United States
Environmental Protection Agency

Office of Chemical Safety and
Pollution Prevention

Draft Risk Evaluation for Trichloroethylene

Supplemental Information File:

Environmental Releases and Occupational Exposure Assessment

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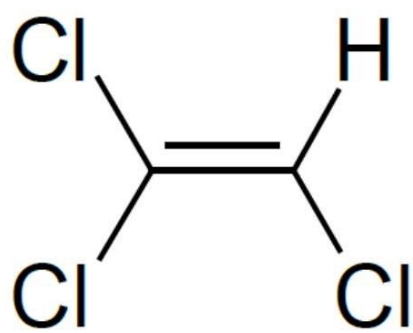

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ABBREVIATIONS

ε_0	Vacuum Permittivity
AF	Assessment Factor
AQS	Air Quality System
ATCM	Airborne Toxic Control Measure
ATSDR	Agency for Toxic Substances and Disease Registries
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BLS	Bureau of Labor Statistics
CAA	Clean Air Act
CARB	California Air Resources Board
CASRN	Chemical Abstracts Service Registry Number
CBI	Confidential Business Information
CCR	California Code of Regulations
CDR	Chemical Data Reporting
CEHD	Chemical Exposure Health Data
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
ChV	Chronic Value (MATC)
CNS	Central Nervous System
COC	Concentration of Concern
COU	Conditions of Use
CPCat	Chemical and Product Categories
CWA	Clean Water Act
CYP2E1	Cytochrome P450 2E1
DMR	Discharge Monitoring Report
EC_{50}	Effect concentration at which 50% of test organisms exhibit an effect
ECHA	European Chemicals Agency
EDC	Ethylene Dichloride
EG	Effluent Guidelines
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ESD	Emission Scenario Document
FDA	Food and Drug Administration
FFDCA	Federal Food, Drug, and Cosmetic Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FR	Federal Register
GACT	Generally Available Control Technology
GST	Glutathione-S-transferase
HAP	Hazardous Air Pollutant
HCFC	Hydrochlorofluorocarbon
HCl	Hydrochloric Acid
HEC	Human Equivalent Concentration
HFC	Hydrofluorocarbon
HHE	Health Hazard Evaluation

HPV	High Production Volume
ICIS-NPDES	Integrated Compliance Information System-National Pollutant Discharge Elimination System
IMIS	Integrated Management Information System
ISOR	Initial Statement of Reasons
IRIS	Integrated Risk Information System
K_{oc}	Soil Organic Carbon-Water Partitioning Coefficient
K_{ow}	Octanol/Water Partition Coefficient
LC_{50}	Lethal Concentration at which 50% of test organisms die
LOEC	Lowest-observable-effect Concentration
MATC	Maximum Acceptable Toxicant Concentration
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MSDS	Material Safety Data Sheet
NAICS	North American Industry Classification System
NATA	National Scale Air-Toxics Assessment
NCEA	National Center for Environmental Assessment
NCP	National Contingency Plan
NEI	National Emissions Inventory
NESHAP	National Emission Standards for Hazardous Air Pollutants
NHANES	National Health and Nutrition Examination Survey - CDC
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NIH	National Institute of Health
NIOSH	National Institute for Occupational Safety and Health
NOEC	No-observable-effect Concentration
NPDWR	National Primary Drinking Water Regulation
NRC	National Research Council
NTP	National Toxicology Program
OCSPP	Office of Chemical Safety and Pollution Prevention
OECD	Organization for Economic Co-operation and Development
OES	Occupational Exposure Scenario
ONU	Occupational Non-User
OPPT	Office of Pollution Prevention and Toxics
OSHA	Occupational Safety and Health Administration
OST	Office of Science and Technology
OW	Office of Water
PECO	Population, Exposure, Comparator, and Outcome
PEL	Permissible Exposure Limit
PESS	Potentially Exposed or Susceptible Subpopulations
POD	Point of Departure
POTW	Publicly Owned Treatment Works
QC	Quality Control
QSAR	Quantitative Structure Activity Relationship
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SDS	Safety Data Sheet

SDWA	Safe Drinking Water Act
SIDS	Screening Information Dataset
SOC	Standard Occupational Classification
SNUN	Significant New Use Notice
SNUR	Significant New Use Rule
STORET	STOrage and RETrieval
TCE	Trichloroethylene
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average
TSDF	Treatment, Storage, and Disposal Facility
U.S.	United States
UV	Ultraviolet
USGS	United States Geological Survey
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

The Toxic Substances Control Act, TSCA § 6(b)(4) requires the United States Environmental Protection Agency (U.S. 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). Trichloroethylene (TCE) was one of these chemicals.

TCE is a colorless volatile liquid with a mildly sweet odor that is used primarily as a manufacturing aid, a reactant or intermediate, a spot and wipe cleaning solvent, a vapor degreasing solvent, and aerosol degreasing solvent and is subject to federal and state regulations and reporting requirements (U.S. EPA, 2014b). TCE 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 TCE. TCE 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 172 million pounds were either manufactured or imported in the U.S. in 2015. The largest use of TCE, accounting for 84% of consumption, is as a reactant/intermediate in manufacturing. The second largest use of TCE, an estimated 15% of consumption, is as a degreasing solvent for vapor degreasing machines and aerosol degreasing products (e.g., brake cleaners) that are used to clean contaminated metal parts or other fabricated materials. The remaining volume is attributed to other uses such as spot cleaners, adhesives, sealants, and coatings, and as an additive in metalworking fluids (U.S. EPA, 2014b).

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

Risk Evaluation Approach

EPA evaluated acute and chronic exposures to workers and occupational non-users in association with TCE conditions of use. EPA used inhalation monitoring data from literature sources where reasonably available and exposure models where monitoring data were not reasonably available or were deemed insufficient for capturing actual exposure within the OES. 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 reasonably 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 TCE 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 from acute and chronic TCE exposure to workers (those directly handling TCE) and occupational non-users (workers not directly involved with the use of TCE) for 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 TCE 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 reasonably available.

1 INTRODUCTION

1.1 Overview

TSCA § 6(b)(4) requires the United States Environmental Protection Agency (U.S. 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). Trichloroethylene (TCE) was one of these chemicals.

TCE, also known as Ethylene trichloride; 1,1,2-Trichloroethylene; Trichloroethene; acetylene trichloride; Ethinyl trichloride, trichloroethene, and TRI, is a colorless volatile liquid with a mildly sweet odor that is used primarily as a reactant or intermediate, and as a vapor and aerosol degreasing solvent and is subject to federal and state regulations and reporting requirements. TCE 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[1] and commercial[2] conditions of use of TCE:

1. Manufacturing;
2. Processing as a Reactant;
3. Formulation of Aerosol and Non-Aerosol Products;
4. Repackaging;
5. Batch Open-Top Vapor Degreasing;
6. Batch Closed-Loop Vapor Degreasing;
7. Conveyorized Vapor Degreasing;
8. Web Vapor Degreasing;
9. Cold Cleaning;
10. Aerosol Applications: Spray Degreasing/Cleaning, Automotive Brake and Parts Cleaners, Penetrating Lubricants, and Mold Releases;
11. Metalworking Fluids;
12. Adhesives, Sealants, Paints, and Coatings (Industrial and Commercial);
13. Other Industrial Uses (such as functional fluids);
14. Spot Cleaning, Wipe Cleaning and Carpet Cleaning;
15. Industrial Processing Aid;
16. Commercial Printing and Copying;
17. Other Commercial Uses; and

[1] Industrial means a site at which one or more chemical substances or mixtures are manufactured (including imported) or processed.
[2] Commercial means the processing or use at a site of a chemical substance or a mixture containing a chemical substance (including as part of an article) in a commercial enterprise providing saleable goods or services.

18. Process Solvent Recycling and Worker Handling of Wastes.

For work place exposures, EPA considered exposures to both workers who directly handle TCE and occupational non-users (ONUs) who do not directly handle TCE but may be exposed to vapors or mists that enter their breathing zone while working in locations in close proximity to where TCE 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) (TSDF - treatment, storage, and disposal facility for example). 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 Trichloroethylene* (U.S. EPA, 2019h).

The assessed conditions of use were described in Table 2-3 of the *Problem Formulation of the Risk Evaluation for Trichloroethylene* (Problem Formulation Document) (U.S. EPA, 2018c); however, due to expected similarities in both processes and exposures/releases several of the subcategories of use (based on CDR) in Table 2-3 were grouped and assessed together during the risk evaluation process. The conditions of use as described in (U.S. EPA, 2018c) were evaluated for occupational scenarios based on corresponding occupational exposure scenarios (OES). A crosswalk of the conditions of use in Table 2-3 to the occupational exposure scenarios 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 Occupational Exposure Scenarios Assessed in the Risk Evaluation

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
Manufacture	Domestic manufacture	Domestic manufacture	Section 2.1 – Manufacturing
	Import	Import	Section 2.4 –Repackaging [c]
Processing	Processing as a reactant/ intermediate	Intermediate in industrial gas manufacturing (e.g., manufacture of fluorinated gases used as refrigerants, foam blowing agents and solvents)	Section 2.2 – Processing as a Reactant
	Processing - Incorporation into formulation, mixture or reaction product	Solvents (for cleaning or degreasing)	Section 2.3 – Formulation of Aerosol and Non-Aerosol Products;
		Adhesives and sealant chemicals	
		Solvents (which become part of product formulation or mixture) (e.g., lubricants and greases, paints and coatings, other uses)	

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
	Processing – Incorporated into articles	Solvents (becomes an integral components of articles)	
	Repackaging [c]	Solvents (for cleaning or degreasing)	Section 2.4 –Repackaging
	Recycling	Recycling	Section 2.18 – Process Solvent Recycling and Worker Handling of Wastes
Distribution in commerce	Distribution	Distribution	Not assessed as a separate operation; exposures/releases from distribution are considered within each condition of use.
Industrial/commercial/consumer use	Solvents (for cleaning or degreasing)	Batch vapor degreaser (e.g., open-top, closed-loop) [c]	Section 2.5 – Batch Open-Top Vapor Degreasing; Section 2.6 – Batch Closed-Loop Vapor Degreasing
		In-line vapor degreaser (e.g., conveyorized, web cleaner) [c]	Section 2.7 – Conveyorized Vapor Degreasing; Section 2.8 – Web Vapor Degreasing
		Cold cleaner	Section 2.9 – Cold Cleaning
	Solvents (for cleaning or degreasing)	Aerosol spray degreaser/cleaner	Section 2.10 – Aerosol Applications: Spray

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
		Mold release [d]	Degreasing/Cleaning, Automotive Brake and Parts Cleaners, Penetrating Lubricants, and Mold Releases
	Lubricants and greases/lubricants and lubricant additives	Tap and die fluid [e]	Section 2.11 – Metalworking Fluids
		Penetrating lubricant	Section 2.10 – Aerosol Applications: Spray Degreasing/Cleaning, Automotive Brake and Parts Cleaners, Penetrating Lubricants, and Mold Releases; Section 2.11 – Metalworking Fluids
	Adhesives and sealants	Solvent-based adhesives and sealants	Section 2.12– Adhesives, Sealants, Paints, and Coatings
		Tire repair cement/sealer [f]	
		Mirror edge sealant [f]	
	Functional fluids (closed systems)	Heat exchange fluid	2.13 – Other Industrial Uses

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
	Paints and coatings	Diluent in solvent-based paints and coatings	Section 2.12 – Adhesives, Sealants, Paints, and Coatings
	Cleaning and furniture care products	Carpet cleaner	Section 2.14 – Spot Cleaning, Wipe Cleaning and Carpet Cleaning
		Cleaning wipes	
	Laundry and dishwashing products	Spot remover	
	Arts, crafts and hobby materials	Fixatives and finishing spray coatings	Section 2.12 – Adhesives, Sealants, Paints, and Coatings
	Corrosion inhibitors and anti-scaling agents	Corrosion inhibitors and anti-scaling agents	Section 2.15 – Industrial Processing Aid [g]
	Processing aids	Process solvent used in battery manufacture	
		Process solvent used in polymer fiber spinning, fluoroelastomer manufacture and Alcantara manufacture	

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
		Extraction solvent used in caprolactam manufacture	
		Precipitant used in beta-cyclodextrin manufacture	
	Ink, toner and colorant products	Toner aid	Section 2.16 –Commercial Printing and Copying
	Automotive care products	Brake and parts cleaner	Section 2.10– Aerosol Applications: Spray Degreasing/Cleaning, Automotive Brake and Parts Cleaners, Penetrating Lubricants, and Mold Releases
	Apparel and footwear care products	Shoe polish	Section 2.17 – Other Commercial Uses
	Other uses	Hoof polishes	
		Pepper spray	
		Lace wig and hair extension glues	
		Gun scrubber	
		Other miscellaneous industrial, commercial and consumer uses	

Life Cycle Stage	Category [a]	Subcategory [b]	Occupational Exposure Scenario
Disposal [h]	Disposal	Industrial pre-treatment	Section 2.18 – Process Solvent Recycling and Worker Handling of Wastes
		Industrial wastewater treatment	
		Publicly owned treatment works (POTW)	

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

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

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

[d] TCE use in mold release applications will be spray applied, therefore, exposures would be similar to spray aerosol degreasing exposures.

[e] As taps and dyes are used to manufacture machined parts, these fluids are used as metalworking lubricants, which serve a similar function to metalworking fluids.

[f] Tire cement/sealers and mirror edge sealants may be applied in the same manner as general adhesives and coatings.

[g] Industrial processing aids added to aid in the manufacture process but not intended to remain in the or become part of the product or product mixture.

[h] Each of the conditions of use of TCE 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 TCE 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 OES comprises the following components:

- **Facility Estimates:** An estimate of the number of sites that use TCE for the given OES.
- **Process Description:** A description of the OES, including the role of the chemical in the use; process vessels, equipment, and tools used during the OES.
- **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 OES.
- **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 OES.
- **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 OES, 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, 2017a), 2016 TRI (U.S. EPA, 2017c), 2016 Discharge Monitoring Report (DMR) (U.S. EPA, 2016a) and 2014 National Emissions Inventory (NEI) (U.S. EPA, 2018a) data to provide a basis to estimate the number of sites using TCE within an OES. Generally, information for reporting sites in CDR and NEI was sufficient to accurately characterize each reporting site's OES. However, information for determining the OES 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 OES at the site. For instances where EPA could not definitively determine the OES because: 1) the report NAICS codes could include multiple conditions of use; 2) the site report 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 OES 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" OES:

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 OES is each site's Standard Industrial Classification (SIC) code. EPA could not determine each reporting site's OES 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 insufficiently capture the number of sites within an OES, EPA supplemented the available 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 number of sites using the U.S. Census' Statistics of US Businesses (SUSB) (U.S. Census Bureau, 2015) data on total establishments by 6-digit NAICS.
3. Use market penetration data to estimate the percentage of establishments likely to be using TCE instead of other chemicals.
4. Combine the data generated in Steps 1 through 3 to produce an estimate of the number of sites using TCE in each 6-digit NAICS code, and sum across all applicable NAICS codes for the OES to arrive at a total estimate of the number of sites within the OES.

1.4.2 Process Description

EPA performed a literature search to find descriptions of processes involved in each OES. Where process descriptions were unclear or not reasonably available, EPA referenced relevant Emission Scenario Documents (ESD) or Generic Scenarios (GS). Process descriptions for each OES 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 reasonably available, EPA referenced relevant ESD's or GS's. Worker activities for each OES 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 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 data (BLS Data).

3. Refine the BLS Data estimates where they are not sufficiently granular by using the U.S. Census' Statistics of US Businesses (SUSB) (U.S. Census Bureau, 2015) data on total employment by 6-digit NAICS.
4. Use market penetration data to estimate the percentage of employees likely to be using TCE instead of other chemicals.
5. Where market penetration data are not reasonably 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 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 TCE in each industry/occupation combination, and sum these to arrive at a total estimate of the number of employees with exposure within the OES.

Appendix A summarizes the methods EPA used to estimate the number of workers potentially exposed to TCE for each OES.

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 OES. 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 50^{th} and 95^{th} 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])

EPA assessed TCE occupational exposure of the following two receptor categories: male or female workers who are ≥16 years or older; and, female workers of reproductive age (≥16 years to less than 50 years).

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, 2018b).

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 value as a what-if exposure. 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, 1994) 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 OES can be found in Section 2. For each OES, 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 OES 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 D through Appendix G.

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, followed by administrative controls, or changes in work practices to reduce exposure potential (e.g., source enclosure, local exhaust ventilation systems). Administrative controls are policies and procedures instituted and overseen by the employer to protect worker exposures. As the last means of control, the use of personal protective equipment (e.g., respirators, gloves) is recommended, when the other control measures cannot reduce workplace exposure to an acceptable level.

Respiratory Protection

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. 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 2-61) and refer to the level of respiratory protection that a respirator or class of respirators is expected to provide to employees when the employer implements a continuing, effective respiratory protection program.

TCE is a central nervous system depressant an is reasonably anticipated to be a human carcinogen (ATSDR, 2014). The United States has several regulatory and non-regulatory exposure limits for TCE: an OSHA PEL of 100 ppm 8-hour TWA, a NIOSH Recommended Exposure Limit (REL) of 2 ppm as a 60-minute ceiling and an American Conference of Government Industrial Hygienists (ACGIH) 8-hour TWA of 50 ppm(ATSDR, 2014). 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 include air-purifying respirators with organic vapor cartridges. Table 1-2 can be used as a guide to show the protectiveness of each category of respirator. Based on the APF, inhalation exposures may be reduced by a factor of 5 to 10,000, when workers and occupational non-users are using respiratory protection.

The respirators should be used when effective engineering controls are not feasible as per OSHA's 29 CFR § 1910.132. The knowledge of the range of respirator APFs is intended to assist employers in selecting the appropriate type of respirator that could provide a level of protection needed for a specific exposure scenario. Table 1-2 lists the range of APFs for respirators. The complexity and burden of wearing respirators increases with increasing APF. The APFs are not to be assumed to be interchangeable for any conditions of use, any workplace, or any worker or ONU. The use of a respirator not necessarily would resolve inhalation exposures since it cannot be assumed that employers have or will implement comprehensive respiratory protection programs for their employees.

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)

1.4.6 Dermal Exposure Assessment Approach

Dermal exposure data was not readily available for the conditions of use in the assessment. Because TCE 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 TCE based on a theoretical framework provided by Kasting (Kasting and Miller, 2006). The amount of liquid on the skin is adjusted by the weight fraction of TCE in the liquid to which the worker is exposed. Specific details of the dermal exposure assessment can be found in Section 2.19 and equations and sample calculations for estimate dermal exposures can be found in Appendix H.

1.4.7 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 OES. Where release sources were unclear or not reasonably available, EPA referenced relevant ESD's or GS's. Water release sources for each OES can be found in Section 2.

1.4.8 Water Release Assessment Approach and Methodology

Where available, EPA used 2016 TRI (U.S. EPA, 2017c) and 2016 DMR (U.S. EPA, 2016a) data to provide a basis for estimating releases. Facilities are only required to report to TRI if the facility has 10 or more full-time employees, is included in an applicable NAICS code, and manufactures, processes, or uses the chemical in quantities greater than a certain threshold (25,000 pounds for manufacturers and processors of TCE and 10,000 pounds for users of TCE). Due to these limitations, some sites that manufacture, process, or use TCE may not report to TRI and are therefore not included in these datasets.

For the 2016 DMR (U.S. EPA, 2016a), EPA used the Water Pollutant Loading Tool within EPA's Enforcement and Compliance History Online (ECHO) to query all TCE 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 TCE 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 sufficiently represent releases of TCE to water for an OES, releases were estimated using data from literature, relevant ESD's or GS's, existing EPA models (e.g., *EPA Water Saturation Loss Model)*, and/or relevant Effluent Limitation Guidelines (ELG). ELG 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 OES can be found in Section 2.

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 OES.

EPA assessed the conditions of use as stated in the *Problem Formulation of the Risk Evaluation for Trichloroethylene* published by EPA in May 2018 (U.S. EPA, 2018c).

2.1 Manufacturing

2.1.1 Facility Estimates

The 2012 CDR shows a national aggregate production volume of 224,674,308 lbs (101,910,552 kg) of TCE manufactured and imported in the U.S. in 2011 (U.S. EPA, 2017a). In the 2016 CDR, there are three sites that domestically manufacture TCE and three sites where the domestic manufacture/import activity field is either claimed as CBI or withheld (U.S. EPA, 2017a). All six sites have production volume data withheld for reporting year 2015 (U.S. EPA, 2017a).

To determine whether the remaining three 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 (Geon Oxy Vinyl Laporte Plant and Occidental Chemical Corp) reported manufacturing TCE in TRI (U.S. EPA, 2017c). Based on visual inspection of a satellite image of the MC International (located in Miami, Florida) site location, only office buildings are visible in a downtown area. Therefore, EPA believes the MC International site is not a manufacturer but is an importer. Therefore, EPA assumes there may be up to five sites that domestically manufacture TCE and provides release and occupational exposure estimates below based on five manufacturing sites.

In the 2016 CDR, all sites claimed CBI on their manufacturing volumes. Using the 2012 CDR data, EPA estimated the average annual production rate at the six facilities by dividing the 2012 total production volume evenly among the five sites. Table 2-1 lists the TCE manufacturing facilities and their estimated production volumes.

Table 2-1. List of Assessed TCE Manufacturing Sites

Site	Basis for Manufacturing Determination	Assessed Production Volume (lb)	Assessed Production Volume (kg)	Production Volume Basis
Solvents & Chemicals, Pearland, TX	2016 CDR	44,934,862	20,382,110	Average of 2011 National Production Volume
Olin Blue Cube, Freeport, TX	2016 CDR	44,934,862	20,382,110	Average of 2011 National Production Volume

Site	Basis for Manufacturing Determination	Assessed Production Volume (lb)	Assessed Production Volume (kg)	Production Volume Basis
Axiall Corporation dba Eagle US 2 LLC, Westlake, LA[a]	2016 CDR	44,934,862	20,382,110	Average of 2011 National Production Volume
Geon Oxy Vinyl Laporte Plant, Laporte, TX	2016 TRI	44,934,862	20,382,110	Average of 2011 National Production Volume
Occidental Chemical Corp Wichita, Wichita, KS	2016 TRI	44,934,862	20,382,110	Average of 2011 National Production Volume

[a] Axiall was purchased by Westlake Chemical in 2016. The site at 1300 PPG Drive Westlake, LA dba Eagle US 2 LLC.

