrealistic values, such as infinity, the step size should be reduced to see if that allows for successful integration.

Exposure Estimate Equations

The dry cleaning industry is characterized by a large number of small businesses, many are family-owned and operated. EPA assumed small dry cleaners operate up to 12 hours a day and up to six days a week. In addition, EPA assumed each facility has a single machine. The assumption of a single machine per facility is supported by a recent dry cleaning industry study conducted in King County, Washington, where 96 percent of 151 respondents reported having only one machine at their facility. Four reported having two machines, and two reported having three machines (Whittaker and Johanson, 2011). Based on the survey results, this assumption is presumably representative of the majority of small dry cleaning shops.

The model accounts for variation in the machine generations operated at each facility. Specifically, the model uses a distribution to estimate the machine generation and then based on the sampled machine generation in each iteration selects a distribution of machine cylinder concentrations and residual solvent in clothing. The distribution of machine types is based on the 2010 survey of dry cleaners in King County, WA, which estimated 7% were first or second generation, 26% of machines were third generation or retrofitted second generation[35], 61% were fourth or fifth generation, and 6% were "other" (e.g., hydrocarbon or CO_2 machines) (Whittaker and Johanson, 2011). Due to the limited information on other machine types, the model only considers two scenarios: 1) facilities operating third generation machines; and 2) facilities operating a fourth or fifth generation machine[36]. These assumptions are not expected to introduce significant error in the exposure estimates as, based on bans on first and second generation machines in the 1993 and 2006 Perchloroethylene NESHAPs for Dry Cleaning Facilities, EPA expects the use of PCE in first and second generation machines to be eliminated (U.S. EPA, 2006a). Additionally, based on several survey results and projections (presented in Table_Apx I-1), EPA expects the industry to be trending towards increasing usage of fourth and fifth generation machines. Therefore, the 7% of facilities reporting using first- and second-generation machines were assumed to be replaced by fourth or fifth generation resulting in 26% third generation machines and 68% fourth or fifth generation machines. The model only considers exposure at facilities using PCE; therefore, EPA re-normalized the distribution to consider only PCE machines resulting in a distribution of 28% third generation machines and 72% fourth or fifth generation machines.

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[35] For modeling purposes, retrofitted second generation machines are assumed to be equivalent to third generation machines.

[36] The model treats fourth and fifth generation machines as equivalent as both are expected to reduce machine cylinder concentrations to approximately 300 ppm (CDC, 1997). The primary difference being that fifth generation machines have an interlock preventing the machine door from being opened until the concentration is below 300 ppm whereas fourth generation machines do not.

Table_Apx I-1. Summary of Survey Responses for Dry Cleaning Machine Generations

Machine Type	Percent of Survey Respondents or Projected Facilities			
	2000 HSIA Survey (Erg, 2005)	2003 CA Survey (California Air Resources Board, 2006)	2006 Projection (Erg, 2005)	2010 King Cunty WA Survey (Whittaker and Johanson, 2011)
1st Generation	1.4%	1%	1%	1%
2nd Generation	3%	--	1%	6%
2nd Generation Retrofitted	--	2%	--	3%
3rd Generation	65%	62%	37%	23%
4th Generation	31%	28%	61%	28%
5th Generation	--	--	--	33%
Other	--	2%	--	6%
Total	100%	95%	100%	100%

EPA assessed three types of workers within the modeled dry cleaning facility: 1) a worker who performs spot cleaning; 2) a worker who unloads the dry cleaning machine and finishes and presses the garments; and 3) an occupational non-user. Each worker type is described in further detail below. EPA assumed each worker activity is performed over the full 12-hour operating day.

- EPA assumed spot cleaning occurs for a duration varying from two to five hours in the middle of the 12-hour day. The worker is exposed at the spot cleaning near-field concentration during this time, and at the far-field concentration for the remainder of the day. Spot cleaning can be performed for both dry cleaned loads and for laundered loads.
- EPA assumed a separate worker unloads the dry cleaning machine and finishes and presses the garments. After each load, EPA assumed this worker spends five minutes unloading the machine, during which he or she is exposed at the machine near-field concentration. After unloading, the worker spends five minutes in the finishing near-field to prepare the garments. Then, the worker spends another 20 minutes finishing and pressing the cleaned garments. During this 20-minute period of finishing and pressing, the residual PCE solvent is off-gassed into the finishing near-field. The amount of residual PCE solvent is estimated using measured data presented in von Grote (2003). These unloading and finishing activities are assumed to occur at regular intervals throughout the twelve-hour day. The frequency of unloading and finishing depends on the number of loads dry cleaned each day, which varies from 1 to 14, where 14 was the maximum number of loads observed in the NIOSH (2010) and Blando (2010) studies. When this worker is not unloading the dry cleaning machine or finishing and pressing garments, the worker is exposed at the far-field concentration.
- EPA assumed one occupational non-user is exposed at the far-field concentration for 12 hours a day. The occupational non-user could be the cashier, tailor, or launderer, who works at the facility but does not perform dry cleaning activities.

Using the model inputs described in Section I.2, EPA estimated PCE inhalation exposures for workers performing spot cleaning, workers unloading the dry cleaning machine and performing finishing and pressing activities, and for occupational non-users in the far-field. EPA then conducted the Monte Carlo simulations using @Risk (Version 7.0.0). The simulations applied 10,000 iterations and the Latin Hypercube sampling method for each model.

I.2 Model Parameters

Table_Apx I-2 summarizes the model parameters and their values for the Dry Cleaning Multi-Zone Inhalation Exposure Model. Each parameter is discussed in detail in the following subsections.

Table_Apx I-2. Summary of Parameter Values and Distributions Used in the Dry Cleaning Multi-Zone Inhalation Exposure Model

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Notes/Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Facility Parameters									
Facility Height	F_H	ft	12	Median	—	—	—	—	See Section I.2.1.1
Facility Floor Area	F_{area}	ft^2	—	—	500	20,000	—	Beta	See Section I.2.1.1
Far-field volume	V_{FF}	ft^3	—	—	6,000	240,000	—	—	See Section I.2.1.1
Air exchange rate	AER	hr^{-1}	—	—	1	19	3.5	Triangular	See Section I.2.1.2
Near-field indoor wind speed	v_{NF}	ft/hr	—	—	—	202.2	—	Lognormal	See Section I.2.1.3
		cm/s	—	—	—	23,882	—	Lognormal	
Dry Cleaning Machine Parameters									
Machine Door Diameter	D	ft	2.083	—	—	—	—	—	See Section I.2.2.1
Number of Loads per Day	LD	loads/day	—	—	1	14	—	Uniform	See Section I.2.2.2
Load Time	LT	hr/load	0.5	—	—	—	—	—	See Section I.2.2.3
3rd Generation Machine Cylinder PCE Concentration	C_{c_3RD}	ppm	—	—	2,000	8,600	—	Uniform	See Section I.2.2.4
4th Generation Machine Cylinder PCE Concentration	C_{C_4TH}	ppm	—	—	240	360	—	Uniform	See Section I.2.2.4
Cylinder Volume	V_C	m^3	—	—	0.24	0.64	—	Uniform	See Section I.2.2.5
Starting time	t_1	hr	0	—	—	—	—	—	Constant value.
Exposure Duration	t_2	hr	0.083	—	—	—	—	—	See Section I.2.2.6
Finishing and Pressing Parameters									
Near-field length	L_{NF}	ft	10	—	—	—	—	—	See Section I.2.3.1
Near-field width	W_{NF}	ft	10	—	—	—	—	—	
Near-field height	H_{NF}	ft	6	—	—	—	—	—	
3rd Generation Machine Residual Solvent	$R_{solvent\_3RD}$	g/kg	—	—	0.26	3.75	—	Discrete	See Section I.2.3.2
4th Generation Machine Residual Solvent	$R_{solvent\_4TH}$	g/kg	—	—	0.12	1.26	—	Discrete	See Section I.2.3.2
Load Size	LS	lb/load	30	—	—	—	—	—	See Section I.2.3.3
Exposure Duration	t_3	hr	0.33	—	—	—	—	—	See Section I.2.3.4

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Notes/Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Spot Cleaning Parameters									
Near-field length	L_{NF}	ft	10	—	—	—	—	—	See Section I.2.4.1
Near-field width	W_{NF}	ft	10	—	—	—	—	—	
Near-field height	H_{NF}	ft	6	—	—	—	—	—	
Use Rate	UR	gal/yr	0	—	—	—	—	—	See Section I.2.4.2
Exposure Duration	t_4	hr	—	—	2	5	—	Uniform	See Section I.2.4.3
Other Parameters									
Operating hours per day	OH	hr	12	—	—	—	—	—	See Section I.2.5.1
Operating days	OD	days/yr	—	—	249	313	300	Triangular	See Section I.2.5.2
Fractional days of exposure	f	unitless	—	—	0.8	1.0	—	Uniform	See Section I.2.5.3

I.2.1 Facility Parameters

I.2.1.1 Far-Field Volume

EPA calculated the far-field volume by setting a distribution for the facility floor area and multiplying the floor area by a facility height of 12 ft (median value per California Air Resources Board (CARB) (2006) study) as discussed in more detail below.