2.1.2 Process Description

Trichloroethylene (TCE) is currently produced domestically by either direct chlorination or oxychlorination of ethylene dichloride (EDC) or other chlorinated ethanes. TCE can be produced separately or as a coproduct of perchloroethylene by varying raw material ratios. TCE was once manufactured predominantly by the chlorination of acetylene. The acetylene-based process consists of two steps. First acetylene is chlorinated to 1,1,2,2-tetrachloroethane. The product is then dehydrohalogenated to trichloroethylene at 96 to 100 °C in aqueous bases such as $Ca(OH)_2$ (GmbH, 1940), or by thermal cracking over a catalyst such as barium chloride on activated carbon or silica or aluminum gels (Elkin, 1969). However, because of the high cost of acetylene, EDC chlorination became the preferred method for producing TCE (Most, 1989).

Chlorination of EDC – The chlorination of EDC involves a non-catalytic reaction of chlorine and EDC or other C2 chlorinated hydrocarbons to form perchloroethylene and TCE as co-products and hydrochloric acid (HCl) as a byproduct (ATSDR, 2014; Snedecor et al., 2004; U.S. EPA, 1985). Following reaction, the product undergoes quenching, HCl separation, neutralization, drying, and distillation (U.S. EPA, 1985). This process is advantageous at facilities that have a feedstock source of mixed C2 chlorinated hydrocarbons from other processes and an outlet for the HCl byproduct (Snedecor et al., 2004). The following illustrates the reaction to form TCE from EDC and chlorine.

$$ClCH_2CH_2Cl + 2\ Cl_2 \rightarrow ClCH{=}CCl_2 + 3\ HCl$$

Oxychlorination of C2 chlorinated hydrocarbons – 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 perchloroethylene and TCE as co-products (ATSDR, 2014; Snedecor et al., 2004). An example reaction using HCl and oxygen to produce TCE is given below.

$$ClCH_2CH_2Cl + HCl + O_2 \rightarrow ClCH{=}CCl_2 + 2\ H_2O$$

Following reaction, the product undergoes HCl separation, drying, distillation, neutralization with ammonia, and a final drying step (U.S. EPA, 1985). The advantage of this process is that no byproduct HCl is produced and can be combined with other processes as a net HCl consumer (ATSDR, 2014; Snedecor et al., 2004).

In both processes the product ratio of TCE to perchloroethylene is controlled by adjusting the reactant ratios (Snedecor et al., 2004).

2.1.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for manufacturing of TCE.

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 TCE 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 TCE 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 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 (ONUs) potentially exposed to TCE at manufacturing sites using 2016 CDR data (where available), BLS 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 BLS' Occupational Employment Statistics data and U.S. Census' SUSB data is detailed in Section 1.4.3. 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 three manufacturing sites. Of the three sites, one site reported at least 100 but fewer than 500 workers, one site reported at least 50 but fewer than 100 workers, and one site reported at least 25 but fewer than 50 workers (U.S. EPA, 2017a). For the other three manufacturing sites, the number of workers in CDR is either claimed as CBI or withheld (U.S. EPA, 2017a).

EPA identified the NAICS code 325199, All Other Basic Organic Chemical Manufacturing, as the code expected to include sites manufacturing TCE. Based on 2016 data from the BLS for this NAICS code and related SOC codes, there are an average of 39 workers and 19 ONUs per site, or a total of 58 potentially exposed workers and ONUs, for sites under this NAICS code (U.S. BLS, 2016). 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 the 2016 CDR for the three 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 67% of the exposed personnel are workers and 33% are ONUs (U.S. BLS, 2016). This resulted in an estimated 354 workers and 174 ONUs (see Table 2-2).

Table 2-2. Estimated Number of Workers Potentially Exposed to Trichloroethylene 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	19	78	38	116
1[b]	201	99	201	99	300
1[c]	50	25	50	25	75
1[d]	25	12	25	12	37
Total Exposed Workers and ONUs[e]			350	170	530

[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 two 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 67% and 33%, 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 67% and 33%, 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 67% and 33%, respectively. Values are rounded to the nearest integer.
[e] Values rounded to two significant figures.

2.1.3.3 Occupational Exposure Results

EPA assessed inhalation exposures during manufacturing using identified inhalation exposure monitoring data. Table 2-3 summarizes 8-hr TWA samples obtained from data submitted by the Halogenated Solvents Industry Alliance (HSIA) via public comment for one company (Halogenated Solvents Industry Alliance, 2018 5176415) listed as “Company B”. HSIA also provided “General 12-hr” full-shift exposure data from “Company A”. However, “Company A” data points were listed as “Not detected ≤0.062 ppm. Two additional studies with monitoring data for manufacturing were identified; however, the data from these studies were not used as the data were from China and almost 30 years old and are unlikely to be representative of current conditions at U.S. manufacturing sites. No data was found to estimate ONU exposures during TCE manufacturing. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 16 data points from 1 source, and the data quality ratings from systematic review for these data were high. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to high.

Table 2-3. Summary of Worker Inhalation Exposure Monitoring Data from TCE Manufacturing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	2.59	0.86	0.59	0.30	16	High
Central Tendency	0.38	0.13	0.09	0.03		

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: (Halogenated Solvents Industry Alliance, 2018 5176415)

2.1.4 Water Release Assessment

The following sections detail EPA's water release assessment for manufacturing of TCE.

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, 2019). Based on the process for manufacturing TCE, EPA expects the sources of water releases to be from aqueous wastes from decanters used to separate catalyst fines, caustic neutralizer column, and caustic scrubbers; and water removed from the TCE product in drying columns (Most, 1989). Additional water releases may occur if a site uses 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 would likely use an organic solvent to clean process equipment.

2.1.4.2 Water Release Assessment Results

Of the five manufacturing sites assessed, three reported in the 2016 TRI (one of these three sites reported zero water releases to TRI). Additionally, one of these sites also reported to 2016 DMR. For the sites that reported water releases, EPA assessed water releases as reported in the 2016 TRI and 2016 DMR. For the remaining two 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 (EG) and Standards (40 C.F.R. Part 414) (U.S. EPA, 2019g). 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 TCE 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 TCE 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 40 C.F.R. Part 414 (U.S. EPA, 2019g). 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 TCE are provided in Table 2-4.

Table 2-4. Summary of OCPSF Effluent Limitations for Trichloroethylene

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	54	21	BAT effluent limitations and NSPS
Subpart J – Direct Discharge Point Sources That Do Not Use End-of-Pipe Biological Treatment	69	26	BAT effluent limitations and NSPS
Subpart K – Indirect Discharge Point Sources	69	26	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, 2019g)

EPA did not identify TCE-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 (ESIG, 2012). In lieu of TCE-specific information, EPA estimated water releases using the SpERC specified wastewater production volume and the annual TCE production rates from each facility as shown in Table 1-1 in Section 2.1.1.

EPA estimated both a maximum daily release and an average daily release using the OCPSF EG limitations for TCE for maximum on any one day, and maximum for any monthly average, respectively. Prevalence of end-of-pipe biological treatment at TCE manufacturing sites is unknown; therefore, EPA used limitations for direct discharges with no end-of-pipe biological treatment and indirect dischargers to address the uncertainty at these sites. EPA estimated annual releases from the average daily release and assuming 350 days/yr of operation[3]. Details of the approach and example 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 TRI and Table 2-6 summarizes water releases from sites not reporting to TRI. The estimated total annual release across all sites is 60.5 – 453.6 kg/yr discharged to surface water or POTWs.

[3] 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 Water Releases of Trichloroethylene from Manufacturing Sites Reporting to 2016 TRI

Site	Annual Release[a] (kg/site-yr)	Annual Release Days (days/yr)	Average Daily Release[a] (kg/site-day)	NPDES Code	Release Media
Olin Blue Cube, Freeport, TX	24	350	0.07	TX0059447	non-POTW WWT
Geon Oxy Vinyl Laporte Plant, Laporte, TX	0	N/A	0	TX0070416	N/A
Axiall Corporation dba Eagle US 2 LLC, Westlake, LA[b]	49.9-443[c]	350	0.14-1.27	LA0000761[d]	Surface Water

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 back-calculated from the annual release rate and assuming 300 days of operation per year.
[b] Axiall was purchased by Westlake Chemical in 2016. The site at 1300 PPG Drive Westlake, LA dba Eagle US 2 LLC.
[c]First value based on 2016 TRI, second value based on 2016 DMR data (U.S. EPA, 2016a).
[d] Based on Eagle US 2 LLC NPDES Permit provided in DMR Data (U.S. EPA, 2016a).

Table 2-6. Estimated Water Releases of Trichloroethylene from Manufacturing Sites Not Reporting to 2016 TRI

Site	Annual Operating Days (days/yr)	Daily Production Volume[a] (kg/site-day)	Daily Wastewater Flow[b] (L/site-day)	Maximum Daily Release[c] (kg/site-day)	Average Daily Release[d] (kg/site-day)	Average Annual Release[e] (kg/site-yr)	NPDES Code	Release Media
Solvents & Chemicals, Pearland, TX	350	58,234	582,345	0.04	0.02	5.3	Not available	Surface Water or POTW
Occidental Chemical Corp. Wichita, KS	350	58,234	582,345	0.04	0.02	5.3	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 (300 days/yr).
[b] The estimated wastewater flow rate is calculated assuming 10 m^3 of wastewater is produced per metric ton of TCE produced (equivalent to 10 L wastewater/kg of TCE) based on the SpERC for the manufacture of a substance (ESIG, 2012).
[c] The maximum daily release is calculated using the maximum daily concentration from the OCPSF EG, 26 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, 69 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 Processing as a Reactant

2.2.1 Facility Estimates

The current largest consumption of TCE in the United States is for use as an intermediate in hydrofluorocarbon manufacturing (U.S. EPA, 2017b). US Census Bureau data indicate there are 440 establishments in the United States under the following NAICS code: 325120, Industrial Gas Manufacturing (U.S. Census Bureau, 2015). One site reported TCE releases in TRI under this NAICS code. Two additional sites reported use of TCE as a reactant under NAICS codes 325180 and 325199 in TRI. DMR data indicate up to two other sites under SIC codes 2819 (Industrial Inorganic Chemicals) and 2813 (Industrial Gases). The table below summarizes information on these sites. For the purposes of this assessment, EPA assumes HCFC manufacturing using TCE may occur at any of these 5 to 440 sites under these NAICS and SIC numbers.

Table 2-7. List of Assessed Sites Using TCE as a Reactant/Intermediate

Site	Basis for Processing as a Reactant Determination
Honeywell International Inc – Geismar Complex, Geismar, LA	2016 DMR
Praxair Technology Center, Tonawanda, NY	2016 DMR
Mexichem Fluor Inc., Saint Gabriel, LA	2016 TRI
Arkema Inc., Calvert City, KY	2016 TRI
Halocarbon Products Corp, North Augusta, SC	2016 TRI

2.2.2 Process Description

Processing as a reactant or intermediate is the use of trichloroethylene as a feedstock in the production of another chemical product via a chemical reaction in which trichloroethylene is consumed to form the product. In the past, trichloroethylene was used as a feedstock (with chlorine) for the manufacture of one- and two-carbon (C1 and C2) chlorofluorocarbons (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, trichloroethylene has been used to manufacture the CFC alternatives, hydrochlorofluorocarbons (HCFCs), specifically the HCFC-134a alternative to CFC-12 (Smart and Fernandez, 2000). TCE is also used to manufacture HCFC-133a, which is then used to manufacture an anesthetic, halothane (ECB, 2004). Byproducts typically recovered and sold from HCFC products include hydrochloric acid (or muriatic acid).

HCFC-134a is produced by fluorination of trichloroethylene with liquid or gaseous hydrogen fluoride (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).

2.2.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for the processing of TCE as a reactant.

2.2.3.1 Worker Activities

During processing TCE as a reactant, 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) 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. TCE exposures from the process are not expected as these reactions occur in closed systems (Arkema Inc., 2018).

ONUs include employees that work at the site where TCE is reacted, 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 processing as a reactant include supervisors, managers, and tradesmen that may be in the same area as exposure sources but do not perform tasks that result in the same level of exposures as workers.

2.2.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed to TCE at sites processing TCE as a reactant using 2016 TRI data (where available), BLS 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 BLS Occupational Employment Statistics data and U.S. Census' SUSB data is detailed in Section 1.4.4. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. Upon review of 2016 TRI and DMR data, EPA found 5 sites reported using TCE as a reactant (U.S. EPA, 2017c) and (U.S. EPA, 2016a). Based on BLS data for the NAICS code 325120, Industrial Gas Manufacturing, there are 440 facilities (see number of facility discussion in Section 2.2.1.

EPA determined the number of workers using the related SOC codes from BLS analysis that are associated with the primary NAICS codes listed in TRI. Two of the submissions in TRI and DMR identified the primary NAICS code to be 325120, Industrial Gas Manufacturing. For NAICS code 325120, there are an average of 14 workers and 7 ONUs per site, or a total of 21 potentially exposed workers and ONUs (U.S. BLS, 2016).

To determine the high-end total number of workers and ONUs, EPA used the high-end number of facilities based on US Census Bureau data for NAICS code: 325120, Industrial Gas Manufacturing (U.S. Census Bureau, 2015) (440 sites) and information from BLS to obtain the number of workers and ONUs per site. This resulted in an estimated 6,100 workers and 2,900 ONUs (see Table 2-8.) at 440 sites.

To determine the low-end total number of workers and ONUs, EPA used the NAICS codes from the five identified facilities reported in the TRI and DMR data and used the worker-to-ONU ratio from the BLS data. This resulted in an estimated 117 workers and 55 ONUs (see Table 2-8.).

Table 2-8. Estimated Number of Workers Potentially Exposed to TCE During Processing as a Reactant

NAICS Code	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]
	High-End					
325120	440	14	7	6,100	2,900	9,000
	Low-End					
325120	2	14	7	28	13	41
325180	2	25	12	50	24	74
325199	1	39	18	39	18	57
Total	5	23	11	120	55	180

[a] Values rounded to two significant figures.

2.2.3.3 Occupational Exposure Results

EPA did not identify inhalation exposure monitoring data related processing TCE as a reactant. Therefore, EPA used monitoring data from the manufacture of TCE as surrogate. EPA believes the handling and TCE concentrations for both conditions of use to be similar. However, EPA is unsure of the representativeness of these surrogate data toward actual exposures to TCE at all sites covered by this OES.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA inhalation air concentrations. The primary strengths include the assessment approach, which is the use of surrogate monitoring data, in the middle of the inhalation approach hierarchy. These monitoring data include 16 data points from 1 source, and the data quality ratings from systematic review for these data were medium. The primary limitations of these data include the uncertainty of the representativeness of these surrogate data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

The surrogate data was obtained from (HSIA) via public comment (Halogenated Solvents Industry Alliance, 2018 5176415), presented in Table 2-9 below. See Section 2.1.3.3 for more information on this data. No data was found to estimate ONU exposures during use of TCE as a reactant. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical.

Table 2-9. Summary of Worker Inhalation Exposure Surrogate Monitoring Data from TCE Use as a Reactant

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Associated Air Concentration Data
High-End	2.59	0.86	0.59	0.30	16	Medium
Central Tendency	0.38	0.13	0.09	0.03		

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 C.
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2.2.4 Water Release Assessment

The following sections detail EPA's water release assessment for the use of TCE as a reactant.

2.2.4.1 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, 2019). Based on the use as a reactant, EPA expects minimal sources of TCE release to water.

2.2.4.2 Water Release Assessment Results

Two of the three sites reporting to TRI did not report any water releases of TCE; the other TRI site reported 13 lb/yr (5.9 kg/yr) released to water. For the two sites found through DMR data, total water releases were calculated to be approximately 11 lb/yr (5 kg/yr). Based on the information for these 5 sites, an average annual release of approximately 2.2 kg/site-yr was calculated. Using this estimate, and assuming 440 sites as a high-end estimate, the total TCE water discharge from these 440 sites equal approximately 968 kg/yr. Table 2-10 summarizes the low and high end water release estimates.

Table 2-10. Water Release Estimates for Sites Using TCE as a Reactant

Number of Sites	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day)	NPDES Code	Release Media
Low End Number of Sites					
Arkema Inc., Calvert City, KY	5.9	350	0.02	KY0003603	Surface Water
Honeywell International - Geismar Complex, Geismar, LA	4.5	350	0.01	LA0006181	Surface Water
Praxair Technology Center, Tonawanda, NY	0.6	350	1.7E-03	NY0000281	Surface Water
High End Number of Sites					
440 unknown sites	2.2[a]	350	6.3E-03	N/A	Surface Water or POTW

[a] Calculated from the total yearly water releases of TCE from DMR and TRI data, and diving by the number of reporting sites (5 sites). Mexichem Fluor Inc. and Halocarbon Products Corp reported no water releases to TRI.

2.3 Formulation of Aerosol and Non-Aerosol Products

2.3.1 Facility Estimates

In TRI, nineteen sites reported TCE as a formulation component under the following NAICS codes: 325510, Paint and Coating Manufacturing, 325520, Adhesive Manufacturing, 325611, Soap and Other Detergent Manufacturing, 325612, Polish and Other Sanitation Good Manufacturing, and 325998, All Other Miscellaneous Chemical Product and Preparation Manufacturing (U.S. EPA, 2017c). No DMR data was found that corresponds to this TCE use. For the purposes of this assessment, EPA assumes formulation of aerosol and non-aerosol products using TCE may occur at any of these 19 sites under these NAICS codes.

Table 2-11. List of Assessed Sites Using TCE in Formulation Products

Site	Basis for Formulation Site Determination
Sherwin-Williams Co, Bedford Heights, OH	2016 TRI
Slocum Adhesives Corp, Lynchburg, VA	2016 TRI
Rema Tip Top/NA, Madison, GA	2016 TRI
IPS Corp, Gardena, CA	2016 TRI
Lord Corp, Saegertown, PA	2016 TRI
ITW Polymers Sealants NA, Rockland, MA	2016 TRI
Quest Specialty Corp, Brenham, TX	2016 TRI
ABC Compounding Co Of Texas Inc, Grand Prairie, TX	2016 TRI
ITW Pro Brands, Tucker, GA	2016 TRI
Plaze Inc, Pacific, MO	2016 TRI
Emco Chemical Distributors Inc, Pleasant Prairie, WI	2016 TRI
American Jetway Corp, Wayne, MI	2016 TRI
3M Cottage Grove Center, Cottage Grove, MN	2016 TRI
Amc International, Dalton, GA	2016 TRI
Calgon Carbon Corp, Catlettsburg, KY	2016 TRI
Chemical Solvents Jennings Road Facility, Cleveland, OH	2016 TRI
Hill Manufacturing Co Inc, Atlanta, GA	2016 TRI
Roberts Capitol, Dalton, GA	2016 TRI

Site	Basis for Formulation Site Determination
RR Street & Co Inc, Chicago, IL	2016 TRI

2.3.2 Process Description

After manufacture, TCE may be supplied directly to end-users, or may be incorporated into various products and formulations at varying concentrations for further distribution. Formulation refers to the process of mixing or blending several raw materials to obtain a single product or preparation. For example, formulators may mix TCE 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).

TCE aerosol packing would be similar to that reported for Perchloroethylene in a 1981 NIOSH HHE. First the halogenated solvent and other components are loaded into a mixing vessel and blending to create the final formulation (Orris and Daniels, 1981). The formulation is then gravity filled the cans and the dispensing valves are placed and crimped on the can (Orris and Daniels, 1981). Then the propellent is injected into the cans and buttons are placed on top of the valves (Orris and Daniels, 1981). Finally, the cans are passed through a tank of heated water to check for leaks and weighed to insure the proper level of contents (Orris and Daniels, 1981).

2.3.3 Exposure Assessment

The following sections detail EPA’s occupational exposure assessment for the use of TCE in formulation of aerosol and non-aerosol products.

2.3.3.1 Worker Activities

During formulation of aerosol and non-aerosol products, workers are potentially exposed to TCE while connecting and disconnecting hoses and transfer lines to containers and packaging to be unloaded (e.g., railcars, tank trucks, totes). 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 TCE 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 formulation activities include supervisors, managers, and tradesmen that may be in the same area as exposure sources but do not perform tasks that result in the same level of exposures as workers.

2.3.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of TCE in the formulation of aerosol and non-aerosol products using BLS Data(U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS codes reported by the sites in the 2016 TRI. 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. Table 2-12 provides the results of the number of worker analysis. There are 306 workers and 99 ONUs potentially exposed during use of TCE in the formulation of aerosol and non-aerosol products.

Table 2-12. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Use in in the Formulation of Aerosol and Non-Aerosol Products

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
325510	1	14	5	20	14	5
325520	6	108	41	149	18	7
325611	2	37	9	46	19	4
325612	2	33	8	41	17	4
325998	8	113	37	150	14	5
Total	19	306	99	405	16	5

[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.
[b] Totals may not add exactly due to rounding.
Sources: (U.S. EPA, 2017c)

2.3.3.3 Occupational Exposure Results

EPA did not identify inhalation exposure monitoring data related using TCE when formulating aerosol and non-aerosol products. Therefore, EPA used monitoring data from repackaging as a surrogate, as EPA believes the handling and TCE concentrations for both conditions of use to be similar. However, EPA is unsure of the representativeness of these surrogate data toward actual exposures to TCE at all sites covered by this OES. See Section 2.4.3.3 for additional information on the data used for the Repackaging OES.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA inhalation air concentrations. The primary strengths include the assessment approach, which is the use of surrogate monitoring data, in the middle of the inhalation approach hierarchy. These monitoring data include 33 data points from 1 source, and the data quality ratings from systematic review for these data were high. The primary limitations of these data include the uncertainty of the representativeness of these surrogate data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium.

Table 2-13 summarizes the 8-hr TWA from monitoring data from unloading/loading TCE from bulk containers. The data were obtained from a Chemical Safety Report (DOW Deutschland, 2014b). No data was found to estimate ONU exposures during formulation of aerosol and non-aerosol products. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical.