The 2006 CARB *California Dry Cleaning Industry Technical Assessment Report* (California Air Resources Board, 2006) and the Local Hazardous Waste Management Program in King County *A Profile of the Dry Cleaning Industry in King County, Washington* (Whittaker and Johanson, 2011) provide survey data on dry cleaning facility floor area. The CARB (California Air Resources Board, 2006) study also provides survey data on facility height. Using survey results from both studies, EPA composed the following distribution of floor area. To calculate facility volume, EPA used the median facility height from the CARB (California Air Resources Board, 2006) study. The facility height distribution in the CARB (California Air Resources Board, 2006) study has a low level of variability, so the median height value of 12 ft presents a simple but reasonable approach to calculate facility volume combined with the floor area distribution.

Table_Apx I-3. Composite Distribution of Dry Cleaning Facility Floor Areas

Floor Area Value (ft^2)	Percentile (as fraction)	Source
20,000	1	(Whittaker and Johanson, 2011)
3,000	0.96	(Whittaker and Johanson, 2011)
2,000	0.84	(Whittaker and Johanson, 2011)
1,600	0.5	(California Air Resources Board, 2006)
1,100	0.1	(California Air Resources Board, 2006)
500	0	(California Air Resources Board, 2006)

EPA fit a beta function to this distribution with parameters: $\alpha_1 = 6.655$, $\alpha_2 = 108.22$, min = 500 ft^2, max = 20,000 ft^2.

I.2.1.2 Air Exchange Rate

von Grote et al. (2006)von Grote et al. (2006)von Grote (2006) indicated typical air exchange rates (AERs) of 5 to 19 hr^{-1} for dry cleaning facilities in Germany. Klein (1994) indicated AERs of 1 to 19 hr^{-1}, with a mean of 8 hr^{-1} for dry cleaning facilities in Germany. During the 2013 peer review of EPA's 2013 draft risk assessment of TCE, a peer reviewer indicated that air exchange rate values around 2 to 5 hr^{-1} are likely (Scg, 2013), in agreement with the low end of the ranges reported by von Grote (2006). and Klein (1994). A triangular distribution is used with the mode equal to the midpoint of the range provided by the peer reviewer (3.5 is the midpoint of the range 2 to 5 hr^{-1}). The minimum and maximum of the distribution are 1 and 19 hr^{-1}, respectively.

I.2.1.3 Near-Field Indoor Air Speed

Baldwin (1998) measured indoor air speeds across a variety of occupational settings in the United Kingdom. Fifty-five work areas were surveyed across a variety of workplaces.

EPA analyzed the air speed data from Baldwin (1998) and categorizing the air speed surveys into settings representative of industrial facilities and representative of commercial facilities. EPA fit separate distributions for these industrial and commercial settings and used the commercial distribution for dry cleaners.

EPA fit a lognormal distribution for both data sets as consistent with the authors observations that the air speed measurements within a surveyed location were lognormally distributed and the population of the mean air speeds among all surveys were lognormally distributed. Since lognormal distributions are bound by zero and positive infinity, EPA truncated the distribution at the largest observed value among all of the survey mean air speeds from Baldwin (1998).

The air speed surveys representative of commercial facilities were fit to a lognormal distribution with the following parameter values: mean of 10.853 cm/s and standard deviation of 7.883 cm/s. In the model, the lognormal distribution is truncated at a maximum allowed value of 202.2 cm/s (largest surveyed mean air speed observed in Baldwin (1998)) to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

Baldwin (1998) only presented the mean air speed of each survey. The authors did not present the individual measurements within each survey. Therefore, these distributions represent a distribution of mean air speeds and not a distribution of spatially variable air speeds within a single workplace setting. However, a mean air speed (averaged over a work area) is the required input for the model.

I.2.2 Dry Cleaning Machine Parameters

I.2.2.1 Machine Door Diameter

EPA determined an approximate door diameter of 25 inches by reviewing images of several 4th generation PCE machine models manufactured by Bowe and Firbimatic.

I.2.2.2 Number of Loads per Day

EPA used a uniform distribution for the number of loads per day ranging from 1 to 14 based on observations from NIOSH (2010) and Blando (2010).

I.2.2.3 Load Time

EPA estimates that dry cleaning loads using PCE have an average cycle duration of 30 minutes (0.5 hours). This estimate is consistent with von Grote (2003), which estimated total cleaning and finishing batch times of between 45 to 65 minutes for machines equivalent to U.S. 3rd generation machines and between 50 to 70 minutes for machines equivalent to U.S. 4th generation machines. von Grote (2003) further estimated that between one-fourth and one-third of the total cleaning and finishing batch time is spent finishing/pressing (see Section I.2.3.4). EPA assumed a total cleaning and finishing batch time of 60 minutes with the following breakdown:

- The finish/pressing duration is 20 minutes (see Section I.2.3.4);
- The time to unload the garments from the machine is 5 minutes based on engineering judgment;

- The time to prepare the garments for finishing/pressing is 5 minutes based on engineering judgment; and
- The machine cycle duration is 30 minutes based on the total cleaning and finishing batch time of 60 minutes minus the above task durations.

I.2.2.4 Machine Cylinder Concentration

EPA used two different distributions for machine cylinder concentration depending on the machine type being modeled (third or fourth generation). For third generation machines, EPA used a uniform distribution from 2,000 to 8,600 ppm to estimate the machine cylinder concentration after a dry cleaning cycle. ERG (2005) indicated that the use of refrigerated condensers (the vapor control system used in third generation machines) can reduce PCE concentrations in the drum to between 2,000 and 8,600 ppm.

For fourth generation machines, EPA used a uniform distribution from 240 to 360 ppm to estimate the machine cylinder concentration after a dry cleaning cycle. NIOSH (1997a) indicated that the use of refrigerated condensers and carbon adsorbers in fourth generation machines can reduce the PCE concentration in the drum below 300 ppm after the cycle is complete. EPA used a uniform distribution of 300 ppm +/- 20% to account for variability and uncertainty in the residual concentration.

I.2.2.5 Cylinder Volume

EPA assessed the cylinder volume using a uniform distribution of 0.24 to 0.64 m^3 based on data from von Grote (2003). von Grote (2003) presented the five most common machine sizes used in Germany based on a 2002 survey with sizes ranging from 0.24 to 0.64 m^3. EPA did not have data on the machine sizes or distributions used in the U.S. Therefore, EPA modeled the cylinder volume using the range provided by von Grote (2003) and assuming a uniform distribution of machine sizes.

I.2.2.6 Exposure Duration

EPA assumes it takes the worker five minutes to unload the dry cleaning machine.

I.2.3 Finishing and Pressing Parameters

I.2.3.1 Near-Field Volume

EPA assumed a near-field of constant dimensions of 10 ft x 10 ft x 6 ft resulting in a total volume of 600 ft^3.

I.2.3.2 Residual Solvent

EPA used two different distributions for the amount of residual solvent that adheres to garments after the dry cleaning cycle depending on the machine type being modeled (third or fourth generation). The distributions for both machine types are based on data from von Grote (2003) who estimated residual solvent for both normal loads and “off-the-peg” loads. von Grote (2003) defines “off-the-peg” loads as loads with suits and jackets with shoulder pads and estimates that approximately 20% of all loads cleaned are off-the-peg with the remaining 80% being normal loads. For third generation machines, von Grote (2003) presents data estimating 0.26 g residual solvent/kg clothes for normal loads and 3.75 g residual solvent/kg clothes for off-the peg loads. It should be noted that von Grote (2003) uses different definitions of machines generations than used in the U.S. The fourth-generation machines in von Grote (2003) are defined as non-vented dry-to-dry machines with refrigerated condensers which corresponds to third-generation machines in the U.S. Therefore, EPA used data for fourth-generation machines in von Grote (2003) to model U.S. third-generation machines.

von Grote (2003) does not have a machine generation corresponding to fourth-generation machines in the U.S. von Grote (2003) fourth-generation machines correspond to U.S. third-generation machines and von Grote (2003) fifth-generation machines correspond to U.S. fifth-generation machines (machines with refrigerated condensers, carbon adsorbers, and interlocks on the door). However, the only difference between U.S. fourth- and fifth-generation machines is the presences of interlocks on the door to prevent workers from opening prior to the solvent concentration dropping below 300 ppm. As discussed in Section I.2.2.4, fourth-generation machines are also expected to reduce cylinder concentrations after a cycle to 300 ppm. Therefore, EPA expects residual solvent for fourth-generation machines to be similar to fifth-generation machines and uses residual solvent data from von Grote (2003) for fifth-generation machines in the estimates for fourth-generation machines. von Grote (2003) presents data estimating 0.12 g residual solvent/kg clothes for normal loads and 1.26 g residual solvent/kg clothes for off-the peg loads for fifth-generation machines. EPA assumes a discrete distribution for both third- and fourth-generation estimates assuming 80% of loads are normal loads and 20% are off-the-peg von Grote (2003).

I.2.3.3 Load Size

The CARB (California Air Resources Board, 2006) and King County (Whittaker and Johanson, 2011) studies provide machine capacities, and the King County study also provides data on actual size of loads used by dry cleaners. EPA used the King County study data on actual load sizes to build a distribution.

Table_Apx I-4 summarizes the survey results for respondents' primary (if facility has more than one machine) or only machine. The study reports a maximum reported load of 150 lb, a minimum reported load of 7 lb, and a median reported load of 30 lb for the primary machine (Whittaker and Johanson, 2011).

Table_Apx I-4. Survey Responses of Actual Pounds Washed per Load for Primary Machine (if more than one machine) from 2010 King County Survey

Actual Pounds of Clothes Washed	Results for Primary Machine	
	Number of Respondents	Percent of Respondents
1 – 10	4	3
11 – 20	36	25
21 – 30	76	53
31 – 40	16	11
41 – 50	6	4
51+	6	4
Total	**144**	**100**

EPA used these survey results to build a distribution to describe the actual wash loads per machine, as summarized in Table_Apx I-5. To build this distribution, EPA set the following:

- The maximum, median, and minimum were set as 150 lb, 30 lb, and 7 lb, respectively, as stated in the King County survey report (Whittaker and Johanson, 2011).
- The 96th percentile was set at 50 lb as the high-end of the bin "41 to 50 lb". Per Table_Apx I-4, 4% of respondents reported greater than 50 lb; therefore, 96% of facilities reported 50 lb or less.

- The 28th percentile was set at 20 lb as the high-end of the bin “11 to 20 lb”. Per Table_Apx I-4, 28% of respondents reported 20 lb or less.

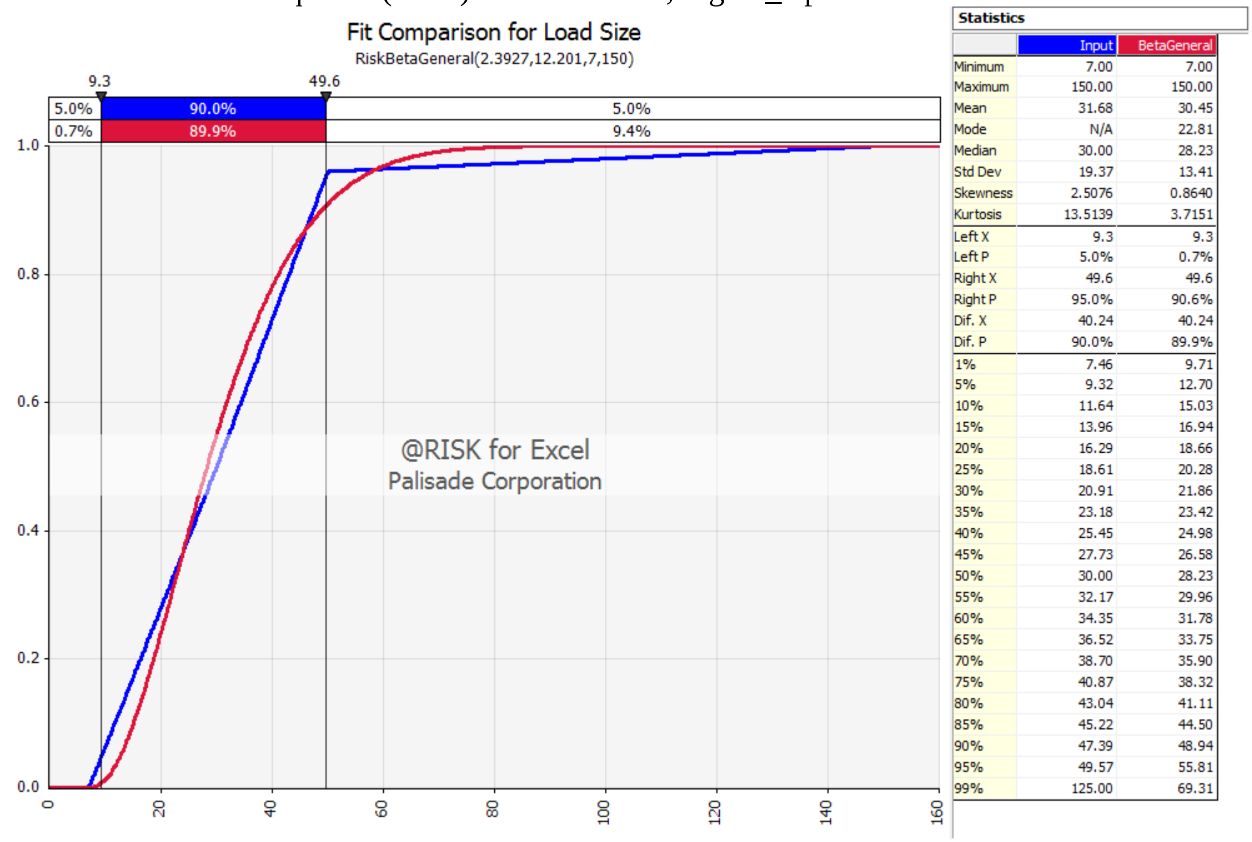
EPA then determined the best-fit distribution using the software @Risk.

Table_Apx I-5. Distribution of Actual Load Sizes from 2010 King County Survey

Actual Load Washed (lb)	Percentile (as fraction)
150	1
50	0.96
30	0.5
20	0.28
7	0

Source: (Whittaker and Johanson, 2011)

EPA fit a beta distribution to this distribution with parameters: $\alpha_1 = 2.3927$, $\alpha_2 = 12.201$, min = 7 lb, max = 150 lb. The root-mean squared (RMS) error is 0.0365, Figure_Apx I-2 illustrates this fit.



	Input	BetaGeneral
Minimum	7.00	7.00
Maximum	150.00	150.00
Mean	31.68	30.45
Mode	N/A	22.81
Median	30.00	28.23
Std Dev	19.37	13.41
Skewness	2.5076	0.8640
Kurtosis	13.5139	3.7151
Left X	9.3	9.3
Left P	5.0%	0.7%
Right X	49.6	49.6
Right P	95.0%	90.6%
Dif. X	40.24	40.24
Dif. P	90.0%	89.9%
1%	7.46	9.71
5%	9.32	12.70
10%	11.64	15.03
15%	13.96	16.94
20%	16.29	18.66
25%	18.61	20.28
30%	20.91	21.86
35%	23.18	23.42
40%	25.45	24.98
45%	27.73	26.58
50%	30.00	28.23
55%	32.17	29.96
60%	34.35	31.78
65%	36.52	33.75
70%	38.70	35.90
75%	40.87	38.32
80%	43.04	41.11
85%	45.22	44.50
90%	47.39	48.94
95%	49.57	55.81
99%	125.00	69.31

Figure_Apx I-2. Fit Comparison of Beta Cumulative Distribution Function to Load Size Survey Results

I.2.3.4 Exposure Duration

EPA assumed workers take 20 minutes to press and finish each load. This estimate is consistent with von Grote (2003), which estimated that residual solvent will evaporate continuously over a period of approximately between one-fourth and one-third of the total time to clean and finish a single load of garments. von Grote (2003) estimated total cleaning and finishing batch times of between 45 to 65 minutes for machines equivalent to U.S. 3rd generation machines and between 50 to 70 minutes for machines equivalent to U.S. 4th generation machines. This yields an overall range of finishing/pressing times of approximately 11 to 23 minutes.

I.2.4 Spot Cleaning Parameters

I.2.4.1 Near-Field Volume

EPA assumed a near-field of constant dimensions of 10 ft x 10 ft x 6 ft resulting in a total volume of 600 ft^3.

I.2.4.2 Spot Cleaning Use Rate

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 TCE-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. This results in the spot cleaning near-field of the model to become part of the far-field with exposure concentrations equivalent to C_{FF}.

I.2.4.3 Exposure Duration

IRTA (2007) used data collected from dry cleaners to develop two model PCE-based dry cleaners: a small and large dry cleaner. The authors estimated the small dry cleaner spends 2.46 hr/day spotting and the large dry cleaner spends 5 hr/day spotting. EPA models the spot cleaning duration as a uniform distribution varying from 2 to 5 hr/day.

I.2.5 Other Parameters

I.2.5.1 Operating Hours

EPA assumed a typical dry cleaner operates 12 hours per day based on engineering judgment.

I.2.5.2 Operating Days per Year

EPA modeled the operating days per year using a triangular distribution from 250 to 312 days per year with a mode of 300 days per year[37]. The low-end operating days per year is based on the assumption that at a minimum the dry cleaner operates five days per week and 50 weeks per year. The mode of 300 days per year is based on an assumption that most dry cleaners will operate six days per week and 50 weeks per year. The high-end value is based on the assumption that the dry cleaner would operate at most six days per week and 52 weeks per year, assuming the dry cleaner is open year-round.