Table 2-13. Summary of Worker Inhalation Exposure Monitoring Data for Unloading TCE During Formulation of Aerosol and Non-Aerosol Products

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	1.1	0.4	0.3	0.1	33	Medium
Central Tendency	4.9E-4	1.6E-4	1.1E-4	4.5E-5		

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

2.3.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in formulation of aerosol and non-aerosol products.

2.3.4.1 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, 2019). Based on the use in formulations and the amount of TCE used for this OES, EPA expects minimal sources of TCE release to water.

2.3.4.2 Water Environmental Release Assessment Results

None of the sites reporting to TRI reported any water releases of TCE. All releases were to off-site land, incineration or recycling. EPA does not expect water releases from this OES.

2.4 Repackaging

2.4.1 Facility Estimates

The repackaging scenario covers only those sites that purchase TCE or TCE containing products from domestic and/or foreign suppliers and repackage the TCE from bulk containers into smaller containers for resale. It does not include sites that import TCE and either: (1) store in a warehouse and resell directly without repackaging; (2) act as the importer of record for TCE but TCE is never present at the site[4]; or (3) import the chemical and process or use the chemical directly at the site. In case #1, there is little or negligible opportunity for exposures or releases as the containers are never opened. In cases #2, the potential for exposure and release is at the site receiving TCE, not the "import" site and exposures/releases at the site receiving TCE are assessed in the relevant OES based on the use for TCE at the site. Similarly, for case #3, the potential for exposure and release at these sites are evaluated in the relevant OES depending on the use for TCE at the site.

To determine the number of sites that may repackage TCE, EPA considered 2016 TRI data, and 2016 DMR data. In the 2016 TRI, 17 facilities report under the NAICS code 424690, Other Chemical and Allied Products Merchant Wholesalers. To address the uncertainty at these sites, EPA assumes that these sites may perform repackaging activities of TCE. Note: CDR data was not used in this case as none of the manufacturing sites provided non-CBI information on downstream repackaging sites.

In the 2016 DMR data, there are three sites that report under the SIC code 4226, Special Warehousing and Storage (NAICS code equivalent: 493110); and one site that reports under the SIC code 5169, Chemical and Allied Products (NAICS code equivalent: 424690). One site reported to DMR using SIC code 4953,Refuse Systems (NAICS code equivalent: 562920) but the company website indicates the facility is a terminal storage facility. EPA assumes the primary OES at these sites is repackaging. Therefore, EPA assesses a total of 22 sites (17+3+1+1 = 22 sites) for the repackaging of TCE.

2.4.2 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 TCE are not known. For this risk evaluation, EPA assesses the repackaging of TCE from bulk packaging to drums and bottles at wholesale repackaging sites.

2.4.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for repackaging TCE.

2.4.3.1 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

[4] 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.

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

2.4.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of TCE during repackaging using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS codes reported by the sites in the 2016 TRI (U.S. EPA, 2017c) and 2016 DMR (U.S. EPA, 2016a). 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. Table 2-14 provides the results of the number of worker analysis. There are 36 workers and 12 ONUs potentially exposed during use of TCE during repackaging.

Table 2-14. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Repackaging

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
424690	18	23	8	31	1	0.4
493110	3	11	2	13	4	0.7
562920	1	2	2	4	2	1.5
Total	22	36	12	48	2	0.5

[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.
[b] Totals may not add exactly due to rounding.
Sources: (U.S. EPA, 2017c), (U.S. EPA, 2016a)

2.4.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data related unloading/loading TCE into/from bulk transport containers. Table 2-15 summarizes the 8-hr TWA from monitoring data from unloading/loading TCE from bulk containers. The data were obtained from a Chemical Safety Report (DOW Deutschland, 2014b). It should be noted that this study indicates that the filling system uses a "largely automated process" (DOW Deutschland, 2014b). Therefore, EPA is unsure of the representativeness of these data toward actual exposures to TCE for all sites covered by this OES.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 33 data points from 1 source, and the data quality ratings from systematic review for these data were high. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to high.

No data was found to estimate ONU exposures during formulation of aerosol and non-aerosol products. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical.

Table 2-15. Summary of Worker Inhalation Exposure Monitoring Data for Unloading/Loading TCE from Bulk Containers

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	1.1	0.4	0.26	0.1	33	Medium to High
Central Tendency	4.9E-4	1.6E-4	1.1E-4	4.5E-5		

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

2.4.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE during repackaging.

2.4.4.1 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 TCE or products containing TCE. EPA expects the use of water/steam for cleaning containers to be limited at repackaging sites as TCE 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.

2.4.4.2 Water Environmental Release Assessment Results

Water releases during repackaging were assessed using data reported in the 2016 DMR and 2016 TRI. One of the 20 sites reporting to TRI reported water releases of TCE to off-site wastewater treatment. All other sites reporting to TRI reported releases to off-site land or incineration. EPA assessed annual releases as reported in the 2016 DMR and assessed daily releases by assuming 250 days of operation per year. A summary of the water releases reported to the 2016 DMR and TRI can be found in Table 2-16.

Table 2-16. Reported Water Releases of Trichloroethylene from Sites Repackaging TCE

Site Identity	Annual Release (kg/site-yr)[a]	Annual Release Days (days/yr)	Daily Release (kg/site-day)[a]	NPDES Code	Release Media
Hubbard-Hall Inc, Waterbury, CT	277	250	1.1	Not available	Non-POTW WWT
St. Gabriel Terminal, Saint Gabriel, LA	1.4	250	5.5E-03	LA0052353	Surface Water
Vopak Terminal Westwego Inc, Westwego, LA	1.2	250	4.7E-03	LA0124583	Surface Water
Oiltanking Houston Inc, Houston, TX	0.8	250	3.3E-03	TX0091855	Surface Water
Research Solutions Group Inc, Pelham, AL	0.01	250	3.3E-05	AL0074276	Surface Water
Carlisle Engineered Products Inc, Middlefield, OH	1.7E-3	250	6.8E-06	OH0052370	Surface Water

[a] Annual release amounts are based on the site reported values. Therefore, daily releases are back-calculated from the annual release rate and assuming 250 days of operation per year.
Sources: (U.S. EPA, 2016a) and (U.S. EPA, 2017c)

2.5 Batch Open Top Vapor Degreasing

2.5.1 Facility Estimates

To determine the number of sites that use TCE in batch open-top vapor degreasers (OTVD), EPA considered 2014 NEI data (U.S. EPA, 2018a), 2016 TRI data (U.S. EPA, 2017c), and 2016 DMR data (U.S. EPA, 2016a). In the 2014 NEI, sites report information for each degreaser at the site, including degreaser type. In the 2014 NEI, 114 sites reported operation of 134 OTVDs (U.S. EPA, 2018a). EPA identified thirty-one facilities, eight of which are the same as NEI sites, in the 2016 TRI where the primary OES is expected to be degreasing based on the activities and NAICS codes reported (U.S. EPA, 2017c). Of the sites with non-zero water discharges in the 2016 DMR data (U.S. EPA, 2016a), there are 63 sites for which EPA expects the primary OES to be degreasing based on the reported SIC codes. However, six of these sites were the same as NEI or TRI reported sites. Therefore, EPA assessed a total of 194 sites for use of TCE in OTVD.

It should be noted that this number is expected to underestimate the total number of sites using TCE in OTVDs. NEI data does not include degreasing operations that are classified as area sources because area sources are reported at the county level and do not include site-specific information. TRI may also underestimate the total number of sites as it does not include sites with use-rates of TCE below the TRI reporting threshold. It should also be noted that sites in TRI and DMR do not include information on specific conditions of use; therefore, it is possible the actual OES 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 TCE as a metalworking fluid. These sites are assessed as OTVD based on the fact that approximately 15% of the production volume of TCE is used in metal cleaning/degreasing (compared to <2% for metalworking) and, based on NEI reporting, OTVDs are expected to be the primary cleaning machines used in industry (134 OTVDs reported compared to 4 closed-loop systems[5], and 8 conveyorized systems (no web cleaning systems using TCE were reported in the 2014 NEI).

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 (Morford, 2017):

- 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.

Figure 2-1 is an illustration of vapor degreasing operations, which can occur in a variety of industries.

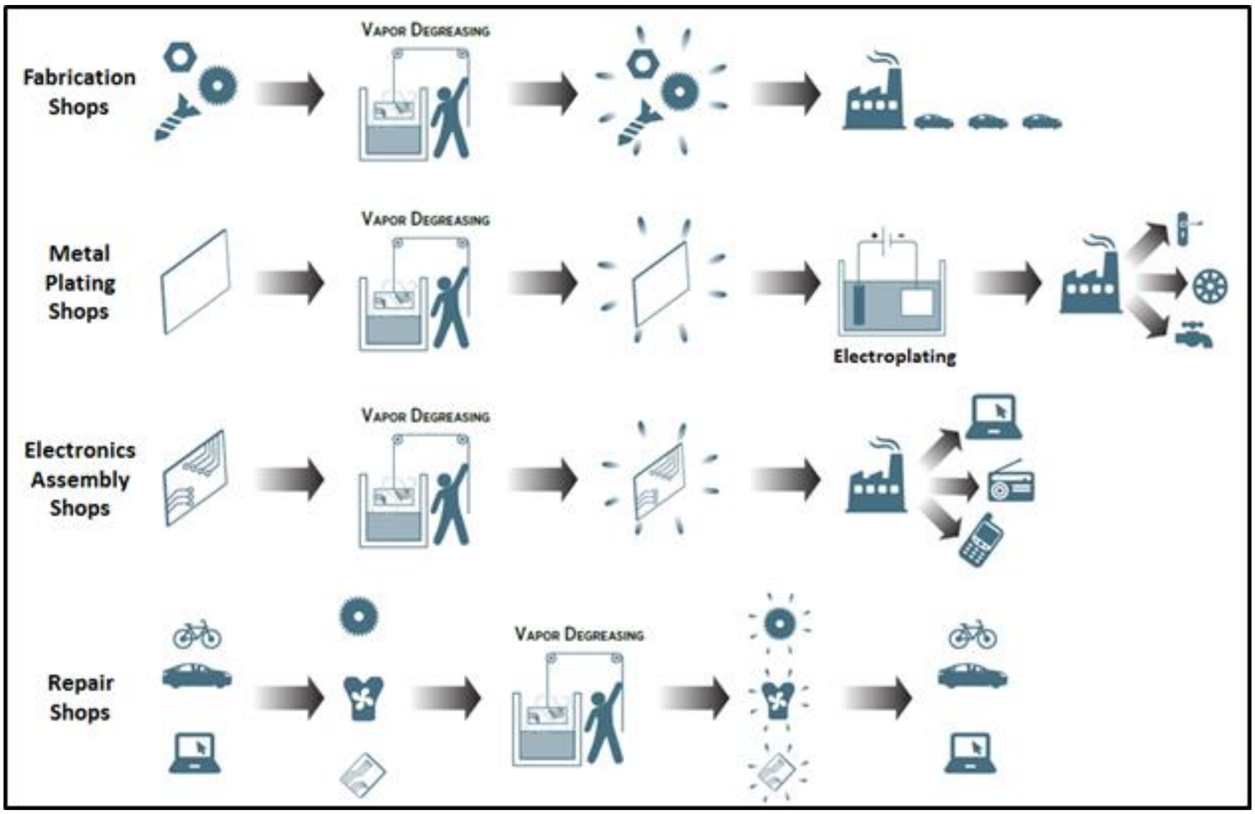

Figure 2-1. Use of Vapor Degreasing in a Variety of Industries

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

[5] Based on throughput limitations and the increased cost of closed-loop systems compared to OTVDs, closed-loop systems are expected to be less prevalent than OTVDs.

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 the liquid solvent in the OTVD causing it to volatilize. 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.

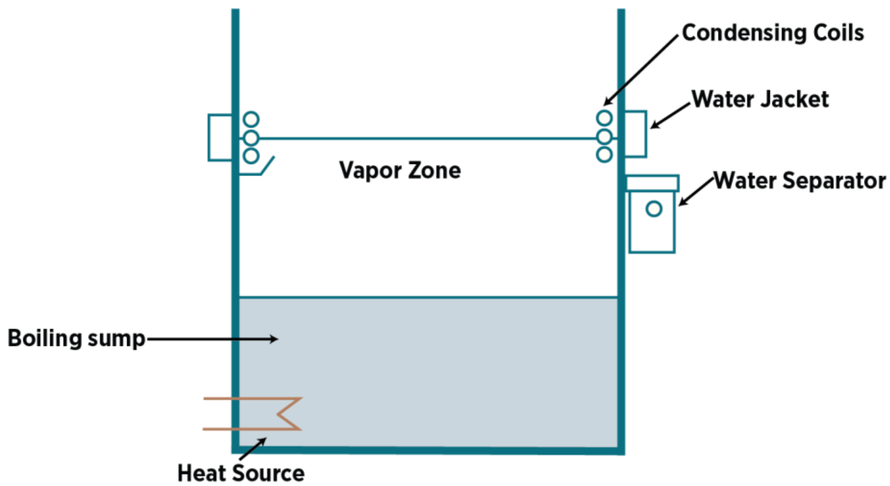

Figure 2-2. Open Top Vapor Degreaser

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 (ICF Consulting, 2004). Figure 2-3 illustrates an OTVD with an enclosure. The dotted lines in Figure 2-3represent the optional carbon filter that may or may not be used with an enclosed OTVD.

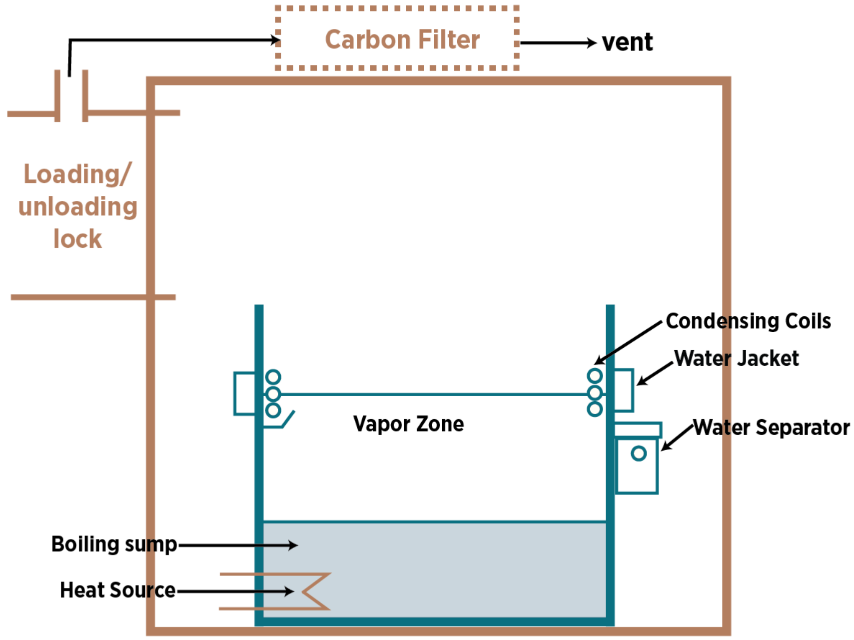

Figure 2-3. Open Top Vapor Degreaser with Enclosure

2.5.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for batch open-top vapor degreasing.

2.5.3.1 Worker Activities

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

2.5.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of TCE in OTVDs using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the primary NAICS code reported by each site in the 2014 NEI, 2016 TRI, or 2016 DMR. 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' Occupational

Employment Statistics 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 2-17. In the 2016 DMR there were nine sites that did not report a SIC code. Also, another thirteen sites where relevant Bureau of Labor Statistics Occupational Employment Statistics data could not be found for the corresponding NAICS codes; for these twenty-two sites, EPA referenced the 2017 Emission Scenario Document (ESD) on the Use of Vapor Degreasers to estimate the number of workers and ONUs (OECD, 2017).

Table 2-17. Crosswalk of Open-Top Vapor Degreasing SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
2821 – Plastics Materials, Synthetic Resins, and Nonvulcanizable Elastomers	325211 – Plastics Material and Resin Manufacturing
2822 – Synthetic Rubber (Vulcanizable Elastomers)	325212 – Synthetic Rubber Manufacturing
3053 – Gaskets; Packing and Sealing Devices	339991 – Gasket, Packing, and Sealing Device Manufacturing
3069 - Fabricated Rubber Products, Not Elsewhere Classified	326199 - All Other Plastics Product Manufacturing
3312 – Steel Works, Blast Furnaces (Including Coke Ovens), and Rolling Mills	331110 – Iron and Steel Mills and Ferroalloy Manufacturing
3398 – Metal Heat Treating	332811 – Metal Heat Treating
3423- Hand and Edge Tools, Except Machine Tools and Handsaws	332216 - Saw Blade and Handtool Manufacturing
3462 - Iron and Steel Forgings	332111 – Iron and Steel Forging
3471 - Electroplating, Plating, Polishing, Anodizing, and Coloring	332813 - Electroplating, Plating, Polishing, Anodizing, and Coloring
3483 - Ammunition, Except for Small Arms	332993 - Ammunition (except Small Arms) Manufacturing
3489 – Ordnance and Accessories, Not Elsewhere Classified	332994 – Small Arms, Ordnance, and Ordnance Accessories Manufacturing
3492 - Fluid Power Valves and Hose Fittings	332912 - Fluid Power Valve and Hose Fitting Manufacturing
3499 - Fabricated Metal Products, Not Elsewhere Classified	332919 - Other Metal Valve and Pipe Fitting Manufacturing
3511 - Steam, Gas, and Hydraulic Turbines, and Turbine Generator Set Units	333611 - Turbine and Turbine Generator Set Units Manufacturing
3537 – Industrial Trucks, Tractors, Trailers, and Stackers	333924 – Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing
3545 - Cutting Tools, Machine Tool Accessories, and Machinists' Precision Measuring Devices	332216 - Saw Blade and Handtool Manufacturing
3546 - Power-Driven Handtools	333991 - Power-Driven Handtool Manufacturing

SIC Code	Corresponding NAICS Code
3552 - Textile Machinery	333249 - Other Industrial Machinery Manufacturing
3566 - Speed Changers, Industrial High-Speed Drives, and Gears	333612 - Speed Changer, Industrial High-Speed Drive, and Gear Manufacturing
3579 - Office Machines, Not Elsewhere Classified	333318 - Other Commercial and Service Industry Machinery Manufacturing
3585 – Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment	333415 – Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
3671 - Electron Tubes	334419 - Other Electronic Component Manufacturing
3674 – Semiconductors and Related Devices	334413 – Semiconductor and Related Device Manufacturing
3675 - Electronic Capacitors	334416 - Capacitor, Resistor, Coil, Transformer, and Other Inductor Manufacturing
3679 - Electronic Components, Not Elsewhere Classified	334418 - Printed Circuit Assembly (Electronic Assembly) Manufacturing
3699 - Electrical Machinery, Equipment, and Supplies, Not Elsewhere	333318 - Other Commercial and Service Industry Machinery Manufacturing
3711 – Motor Vehicles and Passenger Car Bodies[a]	336100 – Motor Vehicle Manufacturing
3714 – Motor Vehicle Parts and Accessories[b]	336300 – Motor Vehicle Parts Manufacturing
3721 - Aircraft	336411 – Aircraft Manufacturing
3724 - Aircraft Engines and Engine Parts	336412 - Aircraft Engine and Engine Parts Manufacturing
3728 - Aircraft Parts and Auxiliary Equipment, Not Elsewhere Classified	336411 – Aircraft Manufacturing
3751 - Motorcycles, Bicycles, and Parts	336991 - Motorcycle, Bicycle, and Parts Manufacturing
3764 - Guided Missile and Space Vehicle Propulsion Units and Propulsion Unit Parts	336415 - Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts Manufacturing
7378 - Computer Maintenance and Repair	811212 - Computer and Office Machine Repair and Maintenance

[a] The SIC code 3711 may map to any of the following NAICS codes: 336111, 336112, 336120, 336211, or 336992. 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, 336100, rather than a specific 6-digit NAICS.
[b] The SIC code 3714 may map to any of the following NAICS codes: 336310, 336320, 336330, 336340, 336350 or 336390. 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, 336300, rather than a specific 6-digit NAICS.

Table 2-18 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 use of TCE in OTVDs. There are approximate 4,900 workers and 2,900 ONUs potentially exposed during use of TCE in OTVDs.

Table 2-18. Estimated Number of Workers Potentially Exposed to Trichlorethylene During Use in Open-Top Vapor Degreasing

NAICS Code	Number of Sites Reporting the NAICS Code	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed	Exposed Workers per Site	Exposed Occupational Non-Users per Site
314999	1	2	5	7	2	5
323111	1	2	1	3	2	1
325211	3	82	36	119	27	12
325220	1	47	21	68	47	21
325998	1	14	5	19	14	5
326199	1	18	5	23	18	5
326200	3	125	20	145	42	7
331210	8	308	76	384	39	9
331222	1	23	6	29	23	6
331491	2	41	13	55	21	7
332111	2	26	9	35	13	5
332119	10	81	29	110	8	3
332215	2	16	6	22	8	3
332216	3	21	8	29	7	3
332613	1	13	3	17	13	3
332618	2	18	5	22	9	2
332721	8	31	16	47	4	2
332722	3	18	10	28	6	3
332811	5	49	11	61	10	2
332812	9	65	15	80	7	2

NAICS Code	Number of Sites Reporting the NAICS Code	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed	Exposed Workers per Site	Exposed Occupational Non-Users per Site
332813	22	174	40	214	8	2
332912	4	111	43	154	28	11
332913	2	37	14	51	19	7
332919	2	36	14	50	18	7
332991	1	39	15	54	39	15
332993	1	63	24	87	63	24
332994	5	56	22	77	11	4
332999	3	17	6	23	6	2
333200	2	17	13	29	8	6
333300	3	41	19	61	14	6
333413	1	21	6	26	21	6
333415	4	173	47	220	43	12
333515	1	4	3	8	4	3
333612	2	37	20	56	18	10
333900	2	26	13	38	13	6
334416	2	44	39	83	22	20
334417	1	41	37	78	41	37
334418	1	28	25	54	28	25
334419	2	39	35	75	20	18
334512	1	9	10	19	9	10
334513	1	11	11	22	11	11
334515	1	9	10	19	9	10

NAICS Code	Number of Sites Reporting the NAICS Code	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed	Exposed Workers per Site	Exposed Occupational Non-Users per Site
335100	1	17	5	22	17	5
335300	2	56	24	80	28	12
336300	5	253	75	328	51	15
336310	1	31	9	41	31	9
336320	1	43	13	56	43	13
336411	8	1,469	1,239	2,708	184	155
336412	3	140	118	258	47	39
336413	5	206	173	379	41	35
336415	3	395	333	728	132	111
336500	1	35	15	50	35	15
337127	1	9	7	16	9	7
339113	1	20	6	27	20	6
339114	1	10	3	13	10	3
339910	1	5	1	6	5	1
339993	1	13	3	15	13	3
339999	3	16	4	19	5	1
488100	1	11	1	12	11	1
811212	1	4	0	4	4	0
811310	1	5	1	5	5	1
Subtotal for Known SIC/NAICS Data	172	4,772	2,796	7,568	28	16
Unknown or No Data	22	150	92	242	7	4

NAICS Code	Number of Sites Reporting the NAICS Code	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed	Exposed Workers per Site	Exposed Occupational Non-Users per Site
Total	194	4,922	2,889	7,810	25	15

[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. [b] Totals may not add exactly due to rounding.
Sources: (U.S. EPA, 2018a; OECD, 2017; U.S. EPA, 2017c, 2016a)

2.5.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from NIOSH investigations at twelve sites using TCE as a degreasing solvent in OTVDs. Due to the large variety in shop types that may use TCE as a vapor degreasing solvent, it is unclear how representative these data are of a "typical" shop. Therefore, EPA supplemented the identified monitoring data using the Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model. The following subsections detail the results of EPA's occupational exposure assessment for batch open-top vapor degreasing based on inhalation exposure monitoring data and modeling.