I.2.5.3 Fractional Number of Operating Days that a Worker Works

To account for lower exposure frequencies and part-time workers, EPA defines a fractional days of exposure as a uniform distribution ranging from 0.8 to 1.0. EPA expects a worker's annual working days may be less than the operating days based on BLS/Census data that showed the weighted average worked hours per year and per worker in the dry cleaning sector is approximately 1,600 (i.e., 200 day/yr

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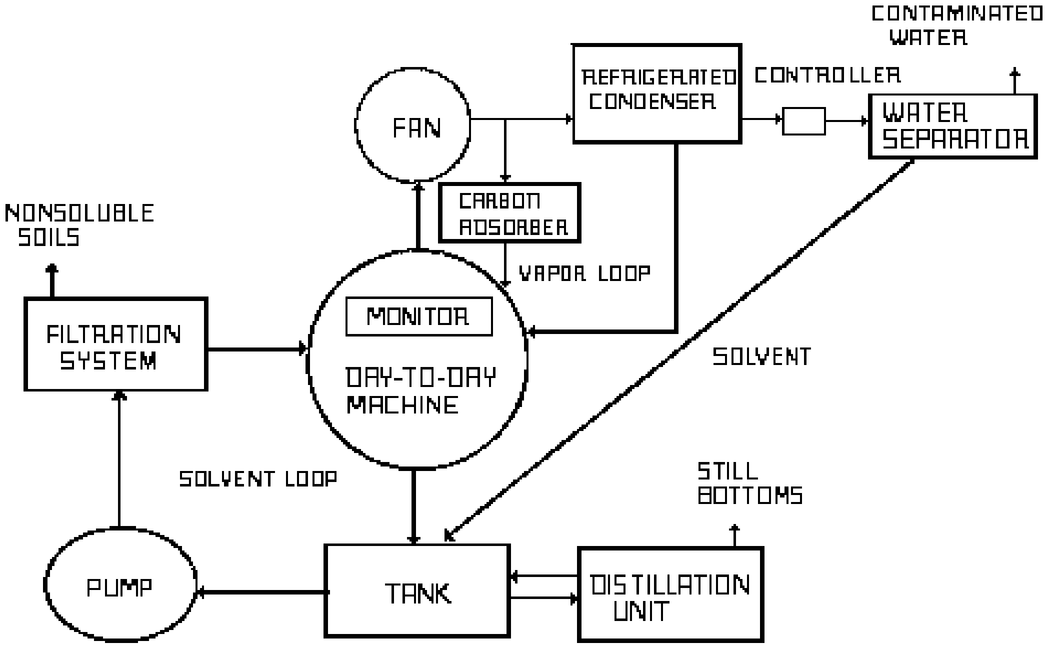
[37] For modeling purposes, the minimum value was set to 249 days per year and the maximum to 313 days per year; however, these values have a probability of zero; therefore, the true range is from 250 to 312 days per year.

at 8 hr/day) which falls outside the range of operating days per year used in the model (250 to 312 day/yr with mode of 300 day/yr).

The low end of the range, 0.8, was derived from the observation that the weighted average of 200 day/yr worked (from BLS/Census) is 80% of the standard assumption that a full-time worker works 250 day/yr. The maximum of 1.0 is appropriate as dry cleaners may be family owned and operated and some workers may work as much as every operating day. EPA defines the exposure frequency as the number of operating days (250 to 312 day/yr) multiplied by the fractional days of exposure (0.8 to 1.0).

Appendix J Solvent Releases in Water Discharge from Dry Cleaning Machines Model Approach and Parameters

This appendix presents the modeling approach and model equations used in the Solvent Release in Water Discharge from Dry Cleaning Machines Model. This model estimates the PCE contained in the produced separator water from the PCE dry cleaning machine. Figure_Apx J-1 illustrates an example process flow diagram of a 5th generation dry cleaning machine (Niosh, 1997a). This diagram illustrates two sets of controls on the vapor loop: a refrigerated condenser and a carbon adsorber. The refrigerated condenser condenses PCE from the vapor prior to its return to the machine chamber. The refrigerated condenser also incidentally condenses any water vapor present in the chamber vapor. The mixed water/PCE condensate drops down into a water separator. The water separator then separates the heavier PCE from the lighter water, returning the PCE to the solvent tank. However, some PCE may remain in the water phase at a concentration up to its solubility. The water is discharged, disposed, or treated, depending on state regulations. Fourth generation machines will have an almost identical process as 5th generation machines except they do not have the monitor shown in Figure_Apx J-1 (Niosh, 1997b). Third generation machines will also be similar to the process shown in Figure_Apx J-1, except they do not use a monitor in the machine to control residual solvent levels in the chamber and do not use carbon adsorbers as secondary vapor controls (Niosh, 1997b).



Figure_Apx J-1. Process Flow Diagram of a 5th Generation Dry Cleaning Machine (Niosh, 1997a)

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 (U.S. EPA, 2015b). The *EPA/OPPT Water Saturation Model* uses Equation_Apx J-1 and Equation_Apx J-2 to calculate annual and daily amount of chemical released per site, respectively (U.S. EPA, 2015b).

Equation_Apx J-1

$$DR = \frac{WS \times CF \times Amt}{1000}$$

Equation_Apx J-2

$$AR = DR \times OD$$

Where:

DR = Daily release rate (kg/site-day)
WS = Water solubility of the chemical (mg/L)
CF = Correction factor (unitless)[38]
Amt = An amount of water in which the chemical reaches saturation (kg/site-day)
AR = Annual release rate (kg/site-yr)
OD = Operating Days (days/yr)

This model uses the same basic principles as used in *EPA/OPPT Water Saturation Model*; however, instead of the default value for "Amt" it uses several parameters and distributions to estimate high-end and central tendency daily and annual release estimates including:

- volume of produced water per pound of clothes cleaned;
- load size;
- number of loads per day;
- number of machines per site; and
- operating days.

To account for parameter distributions, EPA used a Monte Carlo simulation with 100,000 iterations. The following subsections describe EPA's modeling approach for estimating PCE water releases at dry cleaning sites, including supporting rationale, calculations, and input parameters.

J.1 Model Design Equations

The daily and annual release volumes of PCE from produced separator water are calculated using Equation_Apx J-3 and Equation_Apx J-4.

Equation_Apx J-3

$$DR = \frac{WS \times PW \times LS \times LD \times NM}{2.20462\,\frac{lb}{kg}}$$

Equation_Apx J-4

$$AR = DR \times OD$$

Where:

DR = Daily release (kg/site-day)
WS = PCE solubility in water (lb PCE/gal water)

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[38] A correction factor that may be used to account for: 1) multiples of an amount (Amt) of water (e.g., multiple washings); 2) a known or estimated correction of the water solubility of the chemical; and/ or 3) other corrections.

PW = Produced water (gal water/lb clothes)
LS = Load size (lb clothes/load)
LD = Number of loads per day (loads/machine-day)
NM = Number of machines per site (machines/site)
AR = Annual release (kg/site-day)
OD = Operating days per year (days/yr)

J.2 Model Parameters

Table_Apx J-1 summarizes the model parameters and their values.

Table_Apx J-1. Summary of Parameter Values and Distributions for the Solvent Release in Water Discharge from Dry Cleaning Machines Model

Input Parameter	Symbol	Unit	Constant Parameters	Variable Parameters			Distribution Type
			Value	Lower Bound	Upper Bound	Mode	
PCE Solubility in Water	WS	lb PCE/gal	0.0017	—	—	—	Constant Value
Produced Water	PW	gal water/ lb clothes	—	0.0032	0.0037	—	Discrete
Load Size	LS	lb clothes/ load	—	7	150	—	Beta
Number of Loads per Day	LD	loads/day	—	1	14	—	Uniform
Number of Machines	NM	machines/ site	—	1	3	1	Discrete
Operating Days	OD	days/yr	—	250	312	300	Triangular

J.2.1 Solubility in Water

The *Problem Formulation of the Risk Evaluation for Perchloroethylene (Ethene, 1,1,2,2-Tetrachloro)* (U.S. EPA, 2018b) identifies a PCE solubility in water at 25 °C of 206 mg/L. This is converted to 0.0017 lb/gal. This parameter is kept at a constant value in the model.

J.2.2 Produced Water

The CARB *California Dry Cleaning Industry Technical Assessment Report* surveyed dry cleaning facilities in California in 2003 (California Air Resources Board, 2006). The survey results of PCE facilities found an average produced separator water of 141 gal per year for primary machines (equivalent of 3rd generation machines) and 191 gal per year for secondary machines (equivalent of 4th and 5th generation machines) (California Air Resources Board, 2006). The survey also found PCE facilities clean an average of 44,000 lb of clothes per year for primary machines and 52,000 lb of clothes per year for secondary machines (California Air Resources Board, 2006).

EPA calculated produced separator water emission factors by dividing the average annual produced separator water volume by the average annual clothes cleaned for each machine type. EPA calculated the following emission factors:

- Primary machine (3rd generation): 141 gal/yr / 44,000 lb clothes/yr = 0.00320 gal water/lb clothes
- Secondary machine (4th and 5th generation): 191 gal/yr / 52,000 lb clothes/yr = 0.00367 gal water/lb clothes

EPA defined the distribution of the produced separator water emission factor as the distribution of machine types. Using data from the King County survey results (Whittaker and Johanson, 2011), EPA built a distribution of current market shares of 3rd generation (including converted 2nd generation) machines and 4th and 5th generation machines.

Since EPA expects the use of first- and second-generation machines to be eliminated, the 7% for these machine types were assumed to be replaced by fourth or fifth generation machines to give the most conservative water release estimate. EPA then re-normalized the distribution to consider only PCE machines resulting in 28% of facilities using third generation machines and 72% using fourth or fifth generation machines. Table_Apx J-2 summarizes the 2010 King County survey results and Table_Apx J-3 shows the discrete distribution used for produced water.

Table_Apx J-2. Distribution of Machine Types Based on 2010 King County Survey Results

PCE Machine Type	Percent of Respondents Reporting this as their Machine Type	Normalized Percentage of PCE Machine Types Accounting for 3rd and 4th/5th Generation Only
1st Generation	1%	--
2nd Generation	6%	--
2nd Generation retrofitted	3%	28%
3rd Generation	23%	
4th Generation	28%	72%
5th Generation	33%	
Other (non-PCE machines)	6%	--
Total	100%	100%

Source: (Whittaker and Johanson, 2011)

Table_Apx J-3. Distribution of Produced Separator Water Emission Factors by Machine Type Used in Model

Amount of Water per lb Clothing Washed (gal/lb)	Probability of Value
0.00320	0.28
0.00367	0.72

J.2.3 Load Size

The CARB (California Air Resources Board, 2006) and King County (Whittaker and Johanson, 2011) studies provide machine capacities, and the King County study also provides data on actual size of loads used by dry cleaners. EPA used the King County study data on actual load sizes to build a distribution.