2.5.3.3.1 Inhalation Exposure Assessment Results Using Monitoring Data

Table 2-19 summarizes the 8-hr TWA monitoring data for the use of TCE in OTVDs. The data were obtained from NIOSH Health Hazard Evaluation reports (HHEs). 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 (Daniels et al., 1988), (Ruhe et al., 1981), (Barsan, 1991), (Ruhe, 1982), (Rosensteel and Lucas, 1975), (Seitz and Driscoll, 1989), (Gorman et al., 1984), (Gilles et al., 1977), (Vandervort and Polakoff, 1973), and (Lewis, 1980).

Data from these sources cover exposures at several industries including metal tube production, valve manufacturing, jet and rocket engine manufacture, air conditioning prep and assembly, and AC motor parts (Ruhe et al., 1981), (Barsan, 1991), (Rosensteel and Lucas, 1975), (Gorman et al., 1984), (Vandervort and Polakoff, 1973), and (Lewis, 1980). Except for one site, sample times ranged from approximately five to eight hours (Ruhe et al., 1981), (Barsan, 1991), (Rosensteel and Lucas, 1975), (Gorman et al., 1984), and (Lewis, 1980). The majority of samples taken at the other site were taken for 2 hours or less (Vandervort and Polakoff, 1973). 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.

Table 2-19. Summary of Worker Inhalation Exposure Monitoring Data for Batch Open-Top Vapor Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
Workers						
High-End	77.8	25.9	17.8	9.1	113	Medium
Central Tendency	13.8	4.6	3.2	1.3		
Occupational non-users						
High-End	9.1	3.0	2.1	1.1	10	Medium
Central Tendency	1.1	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.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 123 data points from 16 sources, and the data quality ratings from systematic review for these data were medium. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium.

2.5.3.3.2 Inhalation Exposure Assessment Results Using Modeling

EPA also considered the use of modeling, which is in the middle of the inhalation approach hierarchy. A Monte Carlo simulation with 100,000 iterations was used to capture the range of potential input parameters. Vapor generation rates were derived from TCE unit emissions and operating hours reported in the 2014 National Emissions Inventory. The primary limitations of the air concentration outputs from the model include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Added uncertainties include that the underlying methodologies used to estimate these emissions in the 2014 NEI are unknown. Based on these strengths and limitations of the air concentrations, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

A more detailed description of the modeling approach is provided Appendix E. Figure 2-4 illustrates the near-field/far-field model that can be applied to open-top vapor degreasing (AIHA, 2009). As the figure shows, volatile TCE vapors evaporate into the near-field, resulting in worker exposures at a concentration C_{NF}. The concentration is directly proportional to the evaporation rate of TCE, 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 TCE dissipates into the far-field, resulting in occupational non-user exposures to TCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the TCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly TCE dissipates out of the surrounding space and into the outside air. Appendix E outlines the equations uses for this model.

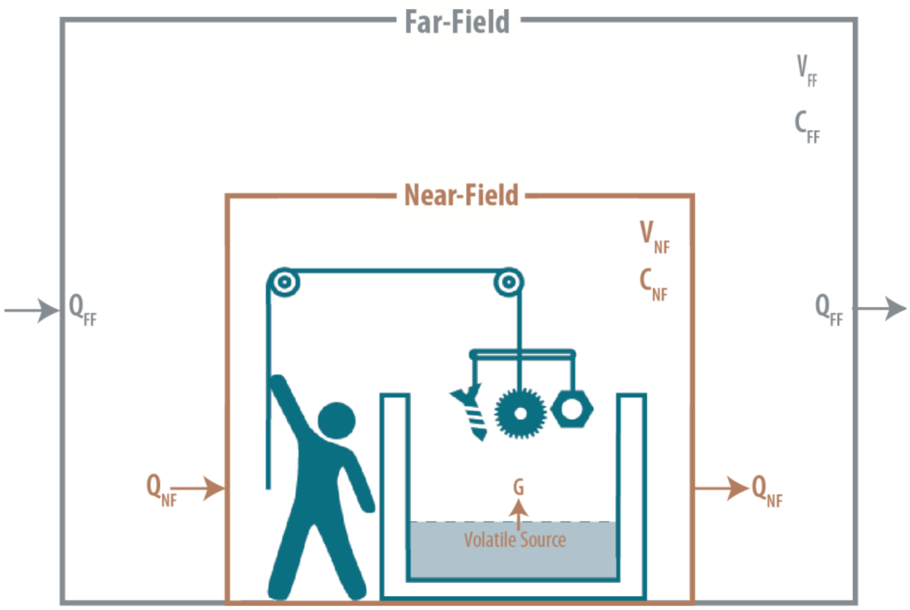

Figure 2-4. Schematic of the Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model

Appendix E presents the model parameters, parameter distributions, and assumptions for the TCE Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model. To estimate the TCE 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.

Batch degreasers are assumed to operate between two and 24 hours per day, based on NEI data on the reported operating hours for OTVD using TCE. 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 2-20 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 34.8 ppm 8-hr TWA, with a 95th percentile of 388 ppm 8-hr TWA.

Both of these values are an order of magnitude higher than identified in the monitoring data. This may be due to the limited number of sites from which the monitoring data were taken whereas the model is meant to capture a broader range of scenarios. It is also uncertain of the underlying methodologies used to estimate emissions in the 2014 NEI data.

Table 2-20. Summary of Exposure Modeling Results for TCE Degreasing in OTVDs

Percentile	8-hr TWA (ppm)	AC[a] (ppm)	ADC (ppm)	LADC (ppm)	Confidence Rating of Air Concentration Data
Workers (Near-field)					
High-End	388	129.3	88.5	35.3	N/A – Modeled Data
Central Tendency	34.8	79.0	8.0	3.0	
Occupational non-users (Far-Field)					
High-End	237	79.0	54.0	21.1	N/A – Modeled Data
Central Tendency	18.1	6.0	4.1	1.5	

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.
[a] Acute exposures calculated as a 24-hr TWA.

2.5.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in OTVDs.

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 1982 EPA (Gilbert et al., 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 in the 2016 TRI and 2016 DMR. As noted in 2.5.1, due to limited information in these reporting programs, these sites may in fact not operate OTVDs, but may operate other solvent cleaning machines or perform metalworking activities. They are included in the OTVD assessment as EPA expects OTVDs to be the most likely OES. EPA assessed annual releases as reported in the 2016 TRI or 2016 DMR and assessed daily releases by assuming 260 days of operation per year, as recommended in the 2017 ESD on Use of Vapor Degreasers, and averaging the annual releases over the operating days. A summary of the water releases reported to the 2016 TRI and DMR can be found in Table 2-21.

Table 2-21. Reported Water Releases of Trichloroethylene from Sites Using TCE in Open-Top Vapor Degreasing

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day)	NPDES Code	Release Media
US Nasa Michoud Assembly Facility, New Orleans, LA	509	260	1.96	LA0052256	Surface Water
GM Components Holdings LLC, Lockport, NY	34.2	260	0.13	NY0000558	Surface Water
Akebono Elizabethtown Plant, Elizabethtown, KY	17.9	260	0.07	KY0089672	Surface Water
Delphi Harrison Thermal Systems, Dayton, OH	9.3	260	0.04	OH0009431	Surface Water
Chemours Company Fc LLC, Washington, WV	6.7	260	0.03	WV0001279	Surface Water
Equistar Chemicals LP, La Porte, TX	4.4	260	0.02	TX0119792	Surface Water
GE Aviation, Lynn, MA	2.6	260	0.01	MA0003905	Surface Water
Certa Vandalia LLC, Vandalia, OH	2.1	260	0.01	OH0122751	Surface Water
GM Components Holdings LLC Kokomo Ops, Kokomo, IN	1.7	260	0.01	IN0001830	Surface Water
Amphenol Corp-Aerospace Operations, Sidney, NY	1.6	260	0.01	NY0003824	Surface Water
Emerson Power Trans Corp, Maysville, KY	1.6	260	0.01	KY0100196	Surface Water
Olean Advanced Products, Olean, NY	1.4	260	0.01	NY0073547	Surface Water
Texas Instruments, Inc., Attleboro, MA	1.3	260	5.18E-03	MA0001791	Surface Water
Hollingsworth Saco Lowell, Easley, SC	1.2	260	4.69E-03	SC0046396	Surface Water
Trelleborg YSH Incorporated Sandusky Plant, Sandusky, MI	0.9	260	3.60E-03	MI0028142	Surface Water
Timken Us Corp Honea Path, Honea Path, SC	0.9	260	3.55E-03	SC0047520	Surface Water
Johnson Controls Incorporated, Wichita, KS	0.6	260	2.28E-03	KS0000850	Surface Water
Accellent Inc/Collegeville Microcoax, Collegeville, PA	0.6	260	2.22E-03	PA0042617	Surface Water
National Railroad Passenger Corporation (Amtrak) Wilmington Maintenance Facility, Wilmington, DE	0.5	260	2.03E-03	DE0050962	Surface Water
Electrolux Home Products (Formerly Frigidaire), Greenville, MI	0.5	260	2.01E-03	MI0002135	Surface Water
Rex Heat Treat Lansdale Inc, Lansdale, PA	0.5	260	1.94E-03	PA0052965	Surface Water
Carrier Corporation, Syracuse, NY	0.5	260	1.77E-03	NY0001163	Surface Water

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day)	NPDES Code	Release Media
Globe Engineering Co Inc, Wichita, KS	0.5	260	1.74E-03	KS0086703	Surface Water
Cascade Corp (0812100207), Springfield, OH	0.3	260	1.17E-03	OH0085715	Surface Water
USAF-Wurtsmith AFB, Oscoda, MI	0.3	260	1.15E-03	MI0042285	Surface Water
AAR Mobility Systems, Cadillac, MI	0.3	260	1.12E-03	MI0002640	Surface Water
Eaton Mdh Company Inc, Kearney, NE	0.3	260	1.07E-03	NE0114405	Surface Water
Motor Components L C, Elmira, NY	0.3	260	9.64E-04	NY0004081	Surface Water
Salem Tube Mfg, Greenville, PA	0.233	260	8.97E-04	PA0221244	Surface Water
Ametek Inc. U.S. Gauge Div., Sellersville, PA	0.227	260	8.72E-04	PA0056014	Surface Water
GE (Greenville) Gas Turbines LLC, Greenville, SC	0.210	260	8.06E-04	SC0003484	Surface Water
Parker Hannifin Corporation, Waverly, OH	0.194	260	7.47E-04	OH0104132	Surface Water
Mahle Enginecomponents USA Inc, Muskegon, MI	0.193	260	7.42E-04	MI0004057	Surface Water
General Electric Company - Waynesboro, Waynesboro, VA	0.191	260	7.33E-04	VA0002402	Surface Water
Gayston Corp, Dayton, OH	0.167	260	6.43E-04	OH0127043	Surface Water
Styrolution America LLC, Channahon, IL	0.166	260	6.37E-04	IL0001619	Surface Water
Remington Arms Co Inc, Ilion, NY	0.159	260	6.12E-04	NY0005282	Surface Water
Lake Region Medical, Trappe, PA	0.1	260	5.06E-04	Not available	Surface Water
United Technologies Corporation, Pratt And Whitney Division, East Hartford, CT	0.1	260	4.80E-04	CT0001376	Surface Water
Atk-Allegany Ballistics Lab (Nirop), Keyser, WV	0.1	260	4.70E-04	WV0020371	Surface Water
Techalloy Co Inc, Union, IL	0.1	260	4.27E-04	IL0070408	Surface Water
Owt Industries, Pickens, SC	0.1	260	3.14E-04	SC0026492	Surface Water
Boler Company, Hillsdale, MI	0.1	260	2.69E-04	MI0053651	Surface Water
Mccanna Inc., Carpentersville, IL	0.1	260	2.68E-04	IL0071340	Surface Water
Cutler Hammer, Horseheads, NY	0.1	260	2.38E-04	NY0246174	Surface Water
Sperry & Rice Manufacturing Co LLC, Brookville, IN	8.54E-02	260	3.28E-04	IN0001473	Surface Water
US Air Force Offutt Afb Ne, Offutt A F B, NE	4.14E-02	260	1.59E-04	NE0121789	Surface Water
Troxel Company, Moscow, TN	3.49E-02	260	1.34E-04	TN0000451	Surface Water
Austin Tube Prod, Baldwin, MI	2.96E-02	260	1.14E-04	MI0054224	Surface Water
LS Starrett Precision Tools, Athol, MA	2.65E-02	260	1.02E-04	MA0001350	Surface Water

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day)	NPDES Code	Release Media
Avx Corp, Raleigh, NC	2.30E-02	260	8.83E-05	NC0089494	Surface Water
Handy & Harman Tube Co/East Norriton, Norristown, PA	1.61E-02	260	6.17E-05	PA0011436	Surface Water
Indian Head Division, Naval Surface Warfare Center, Indian Head, MD	1.08E-02	260	4.16E-05	MD0003158	Surface Water
General Dynamics Ordnance Tactical Systems, Red Lion, PA	6.34E-03	260	2.44E-05	PA0043672	Surface Water
Trane Residential Solutions - Fort Smith, Fort Smith, AR	3.46E-03	260	1.33E-05	AR0052477	Surface Water
Lexmark International Inc., Lexington, KY	3.23E-03	260	1.24E-05	KY0097624	Surface Water
Alliant Techsystems Operations LLC, Elkton, MD	3.02E-03	260	1.16E-05	MD0000078	Surface Water
Daikin Applied America, Inc. (Formally Mcquay International), Scottsboro, AL	2.15E-03	260	8.26E-06	AL0069701	Surface Water
Beechcraft Corporation, Wichita, KS	2.04E-03	260	7.86E-06	KS0000183	Surface Water
Federal-Mogul Corp, Scottsville, KY	1.50E-03	260	5.78E-06	KY0106585	Surface Water
Cessna Aircraft Co (Pawnee Facility), Wichita, KS	1.36E-03	260	5.24E-06	KS0000647	Surface Water
N.G.I, Parkersburg, WV	3.43E-04	260	1.32E-06	WV0003204	Surface Water
Hyster-Yale Group, Inc, Sulligent, AL	2.35E-04	260	9.03E-07	AL0069787	Surface Water
Hitachi Electronic Devices (USA), Inc., Greenville, SC	6.58E-05	260	2.53E-07	SC0048411	Surface Water

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: 2016 TRI (U.S. EPA, 2017c); 2016 DMR (U.S. EPA, 2016a)

As discussed in Section 2.5.1, data from TRI and DMR may not represent the entirety of sites using TCE in OTVDs. EPA did not identify other data sources to estimate water releases from sites not reporting to TRI or DMR. However, sites operating degreasers are regulated by the following national ELGs:

- Electroplating Point Source Category Subparts A, B, D, E, F, G, and H (U.S. EPA, 2019d)[6];
- Iron and Steel Manufacturing Point Source Category Subpart J (U.S. EPA, 2019e);
- Metal Finishing Point Source Category Subpart A (U.S. EPA, 2019f)[7];
- Coil Coating Point Source Category Subpart D (U.S. EPA, 2019b);

[6] The Electroplating ELG 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 ELG (40 C.F.R Part 433).
[7] The Metal Finishing ELG 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 ELGs.

- Aluminum Forming Point Source Category Subparts A, B, C, D, E, and F (U.S. EPA, 2019a); and
- Electrical and Electronic Components Point Source Category Subparts A and B (U.S. EPA, 2019c).

All above ELGs set discharges limits based on the total toxic organics (TTO) concentration in the wastewater stream and not a specific TCE limit. TTO is the summation of the concentrations for a specified list of pollutants which may be different for each promulgated ELG and includes TCE for the above referenced ELGs. Therefore, the concentration of TCE in the effluent is expected to be less than the TTO limit.

The operation of the water separator via gravity separation is such that the maximum concentration of TCE leaving the OTVD is equal to the solubility of TCE in water, 1,280 mg/L (Durkee, 2014). In cases where this concentration exceeds the limit set by the applicable ELGs, EPA expects sites will perform some form of wastewater treatment for the effluent stream leaving the OTVD to ensure compliance with the ELG prior to discharge. EPA did not identify information on the amount of wastewater generated from OTVDs to estimate releases from sites not reporting to TRI or DMR.

2.6 Batch Closed-Loop Vapor Degreasing

2.6.1 Facility Estimates

To determine the number of sites that use TCE in batch closed-loop vapor degreasers, EPA considered 2014 NEI data (U.S. EPA, 2018a), 2016 TRI data (U.S. EPA, 2017c), and 2016 DMR data (U.S. EPA, 2016a). Sites in TRI and DMR do not differentiate between degreaser types and therefore are included in the OTVD assessment and are not considered again here. In the 2014 NEI, four closed-system vapor degreasers were reported in operation at four sites (a single closed-loop vapor degreaser per site) (U.S. EPA, 2018a). Therefore, EPA assesses four sites for closed-loop degreasing. It should be noted that this number is expected to underestimate the total number of sites using TCE in closed-loop degreasers as closed-loop degreasers are not required to report to NEI. Additionally, NEI data does not include degreasing operations that are classified as area sources because area sources are reported at the county level and do not include site-specific information.

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 2-5 illustrates a standard closed-loop vapor degreasing system.

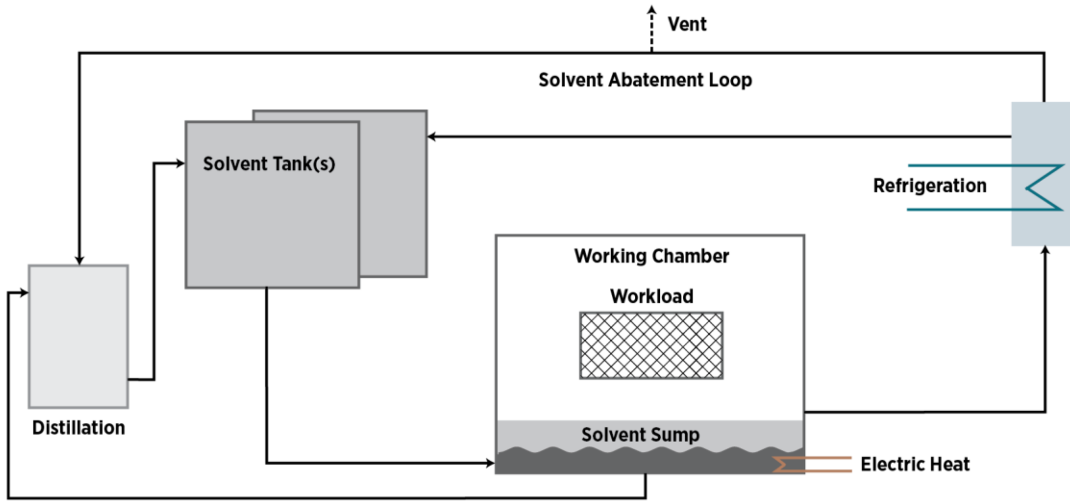

Figure 2-5. Closed-loop/Vacuum Vapor Degreaser

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 2-5 for closed-loop systems except that the work chamber is under vacuum during various stages of the cleaning process.

2.6.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for batch closed-loop vapor degreasing.

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 exposure assessment reported minimal time (less than 1 hour) per shift loading/unloading the degreaser while the same assessment (ENTEK International Limited, 2014) indicated general degreaser exposure for operators are 6-8 hours.

2.6.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of TCE in closed-loop degreasers using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS codes reported by the sites in the 2014 NEI. 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. Table 2-22 provides the results of the number of worker analysis. There are 50 workers and 18 ONUs potentially exposed during use of TCE in closed-loop degreasing.

Table 2-22. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Use in Closed-Loop Vapor Degreasing

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
332720	1	4	2	7	4	2
332900	1	12	5	16	12	5
331200	1	28	7	34	28	7
Subtotal for Known SIC/NAICS Data	3	44	14	57	15	5
Unknown or No Data	1	7	4	11	7	4
Total	4	50	18	68	13	4

[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. [b] Totals may not add exactly due to rounding.
Sources: (U.S. EPA, 2018a)

2.6.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from a European Chemical Safety report using TCE in closed degreasing operations. However, it is unclear how representative these data are of a "typical" batch closed-loop degreasing shop. Table 2-23 summarizes the 8-hr TWA monitoring data for the use of TCE in vapor degreasers. The data were obtained from a Chemical Safety Report (DOW Deutschland, 2014a).

Data from these sources cover exposures at several industries where industrial parts cleaning occurred using vapor degreasing in closed systems. 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.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 19 data points from 1 source, and the data quality ratings from systematic review for these data were high. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to high.

Table 2-23. Summary of Worker Inhalation Exposure Monitoring Data for Batch Closed-Loop Vapor Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	1.4	0.5	0.3	0.2	19	High
Central Tendency	0.5	0.2	0.1	0.04		

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

2.6.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in batch-closed loop degreasers.

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 wastewater disposal practices are unknown with the latest data from a 1982 EPA (Gilbert et al., 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 assumes the TRI and DMR data cover all water discharges of TCE from closed-loop vapor degreasing. However, EPA cannot distinguish between degreaser types in TRI and DMR data; therefore, a single set of water release for all degreasing operations is presented in Section 2.5.4.2 for OTVDs.

2.7 Conveyorized Vapor Degreasing

2.7.1 Facility Estimates

To determine the number of sites that use TCE in conveyorized vapor degreasers, EPA considered 2014 NEI data (U.S. EPA, 2018a), 2016 TRI data (U.S. EPA, 2017c), and 2016 DMR data (U.S. EPA, 2016a). Sites in TRI and DMR do not differentiate between degreaser types and therefore are included in the OTVD assessment and are not considered again here. In the 2014 NEI, eight conveyorized degreasers were reported in operation at eight sites (a single conveyorized vapor degreaser per site) (U.S. EPA, 2018a). Therefore, EPA assesses eight sites for conveyorized degreasing. It should be noted that this number is expected to underestimate the total number of sites using TCE in conveyorized degreasers as NEI data does not include degreasing operations that are classified as area sources. Area sources are reported at the county level and do not include site-specific information.

2.7.2 Process Description

In conveyorized systems, an automated parts handling system, typically a conveyor, 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 2-6 illustrates a typical monorail degreaser (U.S. EPA, 1977).

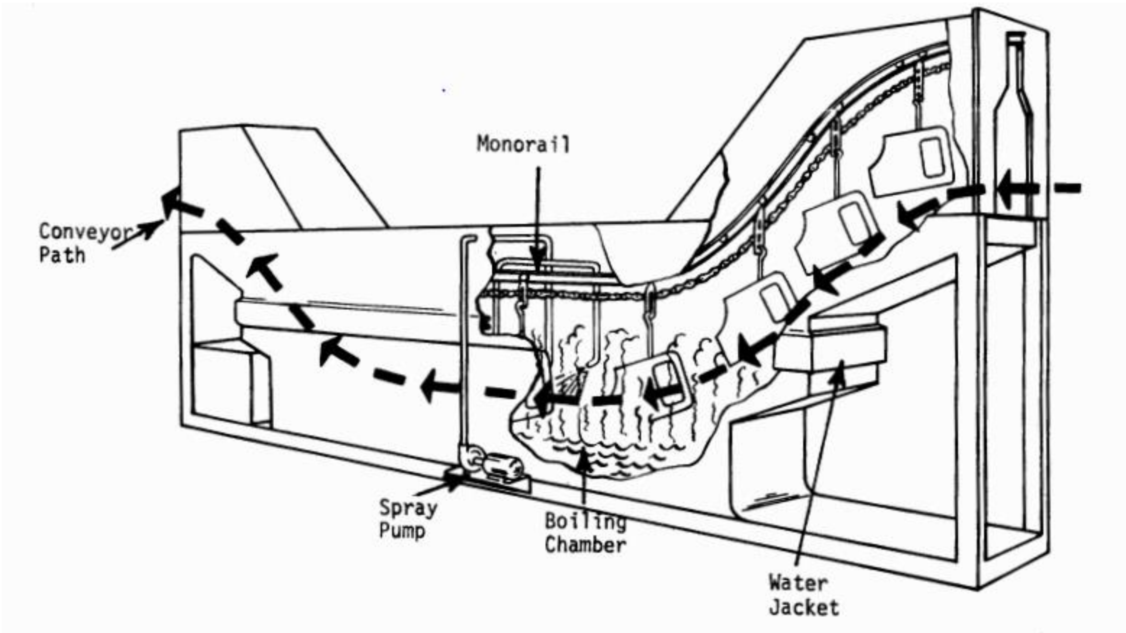

Figure 2-6. Monorail Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- 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 2-7 illustrates a typical cross-rod degreaser (U.S. EPA, 1977).

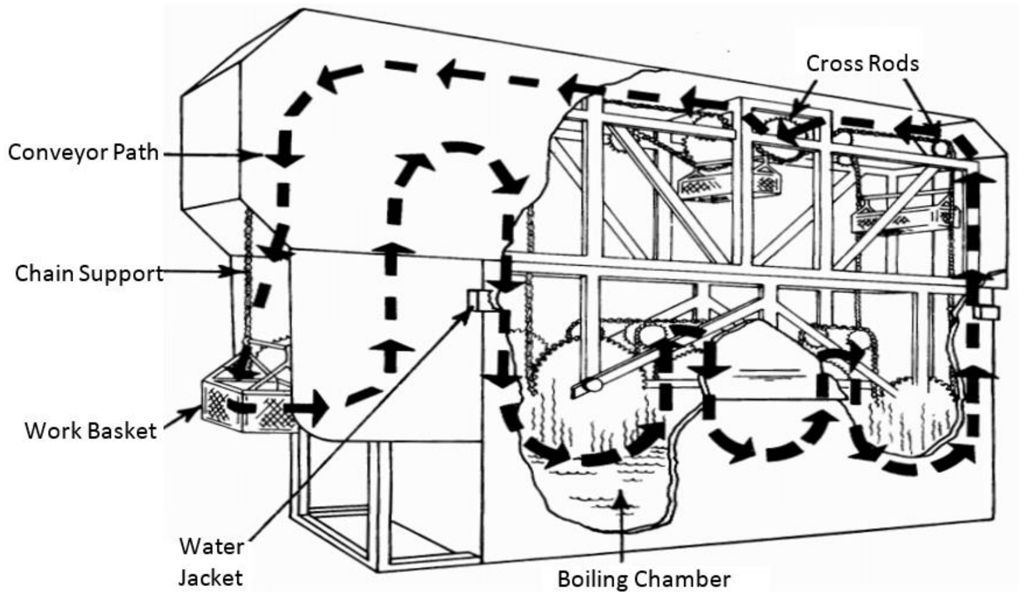

Figure 2-7. Cross-Rod Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- 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 2-8 illustrates a typical vibra degreaser (U.S. EPA, 1977).

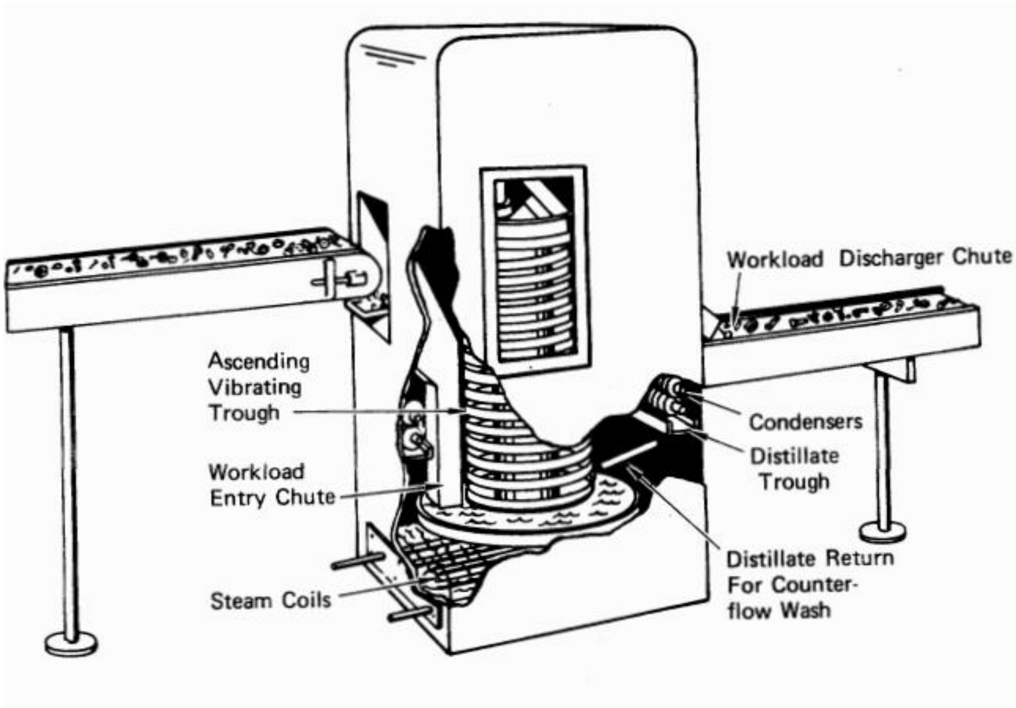

Figure 2-8. Vibra Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- 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 2-9 illustrates a typical ferris wheel degreaser (U.S. EPA, 1977).

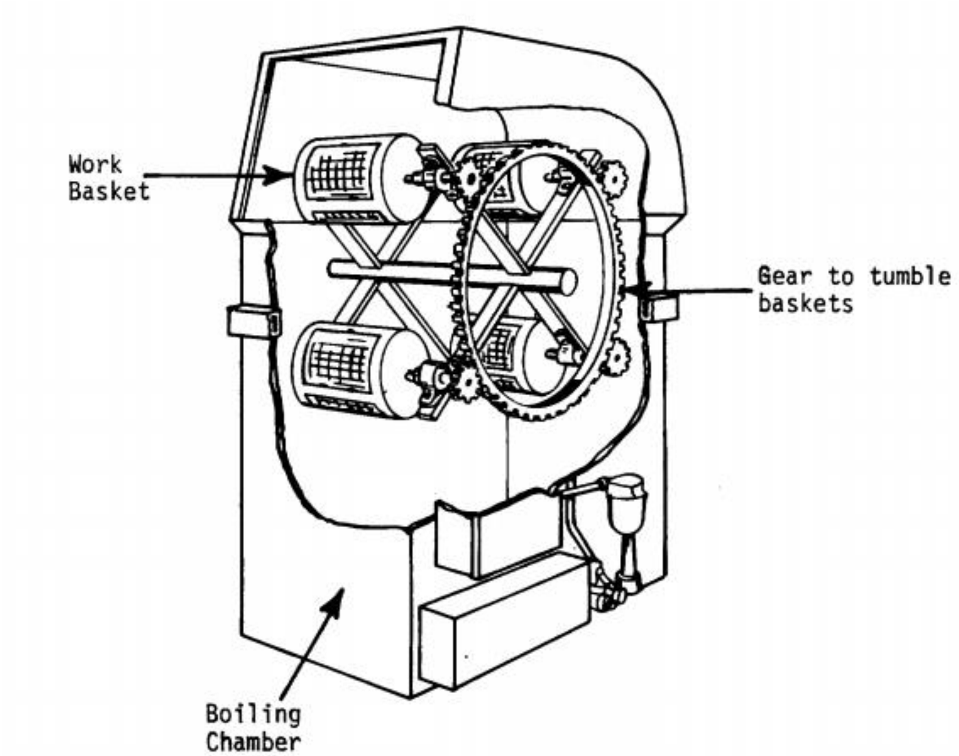

Figure 2-9. Ferris Wheel Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- 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 2-10 illustrates a typical belt or strip degreaser (U.S. EPA, 1977).

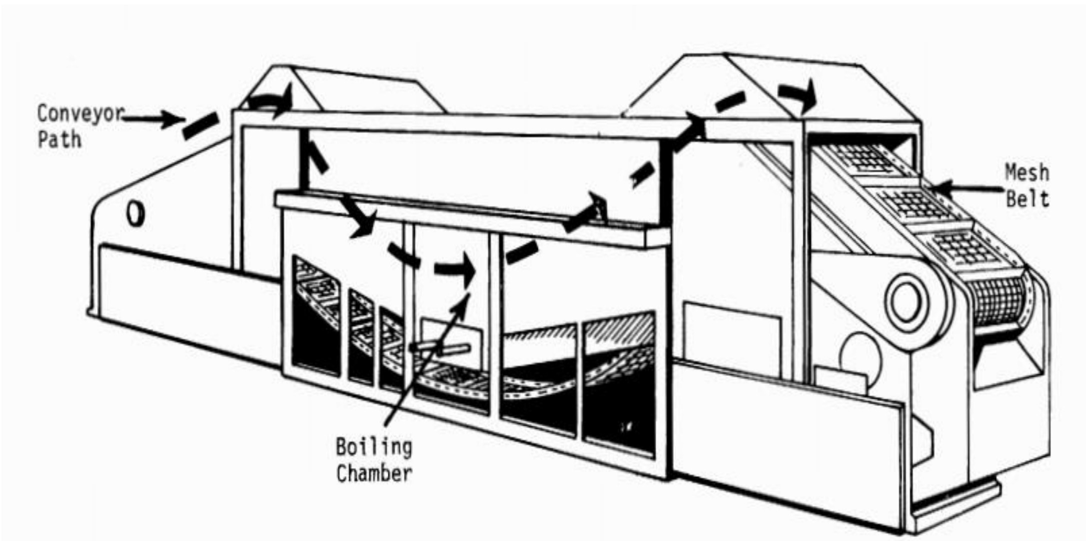

Figure 2-10. Belt/Strip Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- 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 2-10 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

The following sections detail EPA's occupational exposure assessment for conveyorized vapor degreasing.

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 TCE in conveyorized degreasers using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS codes reported by the sites in the 2014 NEI. 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. Table 2-24 provides the results of the number of worker analysis. There are 92 workers and 32 ONUs potentially exposed during use of TCE in conveyorized degreasing.

Table 2-24. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Use in Conveyorized Vapor Degreasing

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
331200	1	28	7	34	28	7
331400	1	22	7	28	22	7
332100	2	20	7	28	10	4
332200	1	7	3	10	7	3
332720	2	9	4	13	4	2

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
Subtotal for Known SIC/NAICS Data	7	85	28	114	12	4
Unknown or No Data	1	7	4	11	7	4
Total	8	92	32	130	12	4

[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. [b] Totals may not add exactly due to rounding.
Sources: (U.S. EPA, 2018a)

2.7.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from NIOSH investigations at two sites using TCE in conveyorized degreasing. Due to the large variety in shop types that may use TCE as a vapor degreasing solvent, it is unclear how representative these data are of a "typical" shop. Therefore, EPA supplemented the identified monitoring data using the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model. The following subsections detail the results of EPA's occupational exposure assessment for batch open-top vapor degreasing based on inhalation exposure monitoring data and modeling.

2.7.3.3.1 Inhalation Exposure Assessment Results Using Monitoring Data

Table 2-25 summarizes the 8-hr TWA monitoring data for the use of TCE in conveyorized degreasing. The data were obtained from two NIOSH Health Hazard Evaluation reports (HHEs) (Crandall and Albrecht, 1989), (Kinnes, 1998).

Table 2-25. Summary of Worker Inhalation Exposure Monitoring Data for Conveyorized Vapor Degreasing

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	48.3	16.1	11.0	5.6	18	Medium
Central Tendency	32.4	10.8	7.4	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.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 18 data points from 2 sources, and the data quality ratings from systematic review for these data were medium. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

2.7.3.3.2 Inhalation Exposure Assessment Results Using Modeling

EPA also considered the use of modeling, which is in the middle of the inhalation approach hierarchy. A Monte Carlo simulation with 100,000 iterations was used to capture the range of potential input parameters. Vapor generation rates were derived from TCE unit emissions and operating hours reported in the 2014 National Emissions Inventory. The primary limitations of the air concentration outputs from the model include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Added uncertainties include that emissions data in the 2014 NEI were only found for three total units, and the underlying methodologies used to estimate these emissions are unknown. Based on these strengths and limitations of the air concentrations, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

A more detailed description of the modeling approach is provided Appendix E. Figure 2-11 illustrates the near-field/far-field model that can be applied to conveyorized vapor degreasing. As the figure shows, TCE 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 TCE, 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 TCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to TCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the TCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly TCE dissipates out of the surrounding space and into the outdoor air. Appendix E outlines the equations uses for this model.

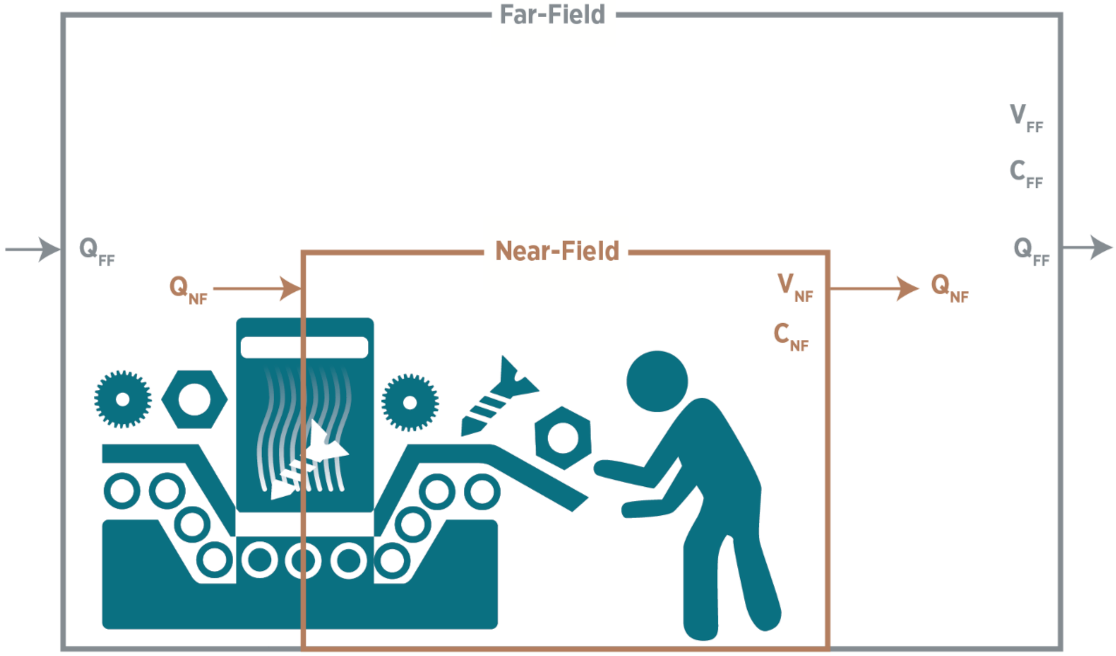

Figure 2-11. Belt/Strip Conveyorized Vapor Degreasing Schematic of the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model

Appendix E presents the model parameters, parameter distributions, and assumptions for the TCE Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model. To estimate the TCE 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. Because the vapor generation rate is based a limited data set, 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 2-26 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 40.8 ppm 8-hr TWA, with a 95th percentile of 3,043 ppm 8-hr TWA.

The high-end value is two orders of magnitude higher than identified in the monitoring data, but the central tendency is comparable to the monitoring data. This may be due to the limited number of sites from which the monitoring data were taken or that limited data for conveyorized degreaser were reported to the 2014 NEI data (data were only found for three total units). It is also uncertain of the underlying methodologies used to estimate emissions in the 2014 NEI data.

Table 2-26. Summary of Exposure Modeling Results for TCE Degreasing in Conveyorized Degreasers

Scenario	8-hr TWA (ppm)	AC[a] (ppm)	ADC (ppm)	LADC (ppm)	Data Quality Rating of Associated Air Concentration Data
Workers (Near-field)					
High-End	3,043	1,014.4	694.8	275.2	N/A – Modeled Data
Central Tendency	40.8	13.6	9.3	5.3	
Occupational non-users (Far-Field)					
High-End	1,878	626	428.8	168.3	N/A – Modeled Data
Central Tendency	23.3	7.8	5.3	3.6	

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.
[a] Acute exposures calculated as a 24-hr TWA.

2.7.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in batch-conveyorized vapor degreasers.

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 1982 EPA (Gilbert et al., 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 assumes the TRI and DMR data cover all water discharges of TCE from conveyorized degreasing. However, EPA cannot distinguish between degreaser types in TRI and DMR data; therefore, a single set of water release for all degreasing operations is presented in Section 2.5.4 for OTVDs.

2.8 Web Vapor Degreasing

2.8.1 Facility Estimates

To determine the number of sites that use TCE in web vapor degreasers, EPA considered 2014 NEI data, 2016 TRI data, and 2016 DMR data. Sites in TRI and DMR do not differentiate between degreaser types and therefore are included in the OTVD assessment and are not considered again here. In the 2014 NEI, no web degreasers were reported in operation (U.S. EPA, 2018a). Although the use of TCE was not reported in web degreasing in 2014 NEI, the use of TCE in web degreasing could still be a reasonably foreseeable OES, as NEI data does not include degreasing operations that are classified as area sources. Area sources are reported at the county level and do not include site-specific information. Therefore, EPA used (U.S. EPA, 2011) data for web degreasing. In the (U.S. EPA, 2011), one web degreasing site was reported. Therefore, EPA assesses one site for web degreasing.

2.8.2 Process Description

Continuous web cleaning machines 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, 2006). In continuous web degreasers, parts are uncoiled and loaded onto rollers that transport the parts through the cleaning and drying zones at speeds greater than 11 feet per minute (U.S. EPA, 2006). The parts are then recoiled or cut after exiting the cleaning machine (Kanegsberg and Kanegsberg, 2011; U.S. EPA, 2006). Figure 2-12 illustrates a typical continuous web cleaning machine.