Table_Apx J-4 summarizes the survey results for respondents' primary (if facility has more than one machine) or only machine. The study reports a maximum reported load of 150 lb, a minimum reported load of 7 lb, and a median reported load of 30 lb for the primary machine (Whittaker and Johanson, 2011).

Table_Apx J-4. Survey Responses of Actual Pounds Washed per Load for Primary Machine (if more than one machine) from 2010 King County Survey

Actual Pounds of Clothes Washed	Results for Primary Machine	
	Number of Respondents	Percent of Respondents
1 – 10	4	3
11 – 20	36	25
21 – 30	76	53
31 – 40	16	11
41 – 50	6	4
51+	6	4
Total	144	100

Source: (Whittaker and Johanson, 2011)

EPA used these survey results to build a distribution to describe the actual wash loads per machine, as summarized in Table_Apx J-5. To build this distribution, EPA set the following:

- The maximum, median, and minimum were set as 150 lb, 30 lb, and 7 lb, respectively, as stated in the King County survey report (Whittaker and Johanson, 2011).
- The 96th percentile was set at 50 lb as the high-end of the bin "41 to 50 lb". Per Table_Apx J-4, 4% of respondents reported greater than 50 lb; therefore, 96% of facilities reported 50 lb or less.
- The 28th percentile was set at 20 lb as the high-end of the bin "11 to 20 lb". Per Table_Apx J-4, 28% of respondents reported 20 lb or less.

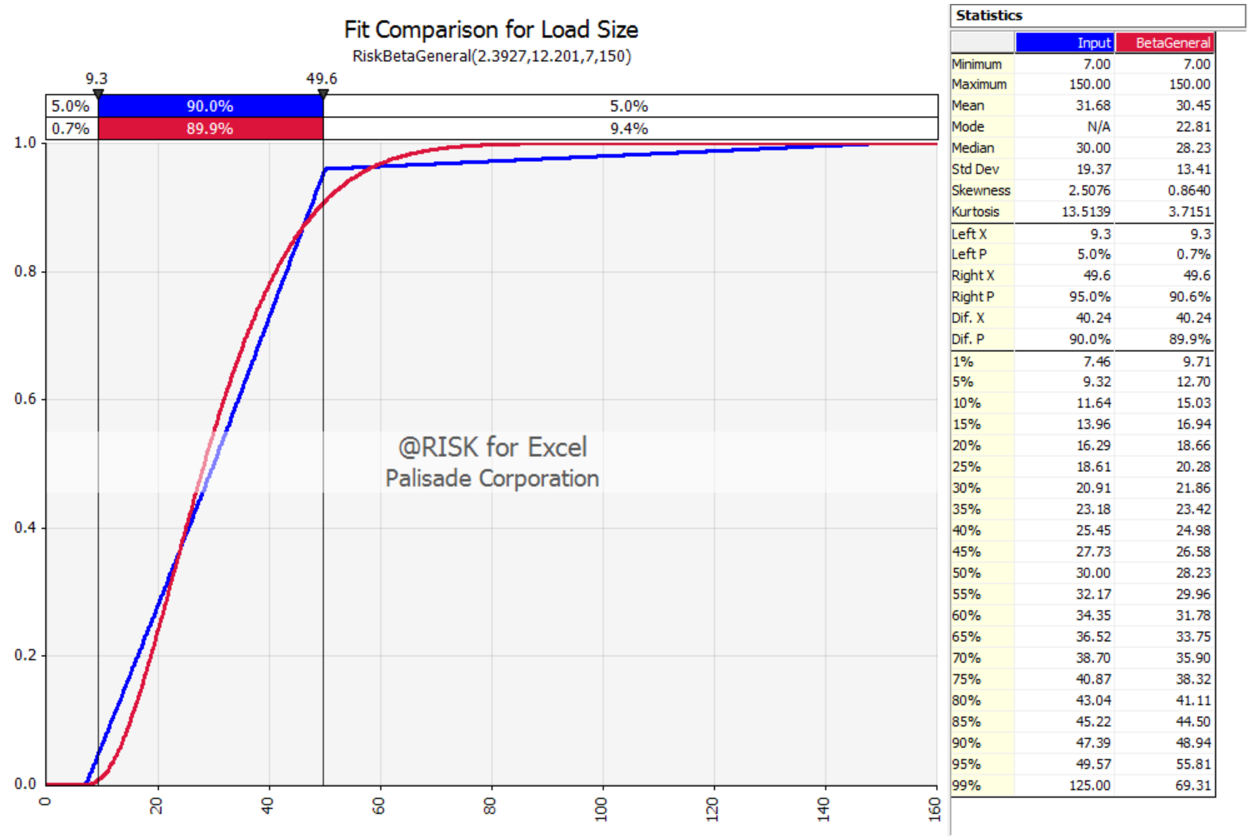
EPA then determined the best-fit distribution using the software @Risk[39].

Table_Apx J-5. Distribution of Actual Load Sizes from 2010 King County Survey

Actual Load Washed (lb)	Percentile (as fraction)
150	1
50	0.96
30	0.5
20	0.28
7	0

Source: (Whittaker and Johanson, 2011)

EPA fit a beta distribution to this distribution with parameters: α1 = 2.3927, α2 = 12.201, min = 7 lb, max = 150 lb. The root-mean squared (RMS) error is 0.0365. Figure_Apx J-2 illustrates this fit.



Statistics

	Input	BetaGeneral
Minimum	7.00	7.00
Maximum	150.00	150.00
Mean	31.68	30.45
Mode	N/A	22.81
Median	30.00	28.23
Std Dev	19.37	13.41
Skewness	2.5076	0.8640
Kurtosis	13.5139	3.7151
Left X	9.3	9.3
Left P	5.0%	0.7%
Right X	49.6	49.6
Right P	95.0%	90.6%
Dif. X	40.24	40.24
Dif. P	90.0%	89.9%
1%	7.46	9.71
5%	9.32	12.70
10%	11.64	15.03
15%	13.96	16.94
20%	16.29	18.66
25%	18.61	20.28
30%	20.91	21.86
35%	23.18	23.42
40%	25.45	24.98
45%	27.73	26.58
50%	30.00	28.23
55%	32.17	29.96
60%	34.35	31.78
65%	36.52	33.75
70%	38.70	35.90
75%	40.87	38.32
80%	43.04	41.11
85%	45.22	44.50
90%	47.39	48.94
95%	49.57	55.81
99%	125.00	69.31

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[39] @Risk; Palisade; https://www.palisade.com/risk/

Figure_Apx J-2. Fit Comparison of Beta Cumulative Distribution Function to Load Size Survey Results

J.2.4 Number of Loads per Day

EPA used a uniform distribution for the number of loads per day ranging from 1 to 14 based on observations from NIOSH (2010) and Blando (2010).

J.2.5 Number of Machines per Site

Based on survey data from CARB (California Air Resources Board, 2006) and Whittaker (2011), the model assumes dry cleaning shops have between one and three machines.

Table_Apx J-6 summarizes the survey results for number of machines per facility from both the 2003 CARB survey (California Air Resources Board, 2006) and the 2010 King County survey (Whittaker and Johanson, 2011). The results of the two surveys are similar. The CARB survey includes industrial facilities: <1% of respondents identified as industrial facilities; 96% identified as plant/retail; 3% identified as other; and a total of <1.5% identified as government, nonprofit, and hotel/motel (California Air Resources Board, 2006). Since the CARB survey includes industrial facilities as respondents, EPA used the CARB survey results for number of machines per facility.

Table_Apx J-6. Survey Results of Number of Machines per Facility

Number of Machines	Percent of Respondents in CARB (California Air Resources Board, 2006) Survey[a]	Percent of Respondents in King County (Whittaker and Johanson, 2011) Survey[b]
Percent of shops with 1 machine	92%	96%
Percent of shops with 2 machines	8%	2.7%
Percent of shops with >2 machines	<1%	1.3%

[a] The 2003 CARB survey had 1,634 respondents.

[b] The 2010 King County survey had 151 respondents respond to this survey question.

Source: (Whittaker and Johanson, 2011; California Air Resources Board, 2006)

Table_Apx J-7 summarizes the distribution of number of machines per facility used in the model based on the results of the CARB survey. The probabilities were normalized to sum to 100%. A maximum of 3 machines per facility was used based on the maximum number of machines reported in the 2010 King County Survey (Whittaker and Johanson, 2011).

Table_Apx J-7. Distribution of Number of Machines per Facility Used in the Model

Number of Machines per Facility	Probability of Value
1	0.91
2	0.08
3	0.01

J.2.6 Operating Days per Year

EPA used a triangular distribution of operating days per year defined as the following:

- Minimum value: 250 days/yr; consistent with operating 5 days/week and 50 weeks/yr.
- Mode value: 300 days/yr; consistent with operating 6 days/week and 50 weeks/yr.
- Maximum value: 312 days/yr; consistent with operating 6 days/week and 52 weeks/yr.