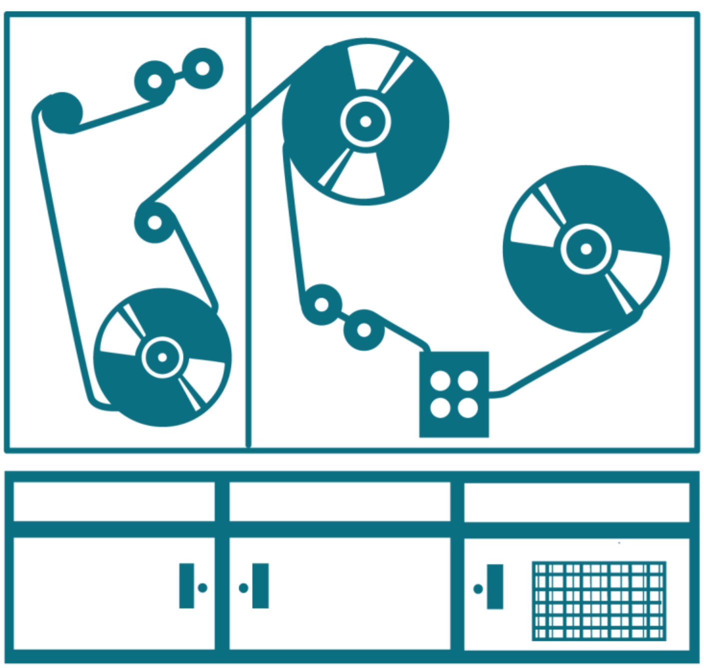

Figure 2-12. Continuous Web Vapor Degreasing System

2.8.3 Exposure Assessment

2.8.3.1 Worker Activities

For web vapor degreasing, worker activities 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 does not have data to estimate the total workers and ONUs exposed to TCE from web degreasing as this information was not available in BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). Refer to Section 2.5 for general information on vapor degreasing.

2.8.3.3 Occupational Exposure Results

EPA did not identify inhalation exposure monitoring data related to the use of TCE in web degreasing. Therefore, EPA used the Near-Field/Far-Field Model to estimate exposures to workers and ONUs. The following details the results of EPA's occupational exposure assessment for use in web degreasers based on inhalation exposure modeling.

A more detailed description of the modeling approach is provided Appendix E. Figure 2-13 illustrates the near-field/far-field model that can be applied to web degreasing. As the figure shows, TCE 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 TCE, 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 TCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to TCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the TCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly TCE dissipates out of the surrounding space and into the outdoor air. Appendix E outlines the equations uses for this model.

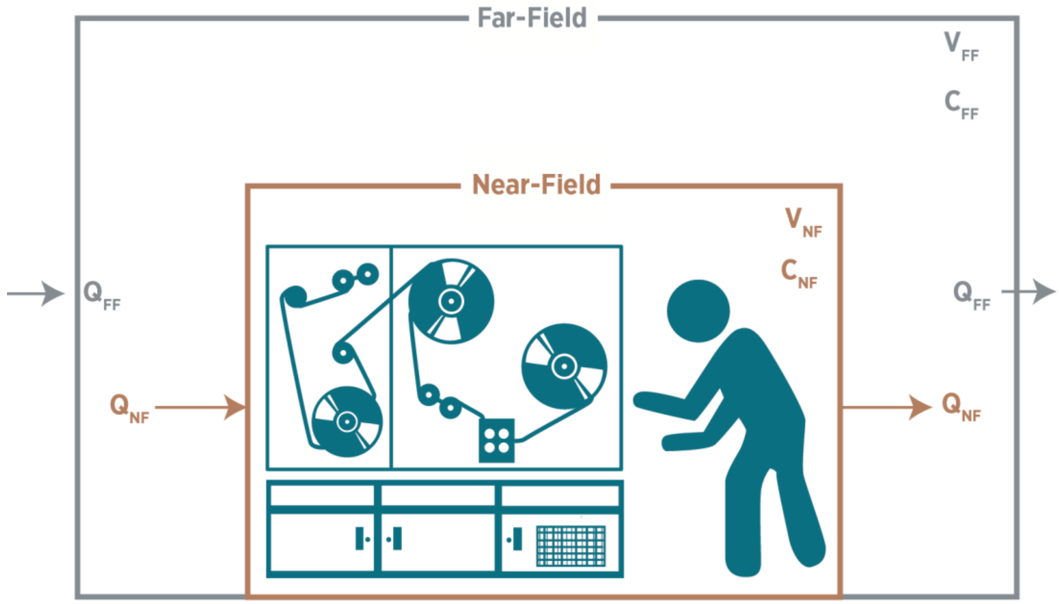

Figure 2-13. Schematic of the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model

Appendix E presents the model parameters, parameter distributions, and assumptions for the TCE Web Degreasing Near-Field/Far-Field Inhalation Exposure Model. To estimate the TCE vapor generation rate, the model uses the annual emission rate and annual operating time from the single web degreasing unit reported in the (U.S. EPA, 2011). Because the vapor generation rate is based a limited data set, it is unknown how representative the model is of a "typical" web degreasing sites.

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 2-27 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 5.9 ppm 8-hr TWA, with a 95th percentile of 14.1 ppm 8-hr TWA.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA inhalation air concentrations. The primary strengths include the assessment approach, which is the use of modeling, in the middle of the inhalation approach hierarchy. A Monte Carlo simulation with 100,000 iterations was used to capture the range of potential input parameters. Vapor generation rates were derived from TCE unit emissions and operating hours reported in the 2014 National Emissions Inventory. The primary limitations of the air concentration outputs from the model include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Added uncertainties include that emissions data in the 2011 NEI were only found for one unit, and the underlying methodologies used to estimate the emission is unknown. Based on these strengths and limitations of the air concentrations, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

Table 2-27. Summary of Exposure Modeling Results for TCE Degreasing in Web Degreasers

Scenario	8-hr TWA (ppm)	AC[a] (ppm)	ADC (ppm)	LADC (ppm)	Confidence Rating of Air Concentration Data
Workers (Near-field)					
High-End	14.1	4.7	3.2	1.4	N/A – Modeled Data
Central Tendency	5.9	2.0	1.4	0.5	
Occupational non-users (Far-Field)					
High-End	9.6	3.2	2.2	0.9	N/A – Modeled Data
Central Tendency	3.1	1.0	0.7	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.
[a] Acute exposures calculated as a 24-hr TWA.

2.8.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in web degreasers.

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 1982 EPA (Gilbert et al., 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 assumes the TRI and DMR data cover all water discharges of TCE from web vapor degreasing. However, EPA cannot distinguish between degreaser types in TRI and DMR data; therefore, a single set of water release for all degreasing operations is presented in Section 2.5.4.2 for OTVDs.

2.9 Cold Cleaning

2.9.1 Estimates of Number of Facilities

To determine the number of sites that use TCE in cold cleaning, EPA considered 2014 NEI data (U.S. EPA, 2018a), 2016 TRI data (U.S. EPA, 2017c), and 2016 DMR data (U.S. EPA, 2016a). Sites in TRI and DMR do not differentiate between vapor degreasers and cold cleaning and therefore are included in the OTVD assessment and are not considered again here. In the 2014 NEI, 13 sites reported operation of a total of 16 cold cleaning machines (U.S. EPA, 2018a). Therefore, EPA assesses 13 sites for cold cleaning. It should be noted that this number is expected to underestimate the total number of sites using TCE 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.

2.9.2 Process Description

Cold cleaners are non-boiling solvent degreasing units. Cold cleaning operations include spraying, brushing, flushing and immersion. Figure 2-14 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, 2006).

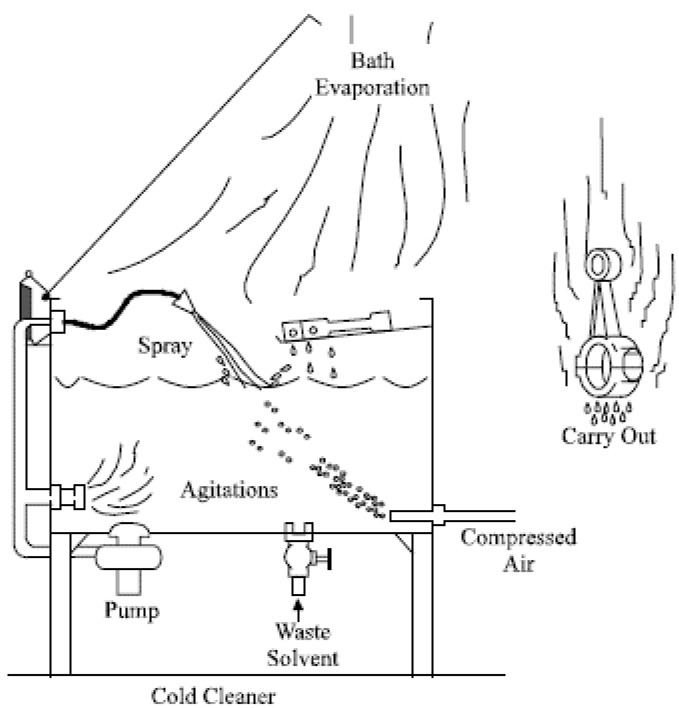

Figure 2-14. Typical Batch-Loaded, Maintenance Cold Cleaner (U.S. EPA, 1981)

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, 2006).

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 TCE in cold cleaners using BLS 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. 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. In the 2014 NEI, one site reported NAICS code for which there was no Census data available. To estimate the number of workers/ONUs at these sites, EPA referenced the 2017 Emission Scenario Document (ESD) on the Use of Vapor Degreasers (OECD, 2017)[8] . Table 2-28 provides the results of the number of worker analysis. There are 660 workers and 400 ONUs potentially exposed during use of TCE in cold cleaning.

Table 2-28. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Use in Cold Cleaning

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users[a]	Total Exposed [a, b]	Exposed Workers per Site[c]	Exposed Occupational Non-Users per Site[c]
322130	1	120	18	139	120	18
322130	1	120	18	139	120	18
326199	1	18	5	23	18	5
326299	1	27	4	32	27	4

[8] 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.

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users[a]	Total Exposed [a, b]	Exposed Workers per Site[c]	Exposed Occupational Non-Users per Site[c]
332813	3	24	5	29	8	2
335921	1	20	7	28	20	7
335991	1	21	8	29	21	8
335999	1	13	5	18	13	5
336411	2	367	310	677	184	155
336413	1	41	35	76	41	35
Subtotal for Known SIC/NAICS Data	12	653	398	1,051	54	33
Unknown or No Data	1	7	4	11	7	4
Total	13	660	400	1,100	51	31

[a] Values rounded to two significant figures.
[b] Totals may not add exactly due to rounding.
[c] 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.
Sources: (U.S. EPA, 2018a; OECD, 2017)

2.9.3.3 Occupational Exposure Results

EPA did not identify inhalation exposure monitoring data for the Cold Cleaning OES. Therefore, EPA used the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model to estimate exposures to workers and ONUs. The following details the results of EPA's occupational exposure assessment for cold cleaning based on modeling.

A more detailed description of the modeling approach is provided Appendix E. Figure 2-15 illustrates the near-field/far-field model that can be applied to cold cleaning. As the figure shows, TCE 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 TCE, 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 TCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to TCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the TCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly TCE dissipates out of the surrounding space and into the outdoor air. Appendix E outlines the equations uses for this model.

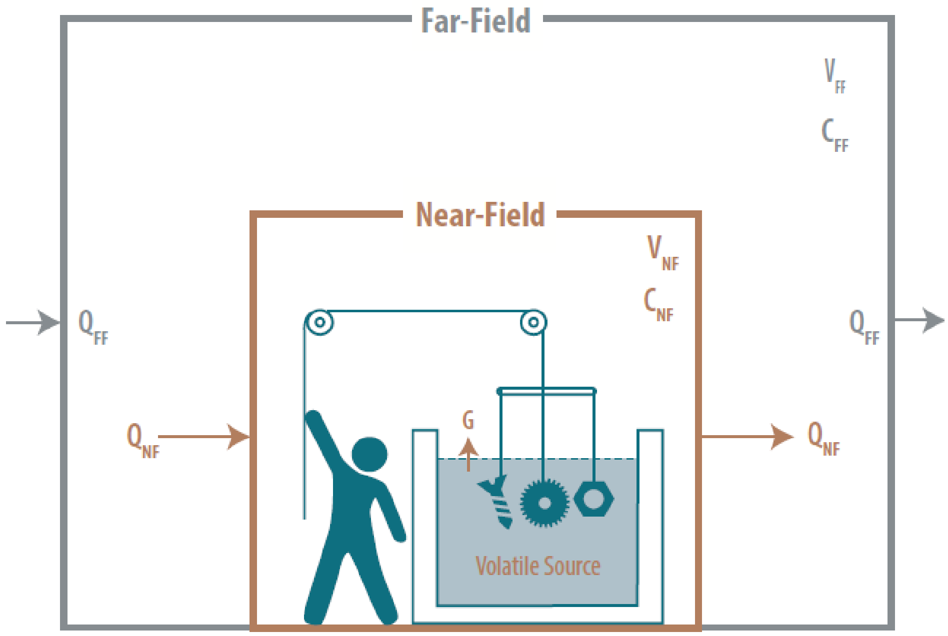

Figure 2-15. Schematic of the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model

Appendix E presents the model parameters, parameter distributions, and assumptions for the TCE Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model. To estimate the TCE 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, 2018a). NEI records where the annual operating time was not reported were excluded from the distribution. Because the vapor generation rate is based a limited data set (ten total units), it is unknown how representative the model is of a "typical" cold cleaning site.

Cold cleaners are assumed to operate between 3 to 24 hours per day, based on NEI data on the reported operating hours for cold cleaners using TCE. 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.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA inhalation air concentrations. The primary strengths include the assessment approach, which is the use of modeling, in the middle of the inhalation approach hierarchy. A Monte Carlo simulation with 100,000 iterations was used to capture the range of potential input parameters. Vapor generation rates were derived from TCE unit emissions and operating hours reported in the 2014 National Emissions Inventory. The primary limitations of the air concentration outputs from the model include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Added uncertainties include that emissions data in the 2014 NEI were only found for ten total units, and the underlying methodologies used to estimate these emissions are unknown. Based on these strengths and limitations of the air concentrations, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

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 3.33 ppm 8-hr TWA, with a 95th percentile of 57.2 ppm 8-hr TWA.

Table 2-29. Summary of Exposure Modeling Results for Use of Trichloroethylene in Cold Cleaning

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Confidence Rating of Air Concentration Data
Workers (Near-field)					
High-End	57.2	19.1	13.1	5.2	N/A – Modeled Data
Central Tendency	3.33	1.11	0.8	0.3	
Occupational non-users (Far-Field)					
High-End	34.7	11.6	7.9	3.1	N/A – Modeled Data
Central Tendency	1.8	0.6	0.4	0.2	

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.

2.9.4 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 1982 EPA (Gilbert et al., 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.

2.10 Aerosol Applications: Spray Degreasing/Cleaning, Automotive Brake and Parts Cleaners, Penetrating Lubricants, and Mold Releases

2.10.1 Facility Estimates

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 2-30 presents the NAICS industry sectors relevant to aerosol degreasing and aerosol lubricants.

Table 2-30. 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 (citation for SUSB). In 1997, the California Air Resources Board (CARB) conducted a survey of automotive maintenance and repair facilities and estimated approximately 11,700 to 27,900 lb/yr of TCE was used in brake servicing (approximately 90% to 96% in aerosol products), while approximately 11,900 to 30,000 lb/yr of TCE was used in brake and non-brake uses (approximately 91% to 95% in aerosol products) in California (CARB, 2000). Also based on CARB's survey, approximately 73% of automotive maintenance and repair facilities use brake cleaning products to perform brake jobs, and approximately 38% of these facilities use brake cleaning products containing chlorinated chemicals (CARB, 2000). Furthermore, approximately 5% to 6% of facilities that use chlorinated products reported using TCE-based products. Approximately 36% of facilities that use chlorinated products reported using methylene chloride-based products. OSHA's final rule on methylene chloride became effective on October 22, 1998, which is after the date of CARB's survey. Therefore, it is possible the TCE market share increased to account for declining methylene chloride usage in response to OSHA's rule.

These data only relate to aerosol brake cleaning products used in the automotive repair industry; however, aerosol degreasing and penetrating lubricants 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 assumes a similar market penetration as for brake cleaning products.

EPA estimates the average market penetration for TCE aerosol degreasers, brake and parts cleaners, and penetrating lubricants as the high-end value calculated from CARB data, or 6% of facilities that use chlorinated-based products that use TCE, multiplied by the 38% of facilities that use brake cleaning products that use chlorinated-based products, multiplied by the 73% of facilities that use brake cleaning products, or 1.7% (6% x 38% x 73% = 1.7%) (CARB, 2000). This results in approximately 4,366 establishments using aerosol products containing TCE. The number of establishments using TCE-based aerosol solvents may have increased since 1997 if the use of methylene chloride decreased in response to OSHA's 1998 rule.

2.10.2 Process Description

EPA's Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal for TCE (U.S. EPA, 2017b) identified 16 aerosol-based degreasing products containing TCE. These products include degreasers for applications such as brake cleaning, mold cleaning, and other metal product cleaning. The weight percent of TCE in these products range from 40% to 100%. Additional aerosol products include film cleaners, coil cleaners, and various lubricants. The weight percent of TCE in these products ranges from 40% to 100% (with most products containing greater than 90% TCE). 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, TCE-based aerosol products generally use carbon dioxide and liquified petroleum gas (LPG) (i.e., propane and butane) as the propellant.

2.10.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for aerosol degreasing and aerosol lubricants.

2.10.3.1 Worker Activities

Figure 2-16 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, 2014a).

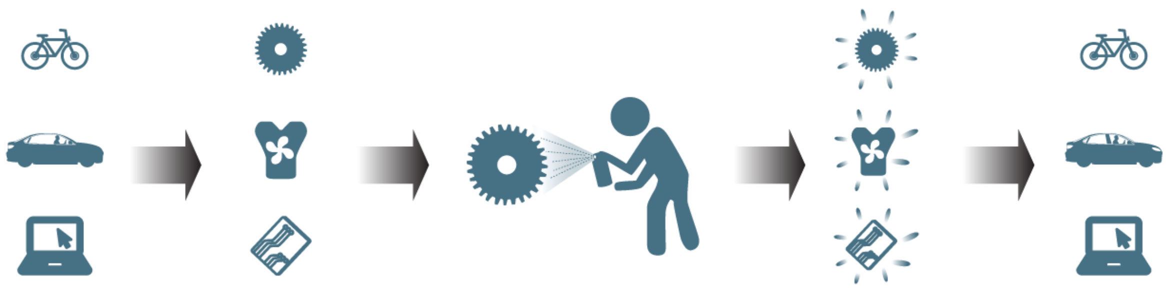

Figure 2-16. Overview of Aerosol Degreasing

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. EPA believes workers would not typically utilize respiratory protection during aerosol degreasing activities.

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 TCE using BLS 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. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census.

Based on the market penetration of 1.7% and data from the BLS and U.S. Census, there are approximately 14,200 workers and 1,690 occupational non-users potentially exposed to TCE as an aerosol degreasing solvent or aerosol lubricant (see Table 2-31) (CARB, 2000), (U.S. BLS, 2016), (U.S. Census Bureau, 2015).

Table 2-31. Estimated Number of Workers Potentially Exposed to Trichloroethylene 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[c]
4,366	3	0.4	14,200	1,690	15,900

[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 up to one.
[b] Values rounded to two significant figures.
[c] Totals may not add exactly due to rounding.

2.10.3.3 Occupational Exposure Results

EPA did not identify inhalation exposure monitoring data related to the use of TCE in aerosol degreasers. Therefore, EPA estimated inhalation exposures using the Brake Servicing Near-field/Far-field Exposure Model. EPA used the brake servicing model as a representative scenario for this OES as there was ample data describing the brake servicing use and it is a significant use of TCE-based aerosol products. The following details the results of EPA's occupational exposure assessment for aerosol degreasing and aerosol lubricants based on modeling.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA inhalation air concentrations. The primary strengths include the assessment approach, which is the use of modeling, in the middle of the inhalation approach hierarchy. A Monte Carlo simulation with 100,000 iterations was used to capture the range of potential input parameters. Various model parameters were derived from a CARB brake service study and TCE concentration data 16 products representative of the OES. The primary limitations of the air concentration outputs from the model include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the air concentrations, the overall confidence for these 8-hr TWA data in this scenario is medium.

A more detailed description of the modeling approach is provided in Appendix E. Figure 2-17 illustrates the near-field/far-field for the aerosol degreasing scenario. As the figure shows, TCE 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 TCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational non-user exposures to TCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the TCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly TCE dissipates out of the surrounding space and into the outside air.

In this scenario, TCE 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 (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 (CARB, 2000), EPA assumes each brake job requires 14.4 oz of aerosol brake cleaner. The model determines the application rate of TCE using the weight fraction of TCE in the aerosol product. EPA uses uniform distribution of weight fractions for TCE 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 F.

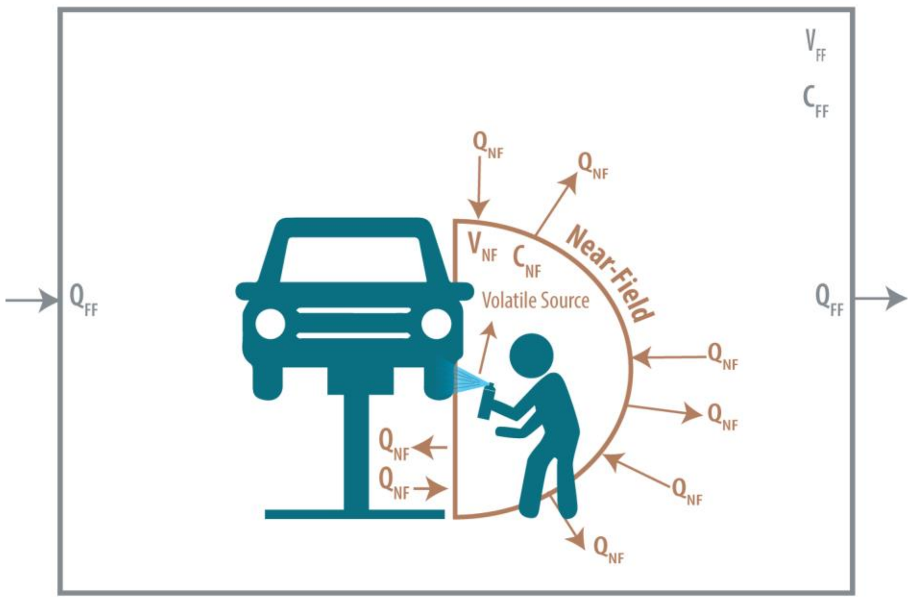

Figure 2-17. Schematic of the Near-Field/Far-Field Model for Aerosol Degreasing

EPA performed a Monte Carlo simulation with 1,000,000 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 acute 24-hr TWA exposure concentrations. Table 2-32 presents a statistical summary of the exposure modeling results.

For workers, the exposures are 7.63 ppm 8-hr TWA at the 50th percentile and 23.98 ppm 8-hr TWA at the 95th percentile. For occupational non-users, the model exposures are 0.14 ppm 8-hr TWA at the 50th percentile and 1.04 ppm 8-hr TWA at the 95th percentile.

Table 2-32. 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)	Confidence Rating of Air Concentration Data
Workers (Near-field)					
High-End	24.0	8.0	5.5	2.2	N/A – Modeled Data
Central Tendency	7.6	2.5	1.7	0.6	
Occupational non-users (Far-Field)					
High-End	1.0	0.4	0.2	0.1	N/A – Modeled Data
Central Tendency	0.1	0.05	0.03	0.01	

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 TCE to water from the use of aerosol products. Due to the volatility of TCE the majority of releases from the use of aerosol products will likely be to air as TCE evaporates from the aerosolized mist and the substrate surface. There is a potential that TCE 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 TCE 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 (Products, 2012). 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 Metalworking Fluids

2.11.1 Facility Estimates

EPA did not identify information to estimate the number of facilities using metalworking fluids containing TCE. However, the Trichloroethylene Market and Use Report (U.S. EPA, 2017d) estimated no more than 1.7% of the national TCE production volume is used for "miscellaneous" uses which includes metalworking fluids. Therefore, EPA expects the number of sites using TCE-containing metalworking fluids to be small.

2.11.2 Process Description

EPA identified one cutting fluid product in the Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal for TCE (2017 citation) that contains TCE. The safety data sheet (SDS) indicate that TCE is present at 98 wt% in the formulation and that the product's recommended use is an cutting fluid (U.S. EPA, 2017b). 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 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 (U.S. EPA, 2017b), EPA assesses as a straight oil. 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, 2011b). 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).

2.11.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for using metalworking fluids containing TCE.

2.11.3.1 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 TCE 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 TCE has a high vapor pressure (73.46 mmHg at 25°C), workers may be exposed to TCE 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 TCE may lead to its evaporation from the airborne mist droplets, potentially creating a fog of vapor and mist.

2.11.3.2 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 also cites an EPA effluent limit guideline development for the MP&M industry, which estimated a single shift supervisor per shift, who may perform tasks such as transferring and diluting neat metalworking fluids, disposing spent metalworking fluids, and cleaning the machines and troughs (OECD, 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. The number of establishments that use TCE-based metalworking fluids is unknown; therefore, EPA does not have data to estimate the total workers and ONUs exposed to TCE from use of metalworking fluids.

2.11.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from OSHA facility inspections (OSHA, 2017) at two sites using TCE in metalworking fluids. Due to small sample sizes, it is unclear how representative these data are of "typical" MWF use. Therefore, EPA supplemented the identified monitoring data with an assessment of inhalation exposures using the ESD on the Use of Metalworking Fluids (OECD, 2011b). The following subsections detail the results of EPA's occupational exposure assessment for TCE use in MWFs based on inhalation exposure monitoring data and modeling.

2.11.3.3.1 Inhalation Exposure Assessment Results Using Monitoring Data

Table 2-33 summarizes the 8-hr TWA monitoring data for the use of TCE in MWFs. No data was found to estimate ONU exposures from use in metalworking fluids. Data from this source covers exposures at a facility that produces various electrical resistors (Gilles and Philbin, 1976). The data were provided as full-shift TWAs.

Table 2-33. Summary of Worker Inhalation Exposure Monitoring Data for TCE Use in Metalworking Fluids

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	75.4	25.1	17.2	8.8	3	High
Central Tendency	69.7	23.2	15.9	6.3		

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.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA inhalation air concentrations. The primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 3 data points from 1 source, and the data quality ratings from systematic review for these data were high. The primary limitations of these data include limited dataset (3 data points from 1 site), and the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

2.11.3.3.2 Inhalation Exposure Assessment Results Using Modeling

EPA also considered the use of modeling, which is in the middle of the inhalation approach hierarchy. Data from the 2011 Emission Scenario Document on the Use of Metalworking Fluids was used to estimate inhalation exposures. The primary limitations of the exposure outputs from this model include the uncertainty of the representativeness of these data toward the true distribution of inhalation for all TCE uses for the industries and sites covered by this scenario, and the difference between the modeling data and monitoring data. Added uncertainties include that the underlying TCE concentration used in the metalworking fluid was assumed from one metalworking fluid product. Based on these strengths and limitations of the air concentrations, the overall confidence for these 8-hr TWA data in this scenario is medium.

The ESD estimates typical and high-end exposures for different types of metalworking fluids. These estimates are provided in Table 2-34 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 2-34. 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 TCE-based metalworking fluid is an oil-based cutting and tapping fluid; therefore, EPA assesses exposure to the TCE-based metalworking fluids using the straight oil mist concentrations and the max concentration of TCE in the metalworking fluid. Straight oils are not diluted; therefore, the concentration of TCE specified in the SDS (98%) (U.S. EPA, 2017b) is equal to the concentration of TCE in the mist. Table 2-35 presents the exposure estimates for the use of TCE-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 TCE during use of metalworking fluids as they do not account for exposure to TCE that evaporates from the mist droplets into the air. This exposure is difficult to estimate and is not considered in this assessment.

Table 2-35. Summary of Exposure Results for Use of TCE in Metalworking Fluids Based on ESD Estimates

Scenario	8-hr TWA (ppm)[a]	ADC (ppm)	LADC (ppm)	Data Quality Rating of Associated Air Concentration Data
High-End	0.3	0.1	0.03	N/A – Modeled Data
Central Tendency	0.1	0.02	6.0E-3	

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 TCE exposure concentrations are calculated by multiplying the straight oil mist concentrations in Table 2-34 by 98% (the concentration of TCE in the metalworking fluid) and converting to ppm.

The monitoring data obtained is two orders of magnitude higher than the modeling data. It is uncertain if the limited monitoring data set (three sample points), or the age of the monitoring data (1976) is representative of exposures to TCE for all sites covered by this OES.

2.11.4 Water Release Assessment

2.11.4.1 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).

2.11.4.2 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 TCE 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.

2.12 Adhesives, Sealants, Paints, and Coatings

2.12.1 Facility Estimates

To determine the number of sites that use TCE adhesives, sealants and coating, EPA considered 2014 NEI (U.S. EPA, 2018a), 2016 TRI (U.S. EPA, 2017c), and 2016 DMR (U.S. EPA, 2016a) data. In the 2014 NEI, sites report information for each adhesive/coating line at the site. In the 2014 NEI, 56 sites reported operation of adhesive/coating lines (U.S. EPA, 2018a). EPA identified 16 facilities, three of which are the same as NEI sites, in the 2016 TRI where the primary OES is expected to be coatings or adhesives based on the activities and NAICS codes reported (U.S. EPA, 2017c). Of the sites with non-zero water discharges in the 2016 DMR data, there is one site for which EPA expects the primary OES to be adhesives based on the reported SIC code. Therefore, EPA assessed a total of 70 sites for use of TCE in adhesives, sealants, paints and coatings.

2.12.2 Process Description

Based on products identified in Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: Trichlorethylene (U.S. EPA, 2017b) and 2016 CDR reporting (U.S. EPA, 2017a), TCE 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, 2018a). In the 2014 NEI (U.S. EPA, 2018a) there are 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.

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 TCE) 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

The following sections detail EPA's occupational exposure assessment for using adhesives and coatings containing TCE.

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 TCE during the application process if mists are generated such as during spray and roll applications (OECD, 2015). Workers may also be exposed to TCE 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 TCE in adhesives/coatings using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS codes reported by the sites in the 2016 TRI (U.S. EPA, 2017c) and 2014 NEI (U.S. EPA, 2018a). The one site reporting to 2016 DMR used SIC code 3053 (Gaskets, Packing and Sealing Development), which corresponds to a NAICS code 339991 (Gasket, Packing, and Sealing Device Manufacturing). 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. Table 2-36 provides the results of the number of worker analysis. There are 43 workers and 19 ONUs potentially exposed per site during use of TCE in adhesives and coatings.

Table 2-36. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Use of Adhesives and Coatings

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
313320	1	9	4	13	9	4
326150	1	15	4	19	15	4
326211	2	449	72	522	225	36
326212	4	39	6	46	10	2
326220	2	85	14	99	43	7
332321	3	53	14	67	18	5
332812	2	14	3	18	7	2
332813	9	71	16	87	8	2
332994	2	22	9	31	11	4
332999	2	11	4	16	6	2
333515	1	4	3	8	4	3
334417	1	41	37	78	41	37
335931	1	25	9	33	25	9
336211	3	100	13	113	33	4
336360	1	74	22	96	74	22
336390	5	225	67	292	45	13
336411	3	551	465	1,016	184	155

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
336415	1	132	111	243	132	111
336611	1	61	19	80	61	19
337110	1	3	2	6	3	2
339113	1	20	6	27	20	6
339991	1	21	5	26	21	5
Subtotal for Known SIC/NAICS Data	48	2,027	906	2,933	42	19
Unknown or No Data	22	994	455	1,448	45	21
Total[c]	70	3,000	1,400	4,400	43	19

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

Sources: (U.S. EPA, 2017c), 2014 NEI (U.S. EPA, 2018a), and (U.S. EPA, 2016a)

2.12.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from a NIOSH a Health Hazard Evaluation report (HHE) (Chrostek, 1981) using TCE in coating applications and from OSHA facility inspections (OSHA, 2017) at three sites using TCE in adhesives and coatings. The following details the results of EPA's occupational exposure assessment for coating applications based on inhalation exposure monitoring data.

Table 2-37 summarizes the 8-hr TWA monitoring data for the use of TCE in coatings. The data were obtained from a HHE (Chrostek, 1981) and from OSHA data (OSHA, 2017). The HHE data also provided two data points where the worker job description was "foreman." EPA assumed this data is applicable to ONU exposure. However, due to the limited data set and the various types of application methods that may be employed, EPA is unsure of the representativeness of these data toward actual exposures to TCE for all sites covered by this OES.

Table 2-37. Summary of Worker Inhalation Exposure Monitoring Data for Adhesives/Paints/Coatings

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
Workers						
High-End	39.5	13.2	9.0	4.6	22	Medium
Central Tendency	4.6	1.6	1.1	0.4		
Occupational non-users						
High-End	1.0	0.3	0.2	0.1	2	Medium
Central Tendency	0.9	0.3	0.2	0.1		

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

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 22 data points from 2 sources, and the data quality ratings from systematic review for these data were medium to high. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

For the ONU inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 2 data points from 1 source, and the data quality ratings from systematic review for the data point was high. The primary limitations of this data is the limited dataset (two data points from 1 site), and the uncertainty of the representativeness of this data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

EPA did not find data to provide inhalation exposure estimates for commercial adhesive, sealant, paint and coating applications. Therefore, EPA uses the industrial data discussed above as surrogate for commercial coatings, as EPA believes the activities and exposures will be similar between industrial and commercial sites covered by this OES.

2.12.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in adhesives, sealants, and paints/coatings.

2.12.4.1 Water Release Sources

In general, potential sources of water releases from adhesive, sealants, and paints/coatings use may include the following: equipment cleaning operations, and container cleaning wastes (OECD, 2011a).

2.12.4.2 Water Environmental Release Assessment Results

Water releases for adhesives, sealants, paints and coating sites were assessed using data reported from three sites in the 2016 TRI and 2016 DMR. For the sites in the 2014 NEI (where release information is not provided), an average release per site was calculated from the total releases of the three aforementioned sites reporting water releases to DMR and TRI, and dividing the total release by the total number of sites in TRI and DMR (17 sites). This average release per site was used to estimate releases from the sites provided in the 2014 NEI. EPA assessed daily releases by assuming 250 days of operation per year, as recommended in the 2011 ESD on the Application of Radiation Curable Coatings, Inks, and Adhesives via Spray, Vacuum, Roll and Curtain Coating, and averaging the annual releases over the operating days (OECD, 2011a). A summary of the water releases can be found in Table 2-38.

Table 2-38. Reported Water Releases of Trichloroethylene from Sites Using TCE in Adhesives, Sealants, Paints and Coatings

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day) [a]	NPDES Code	Release Media
Able Electropolishing Co Inc, Chicago, IL	74.4	250	0.30	Not available	POTW
Garlock Sealing Technologies, Palmyra, NY	0.08	250	3.3E-04	NY0000078	Surface Water
Ls Starrett Co, Athol, MA	9.1E-04	250	3.6E-06	MAR05B615	Surface Water
Aerojet Rocketdyne, Inc., East Camden, AR	4.4	250	1.8E-02	Not available	Surface Water or POTW
Best One Tire & Service, Nashville, TN	4.4	250	1.8E-02	Not available	Surface Water or POTW
Bridgestone Aircraft Tire (USA), Inc., Mayodan, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Clayton Homes Inc, Oxford, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Cmh Manufacturing, Inc. Dba Schult Homes - Plant 958, Richfield, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Delphi Thermal Systems, Lockport, NY	4.4	250	1.8E-02	Not available	Surface Water or POTW
Green Bay Packaging Inc - Coon Rapids, Coon Rapids, MN	4.4	250	1.8E-02	Not available	Surface Water or POTW

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day) [a]	NPDES Code	Release Media
Mastercraft Boat Company, Vonore, TN	4.4	250	1.8E-02	Not available	Surface Water or POTW
Michelin Aircraft Tire Company, Norwood, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
M-Tek, Inc, Manchester, TN	4.4	250	1.8E-02	Not available	Surface Water or POTW
Olin Corp, East Alton, IL	4.4	250	1.8E-02	Not available	Surface Water or POTW
Parker Hannifin Corp - Paraflex Division, Manitowoc, WI	4.4	250	1.8E-02	Not available	Surface Water or POTW
Parrish Tire Company, Yadkinville, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Republic Doors And Frames, Mckenzie, TN	4.4	250	1.8E-02	Not available	Surface Water or POTW
Ro-Lab Rubber Company Inc., Tracy, CA	4.4	250	1.8E-02	Not available	Surface Water or POTW
Royale Comfort Seating, Inc. - Plant No. 1, Taylorsville, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Snider Tire, Inc., Statesville, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Snyder Paper Corporation, Hickory, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Stellana Us, Lake Geneva, WI	4.4	250	1.8E-02	Not available	Surface Water or POTW
Thomas Built Buses - Courtesy Road, High Point, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Unicel Corp, Escondido, CA	4.4	250	1.8E-02	Not available	Surface Water or POTW
Acme Finishing Co Llc, Elk Grove Village, IL	4.4	250	1.8E-02	Not available	Surface Water or POTW

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day) [a]	NPDES Code	Release Media
Aerojet Rocketdyne, Inc., Rancho Cordova, CA	4.4	250	1.8E-02	Not available	Surface Water or POTW
Allegheny Cnty Airport Auth/Pgh Intl Airport, Pittsburgh, PA	4.4	250	1.8E-02	Not available	Surface Water or POTW
Amphenol Corp - Aerospace Operations, Sidney, NY	4.4	250	1.8E-02	Not available	Surface Water or POTW
Aprotech Powertrain, Asheville, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Clayton Homes Inc, Oxford, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Coating & Converting Tech Corp/Adhesive Coatings, Philadelphia, PA	4.4	250	1.8E-02	Not available	Surface Water or POTW
Corpus Christi Army Depot, Corpus Christi, TX	4.4	250	1.8E-02	Not available	Surface Water or POTW
Electronic Data Systems Camp Pendleton, Camp Pendleton, CA	4.4	250	1.8E-02	Not available	Surface Water or POTW
Florida Production Engineering, Inc., Ormond Beach, FL	4.4	250	1.8E-02	Not available	Surface Water or POTW
Goodrich Corporation, Jacksonville, FL	4.4	250	1.8E-02	Not available	Surface Water or POTW
Kasai North America Inc, Madison Plant, Madison, MS	4.4	250	1.8E-02	Not available	Surface Water or POTW
Kirtland Air Force Base, Albuquerque, NM	4.4	250	1.8E-02	Not available	Surface Water or POTW
Marvin Windows & Doors, Warroad, MN	4.4	250	1.8E-02	Not available	Surface Water or POTW
Mcneilus Truck & Manufacturing Inc, Dodge Center, MN	4.4	250	1.8E-02	Not available	Surface Water or POTW
Metal Finishing Co. - Wichita (S Mclean Blvd), Wichita, KS	4.4	250	1.8E-02	Not available	Surface Water or POTW

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day) [a]	NPDES Code	Release Media
Michelin Aircraft Tire Company, Norwood, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Murakami Manufacturing Usa Inc, Campbellsville, KY	4.4	250	1.8E-02	Not available	Surface Water or POTW
Peterbilt Motors Denton Facility, Denton, TX	4.4	250	1.8E-02	Not available	Surface Water or POTW
Portsmouth Naval Shipyard, Kittery, ME	4.4	250	1.8E-02	Not available	Surface Water or POTW
R.D. Henry & Co., Wichita, KS	4.4	250	1.8E-02	Not available	Surface Water or POTW
Raytheon Company, Portsmouth, RI	4.4	250	1.8E-02	Not available	Surface Water or POTW
Rehau Inc, Cullman, AL	4.4	250	1.8E-02	Not available	Surface Water or POTW
Rotochopper Inc, Saint Martin, MN	4.4	250	1.8E-02	Not available	Surface Water or POTW
Rubber Applications, Mulberry, FL	4.4	250	1.8E-02	Not available	Surface Water or POTW
Sapa Precision Tubing Rockledge, Llc, Rockledge, FL	4.4	250	1.8E-02	Not available	Surface Water or POTW
Thomas & Betts, Albuquerque, NM	4.4	250	1.8E-02	Not available	Surface Water or POTW
Thomas Built Buses - Fairfield Road, High Point, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Timco, Dba Haeco Americas Airframe Services, Greensboro, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
Trelleborg Coated Systems Us, Inc - Grace Advanced Materials, Rutherfordton, NC	4.4	250	1.8E-02	Not available	Surface Water or POTW
U.S. Coast Guard Yard - Curtis Bay, Curtis Bay, MD	4.4	250	1.8E-02	Not available	Surface Water or POTW

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day) [a]	NPDES Code	Release Media
Viracon Inc, Owatonna, MN	4.4	250	1.8E-02	Not available	Surface Water or POTW

POTW = Publicly Owned Treatment Works
Releases of 4.4 kg/site-yr for NEI sites estimated from total releases from TRI and DMR sites and divided by the 3 sites reporting water releases and the 14 sites reporting zero water releases in TRI).
[a] Daily releases are back-calculated from the annual release rate and assuming 250 days of operation per year.
Sources: (U.S. EPA, 2018a, 2017c, 2016a)

2.13 Other Industrial Uses

2.13.1 Estimates of Number of Facilities

To determine the number of sites that use TCE for other industrial uses, EPA considered 2016 TRI data, and 2016 DMR data. EPA identified 28 facilities in the 2016 TRI and 21 facilities in the 2016 DMR where EPA could not determine the OES or the use falls into an industrial OES discussed in Section 2.13.2. Therefore, EPA assessed a total of 49 sites for use of TCE in "other industrial uses".

2.13.2 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 TCE may exist. Examples of these uses include, but are not limited to uses in inorganic chemical manufacturing, limestone mining and quarrying, pharmaceutical preparations, plastic products, electrical services, scientific research and development, incorporation into articles, and functional fluids for closed systems such as heat exchange fluid (U.S. EPA, 2017b), (U.S. EPA, 2017d), (U.S. EPA, 2017c) and (U.S. EPA, 2016a). EPA did not identify information on how TCE may be used at these facilities.

2.13.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for other industrial uses of TCE.

2.13.3.1 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 TCE 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 TCE, but who do not directly handle the material. ONUs may also be exposed to TCE but are expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs for this OES may include supervisors, managers, engineers, and other personnel in nearby production areas.

2.13.3.2 Number of Potentially Exposed Workers

Table 2-39 summarizes SIC codes (and the corresponding NAICS codes) reported by the sites in the 2016 DMR (U.S. EPA, 2016a).

Table 2-39. Crosswalk of Other Industrial Use SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
1422– Crushed and Broken Limestone	212312 - Crushed and Broken Limestone Mining and Quarrying
2812 – Alkalies and Chlorine	325180 – Other Basic Inorganic Chemical Manufacturing
2819 – Industrial Inorganic Chemicals, NEC	325180 – Other Basic Inorganic Chemical Manufacturing
2834 – Pharmaceutical Preparations	325412 - Pharmaceutical Preparation Manufacturing
2869 – Industrial Organic Chemicals, NEC	325199 – All Other Basic Inorganic Chemical Manufacturing
3089 – Plastic Products, NEC[a]	326100 – Plastics Products Manufacturing
4911 – Electrical Services[b]	221100 – Electric Power Generation, Transmission and Distribution
9661 – Space Research and Technology	927110 - Space Research and Technology
9711 – National Security	928110 – National Security
3229 - Pressed & Blown Glass and Glassware	327212 – Other Pressed and Blown Glass and Glassware Manufacturing
3069 – Fabricated Rubber Products, NEC	326299 – All Other Rubber Product Manufacturing
1799 – Special Trade Contractors[c]	230000 - Construction
9999 – Nonclassifiable Establishments	No NAICS listed in the crosswalk

[a] The SIC code 3089 may map to any of the following NAICS codes: 326121, 326122, 326199, 336612, 337215, or 339113. 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, 326100, 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 code 1799 may map to any of the following NAICS codes: 236220, 237990, 238150, 238190, 238290, 238310, 238320, 238350, 238390, 238910, 561790, 562910. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 2-digit NAICS, 230000, rather than a specific 6-digit NAICS.

EPA estimated the number of workers and occupational non-users potentially exposed during use of TCE in Other Industrial Uses using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the SIC/NAICS codes reported by the sites in the 2016 TRI (U.S. EPA, 2017c) and 2016 DMR (U.S. EPA, 2016a).

Table 2-40 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. There are approximately 2,300 workers and 1,000 ONUs potentially exposed during other industrial uses.