The triangular distribution is of discrete values only, as the number of operating days is a whole number of days. EPA calculated the probability of each value of operating days using Equation_Apx J-5:

Equation_Apx J-5

$$p_{(x)} = \begin{cases} \dfrac{2(x-a)}{(b-a)(c-a)} \; for\ a \leq x \leq c \\ \dfrac{2(b-x)}{(b-a)(b-c)} \; for\ c < x \leq b \end{cases}$$

Where:

p(x) = Probability of operating days value
x = Value of operating days
a = Minimum value
b = Maximum value
c = Mode value

Since only discrete values are used in the distribution, the bounds of the distribution are set as 249 and 313 to ensure the sampled minimum and maximum are 250 and 312, respectively. Per Equation_Apx J-5, p(x) is equal to zero when *x* equals *a* or *b*. Therefore, setting *a* equal to 249 and *b* equal to 313 ensures 250 and 312 are the true bounds of the sample results.

The assumed distribution of operating days is supported by observed data. The 2003 CARB survey (California Air Resources Board, 2006) found that, of the 1,634 respondents, 100% of facilities are open at least Monday through Friday. Approximately 96% of facilities are open on Saturday but closed on Sunday, and approximately 4% of facilities are open on Sunday but closed on Saturday. Therefore, sites are not expected to operate fewer than five days per week or greater than six days per week.

Appendix K Dermal Exposure to Volatile Liquids Model Approach and Parameters

This method was developed through review of relevant literature and consideration of existing exposure models, such as EPA/OPPT models and the European Centre for Ecotoxicology and Toxicology of Chemicals Targeted Risk Assessment (ECETOC TRA).

K.1 Incorporating the Effects of Evaporation

K.1.1 Modification of EPA/OPPT Models

Current EPA dermal models do not incorporate the evaporation of material from the dermis. The dermal potential dose rate, D_{exp} (mg/day), is calculated as (U.S. EPA, 2015b):

Equation_Apx K-1

$$D_{exp} = S \times Q_u \times Y_{derm} \times FT$$

Where:

S is the surface area of contact (cm^2)
Q_u is the quantity remaining on the skin (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).

Here Q_u does not represent the quantity remaining after evaporation, but represents the quantity remaining after the bulk liquid has fallen from the hand that cannot be removed by wiping the skin (e.g., the film that remains on the skin).

One way to account for evaporation of a volatile solvent would be to add a multiplicative factor to the EPA/OPPT model to represent the proportion of chemical that remains on the skin after evaporation, f_{abs} ($0 \leq f_{abs} \leq 1$):

Equation_Apx K-2

$$D_{exp} = S \times (Q_u \times f_{abs}) \times Y_{derm} \times FT$$

This approach simply removes the evaporated mass from the calculation of dermal uptake. Evaporation is not instantaneous, but the EPA/OPPT model already has a simplified representation of the kinetics of dermal uptake.

K.2 Calculation of f_{abs}

Kasting (2006) developed a diffusion model to describe the absorption of volatile compounds applied to the skin. As of part of the model, Kasting (2006)define a ratio of the liquid evaporation to absorption, χ. They derive the following definition of χ (which is dimensionless) at steady-state:

Equation_Apx K-3

$$\chi = 3.4 \times 10^{-3} u^{0.78} \frac{P_{vp} MW^{3.4}}{K_{oct}^{0.76} S_W}$$

Where:

u is the air velocity (m/s)
K_{oct} is the octanol:water partition coefficient
MW is the molecular weight
S_W is the water solubility (μg/cm^3)
P_{vp} is the vapor pressure (torr)

Chemicals for which $\chi >> 1$ will largely evaporate from the skin surface, while chemicals for which $\chi << 1$ will be largely absorbed; $\chi = 1$ represents a balance between evaporation and absorption. Equation_Apx K-3 is applicable to chemicals having a log octanol/water partition coefficient less than or equal to three (log Kow ≤ 3)[40]. The equations that describe the fraction of the initial mass that is absorbed (or evaporated) are rather complex (Equations 20 and 21 of Kasting (2006) but can be solved.

K.2.1 Small Doses (Case 1: $M_0 \leq M_{sat}$)

In the small dose scenario, the initial dose (M_0) is less than that required to saturate the upper layers of the *stratum corneum* ($M_0 \leq M_{sat}$), and the chemical is assumed to evaporate from the skin surface at a rate proportional to its local concentration.

For this scenario, Frasch (2012) calculated the fraction of applied mass that is absorbed, based on the infinite limit of time (i.e. infinite amount of time available for absorption after exposure):

Equation_Apx K-4

$$f_{abs} = \frac{m_{abs}(\infty)}{M_0} = \frac{2 + f\chi}{2 + 2\chi}$$

Where:

m_{abs} is the mass absorbed
M_0 is the initial mass applied
f is the relative depth of penetration in the *stratum corneum* ($f = 0.1$ can be assumed)
χ is as previously defined

Note the simple algebraic solution in Equation_Apx K-4 provides a theoretical framework for the total mass that is systemically absorbed after exposure to a small finite dose (mass/area) of chemical, which depends on the relative rates of evaporation, permeation, and the initial load. At "infinite time", the applied dose is either absorbed or evaporated (Frasch, 2012). The finite dose is a good model for *splash-type exposure in the workplace* (Frasch and Bunge, 2015).

The fraction of the applied mass that evaporates is simply the complement of that absorbed:

Equation_Apx K-5

$$\frac{m_{evap}(\infty)}{M_0} = 1 - f_{abs} = \frac{2\chi - f\chi}{2 + 2\chi}$$

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[40] For simplification, Kasting (2006) does not consider the resistance of viable tissue layers underlying the *stratum corneum*, and the analysis is applicable to hydrophilic-to-moderately lipophilic chemicals. For small molecules, this limitation is equivalent to restricting the analysis to compounds where Log $K_{ow} \leq 3$.

Where:

m_{evap} is the mass evaporated

The fraction absorbed can also be represented as a function of dimensionless time τ (Dt/h^2), as shown in Equation_Apx K-6:

Equation_Apx K-6

$$f_{abs} = \frac{m_{abs}}{M_0} = 2\sum_{n=1}^{\infty} \frac{1}{\lambda_n}(1 - e^{-\lambda_n{}^2\tau})\left(\frac{\chi^2 + \lambda_n{}^2}{\chi^2 + \lambda_n{}^2 + \chi}\right) \cdot \left(\frac{cos(1-f)\,\lambda_n - cos\lambda_n}{f \cdot \lambda_n}\right)$$

where the eigenvalues λ_n are the positive roots of the equation:

Equation_Apx K-7

$$\lambda_n \cdot \cot(\lambda_n) + \chi = 0$$

Equation_Apx K-6 and Equation_Apx K-7 must be solved analytically. It should be noted that the dimensionless time τ is not a representation of exposure duration for a work activity; rather, it represents the amount of time available for absorption after the initial exposure dose is applied. Since most dermal risk assessments are typically more concerned with the quantity absorbed, rather than the time course of absorption, the simple algebraic solution is recommended over the analytical solution.

K.2.2 Large Doses (Case 2: $M_0 > M_{sat}$)

For large doses ($M_0 > M_{sat}$), the chemical saturates the upper layers of the *stratum corneum*, and any remaining amount forms a residual layer (or pool) on top of the skin. The pool acts as a reservoir to replenish the top layers of the membrane as the chemical permeates into the lower layer. In this case, absorption and evaporation approach steady-state values as the dose is increased, similar to an infinite dose scenario.

The steady-state fraction absorbed can be approximated by Equation_Apx K-8:

Equation_Apx K-8

$$f_{abs}(\infty) = \frac{1}{\chi + 1}$$

Table_Apx K-1 presents the estimated absorbed fraction calculated using the steady-state approximation for large doses (Equation_Apx K-8) for PCE.

Table_Apx K-1. Estimated Fraction Evaporated and Absorbed (f_{abs}) using Equation_Apx K-8

Chemical Name	Perchloroethylene
CASRN	**127-18-4**
Molecular Formula	**C_2Cl_4**
Molecular Weight (g/mol)	165.833
P_{VP} (torr)	18.5

Universal gas constant, R (L*atm/K*mol)	0.0821
Temperature, T (K)	303
Log K_{ow}	3.4
K_{oct}	2511.9
S_w (g/L)	0.206
S_w ($\mu g/cm^3$)	206
Industrial Setting	
u (m/s)[a]	0.1674
Evaporative Flux, χ	6.95
Fraction Evaporated	0.87
Fraction Absorbed	**0.13**
Commercial Setting	
u (m/s)[a]	0.0878
Evaporative Flux, χ	4.20
Fraction Evaporated	0.81
Fraction Absorbed	**0.19**

[a] EPA used air speeds from Baldwin (1998): the 50th percentile of industrial occupational environments of 16.74 cm/s is used for industrial settings and the 50th percentile of commercial occupational environments of 8.78 cm/s is used for commercial settings.

K.3 Comparison of f_{abs} to Experimental Values for 1-BP

Sections K.2 presents theoretical frameworks for estimating the fraction of volatile chemical absorbed in finite dose, infinite dose, and transient exposure scenarios. It is unclear whether these frameworks have been validated against measured data for the specific chemicals of current OPPT interest. Where available, experimental studies and actual measurements of absorbed dose are preferred over theoretical calculations.

In a 2011 study, Frasch (2011)tested dermal absorption characteristics of 1-BP. For the finite dose scenario, Frasch (2011) determined that unoccluded exposure resulted in less than 0.2 percent of applied 1-BP dose penetrated the skin – a value substantially lower than the theoretical ~6 percent absorbed estimated using Equation_Apx K-8. While this discrepancy is unexplained, the Frasch (2011)study recognized the large standard deviation of certain experimental results, and the difficulty of spreading a small, rapidly evaporating dose of 1-BP evenly over the skin surface. Frasch (2011) also raised the possibility that 1-BP may dehydrate the stratum corneum, thereby decreasing the skin permeability after initial exposure.

K.4 Potential for Occlusion

Gloves can prevent the evaporation of volatile chemicals from the skin, resulting in occlusion. Chemicals trapped in the glove may be broadly distributed over the skin (increasing S in Equation_Apx K-1), or if not distributed within the glove, the chemical mass concentration on the skin at the site of contamination may be maintained for prolonged periods of time (increasing Q_u in Equation_Apx K-1). Conceptually, occlusion is similar to the “infinite dose” study design used in *in vitro* and *ex vivo* dermal penetration studies, in which the dermis is exposed to a large, continuous reservoir of chemical.
The impact of occlusion on dermal uptake is complex: continuous contact with the chemical may degrade skin tissues, increasing the rate of uptake, but continuous contact may also saturate the skin,

slowing uptake (Dancik et al., 2015). These phenomena are dependent upon the chemical, the vehicle and environmental conditions. It is probably not feasible to incorporate these sources of variability in a screening-level population model of dermal exposure without chemical-specific studies.

Existing EPA/OPPT dermal models (Equation_Apx K-1) could theoretically be modified to account for the increased surface area and/or increased chemical mass in the glove. This could be achieved through a multiplicative variable (such as used in Equation_Apx K-2 to account for evaporative loss) or a change in the default values of S and/or Q_u. It may be reasonable to assume that the surface area of hand in contact with the chemical, S, is the area of the whole hand owing to the distribution of chemical within the glove. Since Q_u reflects the film that remains on the skin (and cannot be wiped off), a larger value should be used to reflect that the liquid volume is trapped in the glove, rather than falling from the hand. Alternatively, the product S × Qu ($cm^2 \times mg/cm^2$-event) could be replaced by a single variable representing the mass of chemical that deposits inside the glove per event, M (mg/event):

Equation_Apx K-9

$$D_{exp} = M \times Y_{derm} \times FT$$

Garrod (2001) surveyed contamination by involatile components of non-agricultural pesticide products inside gloves across different job tasks and found that protective gloves were nearly always contaminated inside. While the study does not describe the exact mechanism in which the contamination occurs (e.g. via the cuff, permeation, or penetration through imperfections in glove materials), it quantified inner glove exposure as "amount of product per unit time", with a median value of 1.36 mg product per minute, a 75th percentile value of 4.21 mg/min, and a 95th percentile value of 71.9 mg/min. It is possible to use these values to calculate the value of M, i.e. mass of chemical that deposits inside the glove, if the work activity duration is known.

Assuming an activity duration of one hour, the 50th and 95th percentile values translate to 81.6 mg and 4,314 mg of inner glove exposure. While these values may be used as default for M in Equation_Apx K-9, EPA notes the significant difference between the 50th and 95th percentile deposition, with the 95th percentile value being two times more conservative than the defaults for the EPA/OPPT 2-Hand Dermal Exposure Model (where the product S × Qu is 2,247 mg/event). Given the significant variability in inner glove exposure and lack of information on the specific mechanism in which the inner glove contamination occurs, EPA addresses the occlusion scenario in combination with other glove contamination and permeation factors through the use of a protection factor, as described in the next section.

EPA does not expect occlusion scenarios to be a reasonable occurrence for all conditions of use. Specifically, occlusion is not expected at sites using chemicals in closed systems where the only potential for dermal exposure is during the connecting/disconnecting of hoses used for unloading/loading of bulk containers (e.g., tank trucks or rail cars) or while collecting quality control samples including manufacturing sites, repackaging sites, sites processing the chemical as a reactant, formulation sites, and other similar industrial sites. Occlusion is also not expected to occur at highly controlled sites, such as electronics and pharmaceuticals manufacturing sites, where, due to purity requirements, the use of engineering controls is expected to limit potential dermal exposures. EPA also does not expect occlusion at sites where contact with bulk liquid chemical is not expected such as aerosol degreasing sites where workers are only expected to handle the aerosol cans containing the chemical and not the actual bulk liquid chemical.

EPA expects occlusion to be a reasonable occurrence at sites where workers may come in contact with bulk liquid chemical and handle the chemical in open systems. This includes conditions of use such as vapor degreasing, cold cleaning, and dry cleaning where workers are expected to handle bulk chemical during cleanout of spent solvent and addition of fresh solvent to equipment. Similarly, occlusion may occur at coating or adhesive application sites when workers replenish application equipment with liquid coatings or adhesives.

K.5 Incorporating Glove Protection

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 should be explored by considering different percentages of effectiveness (e.g., 25% vs. 50% effectiveness).

Gloves only offer barrier protection until the chemical breaks through the glove material. Using a conceptual model, Cherrie (Cherrie et al., 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 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 APR for respiratory protection, the inverse of the protection factor is the fraction of the chemical that penetrates the glove.

The protection afforded by gloves can be incorporated into the EPA/OPPT model (Equation_Apx K-1) by modification of Q_u with a protection factor, PF (unitless, PF ≥ 1):

Equation_Apx K-10

$$D_{exp} = S \times \frac{Q_u}{PF} \times Y_{derm} \times FT$$

Given the limited state of knowledge about the protection afforded by gloves in the workplace, it is reasonable to utilize the PF values of the ECETOC TRA model (Marquart et al., 2017), rather than attempt to derive new values. Table_Apx K-2 presents the PF values from ECETOC TRA model (version 3). In the exposure data used to evaluate the ECETOC TRA model, Marquart (2017) reported that the observed glove protection factor was 34, compared to PF values of 5 or 10 used in the model.

Table_Apx K-2. Exposure Control Efficiencies and 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

K.6 Proposed Dermal Dose Equation

Accounting for all parameters above, the proposed, overall equation for estimating dermal exposure is:

Equation_Apx K-11

$$D_{exp} = S \times \frac{(Q_u \times f_{abs})}{PF} \times Y_{derm} \times FT$$

EPA presents exposure estimates for the following deterministic dermal exposure scenarios:

- Dermal exposure without the use of protective gloves (Equation_Apx K-11, PF = 1)
- Dermal exposure with the use of protective gloves (Equation_Apx K-11, PF = 5)
- Dermal exposure with the use of protective gloves and employee training (Equation_Apx K-11, PF = 20 for industrial users and PF = 10 for professional users)
- Dermal exposure with occlusion (Equation_Apx K-9)

EPA assumes the following parameter values for Equation_Apx K-11 in addition to the parameter values presented in Table_Apx K-1:

- S, the surface area of contact: 535 cm^2 (central tendency) and 1,070 cm^2 (high-end), representing the total surface area of both hands.
- Q_u, the quantity remaining on the skin: 1.4 mg/cm^2-event (central tendency) and 2.1 mg/cm^2-event (high-end). These are the midpoint value and high-end of range default value, respectively, used in the EPA/OPPT dermal contact with liquids models (U.S. EPA, 2015b).
- Y_{derm}, the weight fraction of the chemical of interest in the liquid: EPA will assess a unique value of this parameter for each occupational scenario or group of similar occupational scenarios.

- FT, the frequency of events: 1 event per day. Equation_Apx K-11 shows a linear relationship between FT and D_{exp}; however, this fails to account for time between contact events. Since the chemical simultaneously evaporates from and absorbs into the skin, the dermal exposure is a function of both the number of contact events per day and the time between contact events. EPA did not identify information on how many contact events may occur and the time between contact events. Therefore, EPA assumes a single contact event per day for estimating dermal exposures.

For Equation_Apx K-9, EPA assumes the quantity of liquid occluded underneath the glove (M) is equal to the product of the entire surface area of contact ($S = 1{,}070\ cm^2$) and the assumed quantity of liquid remaining on the skin ($Q_u = 2.1\ mg/cm^2$-event), which is equal to 2,247 mg/event. See discussion in Section K.4.

K.7 Equations for Calculating Acute and Chronic (Non-Cancer and Cancer) Dermal Dose

Equation_Apx K-11 estimates dermal potential dose rates (mg/day) to workers in occupational settings. The potential dose rates are then used to calculate acute retained doses (ARD), and chronic retained doses (CRD) for non-cancer and cancer risks.

Acute retained doses are calculated using Equation_Apx K-12.

Equation_Apx K-12

$$\boldsymbol{ARD = \frac{D_{\mathrm{exp}}}{BW}}$$

Where:

ARD = acute retained dose (mg/kg-day)
D_{exp} = dermal potential dose rate (mg/kg)
BW = body weight (kg)

CRD is used to estimate exposures for non-cancer and cancer risks. CRD is calculated as follows:

Equation_Apx K-13

$$CRD = \frac{D_{exp} \times EF \times WY}{BW \times (AT\ or\ AT_c)}$$

Equation_Apx K-14

$$AT = WY \times 365 \frac{day}{yr}$$

Equation_Apx K-15

$$\boldsymbol{AT_c = LT \times 365 \frac{day}{yr}}$$

Where:

CRD = Chronic retained dose used for chronic non-cancer or cancer risk calculations
EF = Exposure frequency (day/yr)
WY = Working years per lifetime (yr)
AT = Averaging time (day) for chronic, non-cancer risk
AT_C = Averaging time (day) for cancer risk
LT = Lifetime years (yr) for cancer risk

Table_Apx K-3 summarizes the default parameter values used to calculate each of the above acute or chronic exposure estimates. Where multiple values are provided for EF, it indicates that EPA may have used different values for different conditions of use. The rationales for these differences are described below in this section.

Table_Apx K-3. Parameter Values for Calculating Dermal Dose Estimates

Parameter Name	Symbol	Value	Unit
Exposure Frequency	EF	250 258 (50th percentile) to 293 (95th percentile) (dry cleaning only) 125 to 150 (DoD – oil analysis only) 30 to 36 (DoD – water pipe repair only)	days/yr
Working years	WY	31 (50th percentile) 40 (95th percentile)	years
Lifetime Years, cancer	LT	78	years
Body Weight	BW	80	kg
Averaging Time, non-cancer	AT	11,315 (central tendency)[a] 14,600 (high-end)[b]	day
Averaging Time, cancer	AT_c	28,470	day

[a] Calculated using the 50th percentile value for working years (WY)
[b] Calculated using the 95th percentile value for working years (WY)

Exposure Frequency (EF)

EPA generally uses an exposure frequency of 250 days per year with two notable exceptions: dry cleaning and DoD uses. EPA assumed dry cleaners may operate between five and six days per week and 50 to 52 weeks per year resulting in a range of 250 to 312 annual working days per year (AWD). Taking into account fractional days exposed (f) resulted in an exposure frequency (EF) of 258 at the 50th percentile and 293 at the 95th percentile. For the two DoD uses, information was provided indicating process frequencies of two to three times per week (oil analysis) and two to three times per month (water pipe repair). EPA used the maximum frequency for high-end estimates and the midpoint frequency for central tendency estimates. For the oil analysis use this resulted in 125 days/yr at the central tendency and 150 days/yr at the high-end. For the water pipe repair, this resulted in 30 days/yr at the central tendency and 36 days/yr at the high-end.

EF is expressed as the number of days per year a worker is exposed to the chemical being assessed. In some cases, it may be reasonable to assume a worker is exposed to the chemical on each working day. In other cases, it may be more appropriate to estimate a worker's exposure to the chemical occurs during a subset of the worker's annual working days. The relationship between exposure frequency and annual working days can be described mathematically as follows:

Equation_Apx K-16

$$EF = f \times AWD$$

Where:

EF = exposure frequency, the number of days per year a worker is exposed to the chemical (day/yr)
f = fractional number of annual working days during which a worker is exposed to the chemical (unitless)
AWD = annual working days, the number of days per year a worker works (day/yr)

U.S. BLS (2016) provides data on the total number of hours worked and total number of employees by each industry NAICS code. These data are available from the 3- to 6-digit NAICS level (where 3-digit NAICS are less granular and 6-digit NAICS are the most granular). Dividing the total, annual hours worked by the number of employees yields the average number of hours worked per employee per year for each NAICS.

EPA has identified approximately 140 NAICS codes applicable to the multiple conditions of use for the ten chemicals undergoing risk evaluation. For each NAICS code of interest, EPA looked up the average hours worked per employee per year at the most granular NAICS level available (i.e., 4-digit, 5-digit, or 6-digit). EPA converted the working hours per employee to working days per year per employee assuming employees work an average of eight hours per day. The average number of days per year worked, or AWD, ranges from 169 to 282 days per year, with a 50th percentile value of 250 days per year. EPA repeated this analysis for all NAICS codes at the 4-digit level. The average AWD for all 4-digit NAICS codes ranges from 111 to 282 days per year, with a 50th percentile value of 228 days per year. 250 days per year is approximately the 75th percentile. In the absence of industry- and PCE-specific data, EPA assumes the parameter *f* is equal to one for all conditions of use except dry cleaning. Dry cleaning used a uniform distribution from 0.8 to 1 for *f*. The 0.8 value was derived from the observation that the weighted average of 200 day/yr worked (from BLS/Census) is 80% of the standard assumption that a full-time worker works 250 day/yr. The maximum of 1 is appropriate as dry cleaners may be family owned and operated and some workers may work as much as every operating day.

Working Years (WY)

EPA has developed a triangular distribution for working years. EPA has defined the parameters of the triangular distribution as follows:

- Minimum value: BLS CPS tenure data with current employer as a low-end estimate of the number of lifetime working years: 10.4 years;

- Mode value: The 50th percentile tenure data with all employers from SIPP as a mode value for the number of lifetime working years: 36 years; and

- Maximum value: The maximum average tenure data with all employers from SIPP as a high-end estimate on the number of lifetime working years: 44 years.

This triangular distribution has a 50th percentile value of 31 years and a 95th percentile value of 40 years. EPA uses these values for central tendency and high-end ADC and LADC calculations, respectively.

The U.S. BLS (2014) provides information on employee tenure with *current employer* obtained from the Current Population Survey (CPS). CPS is a monthly sample survey of about 60,000 households that provides information on the labor force status of the civilian non-institutional population age 16 and over; CPS data are released every two years. The data are available by demographics and by generic industry sectors but are not available by NAICS codes.

The U.S. Census Bureau (2019a) Survey of Income and Program Participation (SIPP) provides information on *lifetime tenure with all employers*. SIPP is a household survey that collects data on income, labor force participation, social program participation and eligibility, and general demographic characteristics through a continuous series of national panel surveys of between 14,000 and 52,000 households (U.S. Census Bureau, 2019b). EPA analyzed the 2008 SIPP Panel Wave 1, a panel that began in 2008 and covers the interview months of September 2008 through December 2008 (U.S. Census Bureau, 2019a, b). For this panel, lifetime tenure data are available by Census Industry Codes, which can be cross-walked with NAICS codes.

SIPP data include fields for the industry in which each surveyed, employed individual works (TJBIND1), worker age (TAGE), and years of work experience *with all employers* over the surveyed individual's lifetime.[41] Census household surveys use different industry codes than the NAICS codes used in its firm surveys, so these were converted to NAICS using a published crosswalk (U.S. Census Bureau, 2013). EPA calculated the average tenure for the following age groups: 1) workers age 50 and older; 2) workers age 60 and older; and 3) workers of all ages employed at time of survey. EPA used tenure data for age group "50 and older" to determine the high-end lifetime working years, because the sample size in this age group is often substantially higher than the sample size for age group "60 and older". For some industries, the number of workers surveyed, or the *sample size*, was too small to provide a reliable representation of the worker tenure in that industry. Therefore, EPA excluded data where the sample size is less than five from our analysis.

Table_Apx K-4 summarizes the average tenure for workers age 50 and older from SIPP data. Although the tenure may differ for any given industry sector, there is no significant variability between the 50th and 95th percentile values of average tenure across manufacturing and non-manufacturing sectors.

Table_Apx K-4. Overview of Average Worker Tenure from U.S. Census SIPP (Age Group 50+)

Industry Sectors	Working Years			
	Average	50th Percentile	95th Percentile	Maximum
All industry sectors relevant to the 10	35.9	36	39	44

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[41] To calculate the number of years of work experience EPA took the difference between the year first worked (TMAKMNYR) and the current data year (i.e., 2008). EPA then subtracted any intervening months when not working (ETIMEOFF).

Industry Sectors	Working Years			
	Average	50th Percentile	95th Percentile	Maximum
chemicals undergoing risk evaluation				
Manufacturing sectors (NAICS 31-33)	35.7	36	39	40
Non-manufacturing sectors (NAICS 42-81)	36.1	36	39	44

Source: (U.S. Census Bureau, 2019a)
Note: Industries where sample size is less than five are excluded from this analysis.

BLS CPS data provides the median years of tenure that wage and salary workers had been with their current employer. Table_Apx K-5 presents CPS data for all demographics (men and women) by age group from 2008 to 2012. To estimate the low-end value on number of working years, EPA uses the most recent (2014) CPS data for workers age 55 to 64 years, which indicates a median tenure of 10.4 years with their current employer. The use of this low-end value represents a scenario where workers are only exposed to the chemical of interest for a portion of their lifetime working years, as they may change jobs or move from one industry to another throughout their career.

Table_Apx K-5. Median Years of Tenure with Current Employer by Age Group

Age	January 2008	January 2010	January 2012	January 2014
16 years and over	4.1	4.4	4.6	4.6
16 to 17 years	0.7	0.7	0.7	0.7
18 to 19 years	0.8	1.0	0.8	0.8
20 to 24 years	1.3	1.5	1.3	1.3
25 years and over	5.1	5.2	5.4	5.5
25 to 34 years	2.7	3.1	3.2	3.0
35 to 44 years	4.9	5.1	5.3	5.2
45 to 54 years	7.6	7.8	7.8	7.9
55 to 64 years	9.9	10.0	10.3	10.4
65 years and over	10.2	9.9	10.3	10.3

Source: (U.S. BLS, 2014)

Lifetime Years (LT)

EPA assumes a lifetime of 78 years for all worker demographics.

Body Weight (BW)

EPA assumes a body weight of 80 kg for all worker demographics.