Table 2-40. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Other Industrial Uses

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
324110	1	340	151	491	170	75
325110	2	127	60	187	64	30
325199	14	540	255	795	39	18
325211	6	165	72	237	27	12
326299	4	110	18	127	27	4
325180	4	101	47	148	25	12
325412	1	44	27	71	44	27
325510	1	14	5	20	14	5
325998	2	28	9	37	14	5
334511	1	53	55	108	53	55
Subtotal for Known SIC/NAICS Data	37	1,523	699	2,223	41	19
Unknown or No Data	12	786	336	1,122	65	28
Total[c]	49	2,300	1,000	3,300	47	21

[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. [b] Totals may not add exactly due to rounding.
[c] Values rounded to two significant figures.
Sources: (U.S. EPA, 2017c)and (U.S. EPA, 2016a)

2.13.3.3 Occupational Exposure Results

EPA did not identify inhalation exposure monitoring data related to using TCE for other industrial uses. Therefore, EPA used monitoring data from loading/unloading TCE during manufacturing as a surrogate. See section 2.1.3 for additional information on the data used. EPA assumes the exposure sources, routes, and exposure levels are similar to those during loading at a TCE manufacturing facility. However, EPA is unsure of the representativeness of these surrogate data toward actual exposures to TCE at all sites covered by this OES.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA inhalation air concentrations. The primary strengths include the assessment approach, which is the use of surrogate monitoring data, in the middle of the inhalation approach hierarchy. These monitoring data include 16 data points from 1 source, and the data quality ratings from systematic review for these data were medium. The primary limitations of these data include the uncertainty of the representativeness of these surrogate data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium.

Table 2-41 summarizes the 8-hr TWA from monitoring data from TCE manufacturing. The data were obtained from obtained from data submitted by the Halogenated Solvents Industry Alliance (HSIA) via public comment for one company (Halogenated Solvents Industry Alliance, 2018 5176415). No data was found to estimate ONU exposures during other industrial uses of TCE. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical.

Table 2-41 Summary of Occupational Exposure Surrogate Monitoring Data for Unloading TCE During Other Industrial Uses

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	2.6	0.9	0.6	0.3	16	Medium
Central Tendency	0.4	0.1	0.1	0.03		

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

2.13.4 Water Release Assessment

The following sections detail EPA's water release assessment for other industrial uses of TCE.

2.13.4.1 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, 2019).

2.13.4.2 Water Release Assessment Results

EPA assessed water releases using the annual discharge values reported to the 2016 TRI and the 2016 DMR by the 49 sites using TCE in other industrial uses. In the 2016 TRI, all 28 reported zero discharge to water. In the 2016 DMR, twenty-one sites reported a direct discharge to surface water (indirect discharges not reported in DMR data).

To estimate the daily release, EPA assumed a default of 250 days/yr of operation and averaged the annual release over the operating days. Table 2-42 summarizes the water releases from the 2016 TRI and DMR for sites with non-zero discharges.

Table 2-42. Reported Water Releases of Trichloroethylene from Other Industrial Uses

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)[a]	Daily Release (kg/site-day)[a]	NPDES Code	Release Media
Eli Lilly And Company-Lilly Tech Ctr, Indianapolis, IN	388	250	1.6	IN0003310	Surface Water
Oxy Vinyls LP - Deer Park Pvc, Deer Park, TX	37	250	0.15	TX0007412	Surface Water
Solvay - Houston Plant, Houston, TX	8.3	250	0.03	TX0007072	Surface Water
Washington Penn Plastics, Frankfort, KY	8.0	250	0.03	KY0097497	Surface Water
Natrium Plant, New Martinsville, WV	5.5	250	2.2E-02	WV0004359	Surface Water
Leroy Quarry, Leroy, NY	4.8	250	1.9E-02	NY0247189	Surface Water
George C Marshall Space Flight Center, Huntsville, AL	2.6	250	1.0E-02	AL0000221	Surface Water
Whelan Energy Center Power Plant, Hastings, NE	2.4	250	9.4E-03	NE0113506	Surface Water
Akzo Nobel Surface Chemistry LLC, Morris, IL	0.1	250	4.6E-04	IL0026069	Surface Water
Solutia Nitro Site, Nitro, WV	0.1	250	4.4E-04	WV0116181	Surface Water
Amphenol Corporation - Columbia, Columbia, SC	0.1	250	2.8E-04	SC0046264	Surface Water
Army Cold Regions Research & Engineering Lab, Hanover, NH	0.1	250	2.3E-04	NH0001619	Surface Water
Corning - Canton Plant, Canton, NY	0.1	250	2.2E-04	NY0085006	Surface Water
Keeshan And Bost Chemical Co., Inc., Manvel, TX	0.03	250	1.3E-04	TX0072168	Surface Water
Ames Rubber Corp Plant #1, Hamburg Boro, NJ	0.03	250	1. 1E-04	NJG000141	Surface Water
Gorham, Providence, RI	0.02	250	9.2E-05	RIG85E004	Surface Water
Emerson Power Transmission, Ithaca, NY	0.02	250	6.9E-05	NY0002933	Surface Water
Chemtura North and South Plants, Morgantown, WV	8.3E-03	250	3.3E-05	WV0004740	Surface Water
Indorama Ventures Olefins, LLC, Sulphur, LA	5.1E-03	250	2.0E-05	LA0069850	Surface Water
William E. Warne Power Plant, Los Angeles County, CA	3.1E-03	250	1.2E-05	CA0059188	Surface Water
Raytheon Aircraft Co (Was Beech Aircraft), Boulder, CO	2.3E-03	250	9.2E-06	COG315176	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, 2017c, 2016a)

2.14 Spot Cleaning, Wipe Cleaning and Carpet Cleaning

2.14.1 Facility Estimates

There are 34,650 establishments in the United States under NAICS 812300, Dry Cleaning and Laundry Services and 21,370 establishments in the United States under NAICS 812320, Dry Cleaning and Laundry Services (except coin-operated) (U.S. Census Bureau, 2015). There are 7,728 establishments in the United States under NAICS 561740, Cleaning and Furniture Care Products (U.S. Census Bureau, 2015). For the purposes of this assessment, EPA assumes spot cleaning, wipe cleaning, and carpet cleaning using TCE may occur at all 63,748 sites under these NAICS numbers.

2.14.2 Process Description

The following sections outline how TCE is used to spot clean garments and carpets, was well as use as a wipe cleaner.

2.14.2.1 Spot Cleaning

On receiving a garment, dry cleaners inspect for stains or spots they can remove as much 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 TCE. 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 TCE if using a brush, spatula, pressurized air or steam, or their fingers to scrape or flush away the stain (NIOSH, 1997) and (Young, 2012).

Figure 2-18. Exposure Scenario for Spot Cleaning Process

As TCE is only used as a spot cleaner at dry cleaning facilities, EPA does not assess a dry cleaning scenario. Therefore, this scenario represents dry cleaners where spot cleaning is the only source of TCE exposure. The extent of such uses is likely limited, several TCE-free spot cleaner formulations are available.

2.14.2.2 Carpet Cleaning

The process of carpet cleaning using TCE is similar to that discussed for Spot Cleaning above (Section 2.8.2.1). Carpets are inspected for stains, then 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 cleaner may come into further contact with the TCE if using a brush, spatula, pressurized air or steam, or their fingers to scrape or flush away the stain(Young, 2012; NIOSH, 1997).

2.14.2.3 Wipe Cleaning

TCE can also be used as a solvent in non-aerosol 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, 2014a). The cleaning solvent is usually applied in excess and allowed to air-dry (U.S. EPA, 2014a). Parts may be cleaned in place or removed from the service item for more thorough cleaning (U.S. EPA, 2014a).

2.14.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for spot cleaning and wipe cleaning uses.

2.14.3.1 Worker Activities

Workers manually apply the spotting agent from squeeze bottles, hand-held spray bottles, or spray guns, either before or after a cleaning cycle. After application, the worker may manually scrape or flush away the stain using a brush, spatula, pressurized air or steam, or their fingers (Young, 2012; NIOSH, 1997). Section 2.14.2.3 summarizes worker activities associated with wipe cleaning. EPA believes workers would not typically utilize respiratory protection during spot cleaning and wipe cleaning activities.

2.14.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed to TCE during spot cleaning at dry cleaners and from carpet spot cleaning using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015). Based on 63,748 establishments, there are approximately 244,000 total exposed workers in relevant occupations, and 25,300 occupational non-users. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. See Table 2-43 below.

Table 2-43. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Spot, Wipe, and Carpet 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[b]
812300	34,650	5	0.5	165,890	17,170	183,060
812320	21,370	4	0.4	76,268	7,894	84,162
561740	7,728	0.2	0.03	1,383	199	1,582
Total[c]	63,748	3.8	0.4	244,000	25,300	269,000

[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 exposed workers per site is shown as 3.8, as it rounds up to 4.
The number of occupational non-users per site is shown as 0.4, as it rounds up to one.
[b] Totals may not add exactly due to rounding.
[c] Total exposed workers, total exposed occupational Non-Users and Total Exposed rounded to two significant figures.

2.14.3.3 Occupational Exposure Results

EPA identified minimal inhalation exposure monitoring data related to the spot cleaning using TCE. Therefore, EPA supplemented the identified monitoring data using the Near-field/Far-field Exposure Model. The following subsections detail the results of EPA's occupational exposure assessment for spot cleaning based on inhalation exposure monitoring data and modeling.

2.14.3.3.1 Inhalation Exposure Assessment Results Using Monitoring Data

Table 2-44 summarizes the 8-hr TWA monitoring data and acute TWAs from the monitoring data for the use of TCE in in spot cleaning. No data was found to estimate ONU exposures during spot cleaning. The data were obtained from NIOSH a Health Hazard Evaluation report (HHE) (Burton and Monesterskey, 1996), as well as a NIOSH Report on Control of Health and Safety Hazards on Commercial Drycleaners document (NIOSH, 1997). 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. NIOSH Health and Safety documents represents NIOSH research in collaboration with industry, labor and other government organizations to protect the health of workers in industry.

For full shift values, sample times ranged from approximately seven to nine hours (Burton and Monesterskey, 1996). 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. Because of the limited data set, EPA is unsure of the representativeness of these data toward actual exposures to TCE for all sites covered by this OES.

Table 2-44. Summary of Worker Inhalation Exposure Monitoring Data for Spot Cleaning Using TCE

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of 8-hr TWA Data Points	Confidence Rating of Air Concentration Data
High-End	2.8	1.0	0.7	0.3	8	Medium
Central Tendency	0.4	0.1	0.1	0.04		

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.

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 8 data points from 2 sources, and the data quality ratings from systematic review for these data were medium. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

2.14.3.3.2 Inhalation Exposure Assessment Results Using Modeling

EPA also considered the use of modeling, which is in the middle of the inhalation approach hierarchy. A Monte Carlo simulation with 100,000 iterations was used to capture the range of potential input parameters. Various model parameters were derived from a CARB study. The primary limitations of the air concentration outputs from the model include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Added uncertainties include that the underlying methodologies used to obtain the values in the CARB study, as well as the assumed TCE concentration in the spot cleaning product. Based on these strengths and limitations of the air concentrations, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

Wolf and Morris (IRTA, 2007) estimated 42,000 gal of TCE-based spotting agents are sold in California annually. Review of SDS's identified TCE-based spotting agents contain 10% to 100% TCE. The study also estimated approximately 5,000 textile cleaning facilities in California. Results in average of 8.4 gal/site-yr of TCE-based spotting agents used.

A more detailed description of the modeling approach is provided in Appendix G. Figure 2-19 illustrates the near-field/far-field modeling approach that EPA applied to spot cleaning facilities. As the figure shows, chemical 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 amount of spot cleaner 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 the chemical of interest dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational non-user exposures at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the chemical of interest dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly the chemical dissipates out of the surrounding space and into the outdoor air.

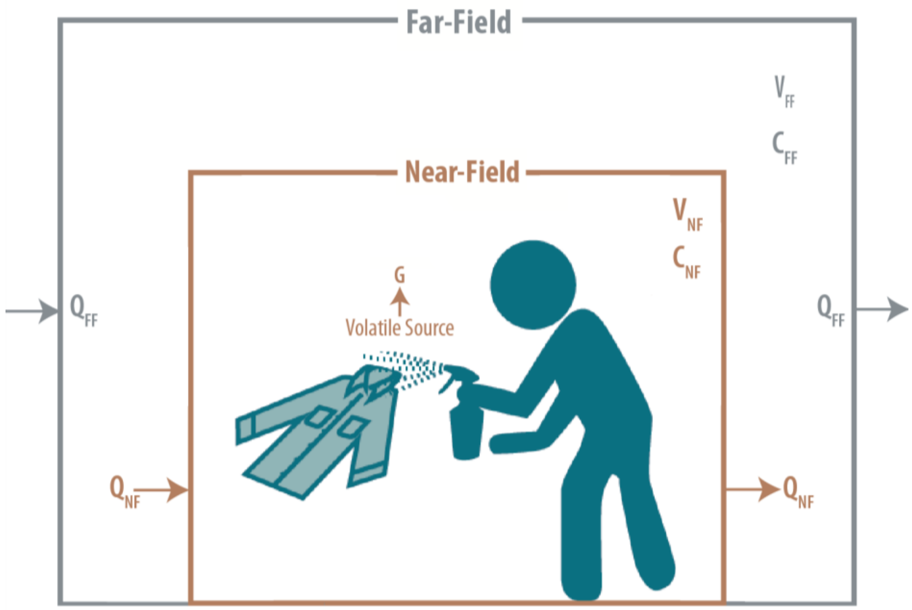

Figure 2-19. Schematic of the Near-Field/Far-Field Model for Spot Cleaning

EPA performed Monte Carlo simulations, applying one hundred thousand iterations and the Latin hypercube sampling method. Table 2-45 presents a statistical summary of the exposure modeling results. The 50th and 95th percentile near-field exposures are 0.96 ppm and 2.77 ppm 8-hr TWA, respectively. These results are comparable to the monitoring data. For occupational non-users (far-field), model 50th and 95th percentile exposure levels are 0.48 ppm and 1.75 ppm 8-hr TWA, respectively. EPA assumes no engineering controls are used at dry cleaning shops, which are typically small, family owned businesses.

The modeling results are comparable to the monitoring data. However, EPA is unsure of the representativeness of these data toward actual exposures to TCE for all sites covered by this OES. Despite these limitations, as the modeling and monitoring results match each other very closely, the overall confidence is medium.

Estimates of Acute Concentration (AC), Average Daily Concentrations (ADC) and Lifetime Average Daily Concentration (LADC) for use in assessing risk were made using the approach and equations described in Appendix B.

Table 2-45. Summary of Exposure Modeling Results for Spot Cleaning Using TCE

Scenario	8-hr TWA (ppm)	AC (24-hr) (ppm)	ADC (ppm)	LADC (ppm)	Data Quality Rating of Associated Air Concentration Data
Workers (Near-field)					
High-End	2.8	0.9	0.6	0.3	N/A – Modeled Data
Central Tendency	1.0	0.3	0.2	0.1	
Occupational non-users (Far-Field)					
High-End	1.8	0.6	0.4	0.2	N/A – Modeled Data
Central Tendency	0.5	0.2	0.1	0.04	

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.

2.14.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in spot cleaning.

2.14.4.1 Water Release Sources

TCE releases to water from spot cleaning will depend upon whether the stained surface is washed with water after spotting. For example, TCE-based cleaners used to pre-spot garments prior to cleaning in water or hydrocarbon-based machines would be a source of TCE in wastewater.

2.14.4.2 Water Release Assessment Results

Water releases for spot cleaning were assessed using data reported in the 2016 DMR. No sites discharging TCE from spot cleaning activities were found in the 2016 TRI. EPA assessed annual releases as reported in the 2016 DMR and assessed daily releases by assuming 300 days of operation per year. A summary of the water releases reported to the 2016 DMR can be found in Table 2-46. The annual release for each of the unknown sites is calculated by taking the average annual release of the two sites reporting to DMR.

Table 2-46. Reported Water Releases of Trichloroethylene from Sites Using TCE Spot Cleaning

Site	Annual Release[a] (kg/site-year)	Annual Release Days (days/yr)	Daily Release (kg/site-day)[a]	Media of Release
Boise State University, Boise, ID	0.02	300	8.0E-05	Surface Water
Venetian Hotel And Casino, Las Vegas, NV	8.8E-3	300	2.9E-05	Surface Water
63,746 Unknown Sites	0.02	300	5.4E-05	Surface Water or POTW

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

2.15 Industrial Processing Aid

2.15.1 Facility Estimates

To determine the number of sites that use TCE as a processing aid, EPA considered 2016 TRI and 2016 DMR data. In the 2016 TRI, sixteen facilities report use of TCE as a chemical processing aid and/or a manufacturing aid under several NAICS codes. Two sites were identified as sites using TCE as a processing aid from the 2016 DMR. These codes and a description for these 18 sites are provided in Table 2-47.

Table 2-47. Summary of NAICS Codes and Descriptions of TRI and DMR Sites Reporting TCE Used as A Processing Aid

NAICS Code	NAICS Description
325180	Other Basic Inorganic Chemical Manufacturing
325212	Synthetic Rubber Manufacturing
325613	Surface Active Agent Manufacturing
335912	Primary Battery Manufacturing
339920	Sporting and Athletic Goods Manufacturing
326113	Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing
326299	All Other Rubber Product Manufacturing

NAICS Code	NAICS Description
332721	Precision Turned Product Manufacturing
332811	Metal Heat Treating
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers
335991	Carbon and Graphite Product Manufacturing
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing

EPA assumes that all 18 sites use TCE as an industrial processing aid.

2.15.2 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, 2018d). Additionally, processing aids are intended to improve the processing characteristics or the operation of process equipment, but not intended to affect the function of a substance or article created (U.S. EPA, 2016b).

One processing aid use of TCE is in the manufacturing of photographic and x-ray films, plastics manufacturing and ink processing (Halogenated Solvents Industry Alliance, 2017 5176417). According to public comments from the Saft America, Inc. (Saft America, 2017), TCE is used in research and development, occasionally battery production. Dow states TCE is used as a solvent in waterless drying and finishing operations (Dow Chemical, 2014). Other specific processing aid uses of TCE were not identified; however, EPA expects use as a process solvent to be amongst the major processing aid uses.

2.15.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for the use of TCE as a processing aid.

2.15.3.1 Worker Activities

During the use of TCE as a processing aid, workers are potentially exposed to TCE while connecting and disconnecting hoses and transfer lines to containers and packaging to be unloaded (e.g., railcars, tank trucks, totes). 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 TCE 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 formulation activities include supervisors, managers, and tradesmen that may be in the same area as exposure sources but do not perform tasks that result in the same level of exposures as workers.

2.15.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of TCE as an industrial processing aid using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS codes reported by the sites in the 2016 TRI and 2016 DMR. 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. Table 2-48 provides the results of the number of worker analysis. There are 310 workers and 140 ONUs potentially exposed during use of TCE during use as an industrial processing aid.

Table 2-48. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Use as an Industrial Processing Aid

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
325180	2	50	24	74	25	12
325212	1	25	11	36	25	11
326299	1	27	4	32	27	4
332721	2	8	4	12	4	2
332811	2	20	4	24	10	2
332812	2	14	3	18	7	2
335991	1	21	8	29	21	8
336413	1	41	35	76	41	35
339920	1	9	2	11	9	2
Subtotal for Known SIC/NAICS Data	13	216	95	311	17	7
Unknown or No Data	5	94	42	137	19	8
Total[c]	18	310	140	450	17	8

[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. [b] Totals may not add exactly due to rounding.
[c] Values rounded to two significant figures.
Sources: (U.S. EPA, 2017c) and (U.S. EPA, 2016a)

2.15.3.3 Occupational Exposure Results

EPA did identify inhalation exposure monitoring data related using TCE when used as an industrial processing aid from one site. The following details the results of EPA's occupational exposure assessment for use of TCE as an industrial processing aid based on inhalation exposure monitoring data.

Table 2-49 summarizes the 12-hr TWA monitoring data and acute TWAs from the monitoring data for the use of TCE as a processing aid for both workers and for ONUs. The data were obtained from a European Commission (EC) Technical Report (EC, 2014). The data was supplied to the EC as supporting documentation in an application for continued use of TCE under the REACH Regulation. The data indicate a full shift is 12 hours. Therefore, all exposures were calculated using a 12-hr shift. Because of the limited data set, EPA is unsure of the representativeness of these data toward actual exposures to TCE for all sites covered by this OES.

Table 2-49. Summary of Exposure Monitoring Data for Use as a Processing Aid

Scenario	12-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of 12-hr Data Points	Confidence Rating of Air Concentration Data
Workers						
High-End	12.8	6.4	4.4	2.2	30	Medium to High
Central Tendency	4.2	2.1	1.5	0.6		
Occupational non-users						
High-End	2.9	1.4	1.0	0.5	4	Medium
Central Tendency	1.3	0.7	0.4	0.2		

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

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 12-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 30 data points from 1 source, and the data quality ratings from systematic review for these data were high. The primary limitations of these data include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 12-hr TWA data in this scenario is medium to high.

For the ONU inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 4 data points from 1 source, and the data quality ratings from systematic review for the data point was high. The primary limitations of this single data point include the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario. Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 12-hr TWA data in this scenario is medium to low.

2.15.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE as an industrial processing aid.

2.15.4.1 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, 2019). Based on the use as a processing aid and the amount of TCE used for this OES, EPA expects minimal sources of TCE release to water.

2.15.4.2 Water Release Assessment Results

Water releases during use as a processing aid were assessed using data reported in the 2016 TRI as well as 2016 DMR. Four of the 16 sites reporting to TRI provided water releases. The remaining 12 sites reported all releases were to off-site land, incineration or recycling. EPA assessed annual releases as reported in the 2016 TRI and assessed daily releases by assuming 300 days of operation per year. A summary of the water releases reported to the 2016 DMR and 2016 TRI can be found in Table 2-50.

Table 2-50. Reported Water Releases of Trichloroethylene from Industrial Processing Aid Sites Using TCE

Site Identity	Annual Release (kg/site-yr)[a]	Annual Release Days (days/yr)	Daily Release (kg/site-day)[a]	NPDES Code	Release Media
Entek International LLC, Lebanon, OR	113	300	0.4	Not available	POTW
Occidental Chemical Corp Niagara Plant, Niagara Falls, NY	5.8	300	0.02	NY0003336	Surface Water
National Electrical Carbon Products Dba Morgan Adv Materials, Fostoria, OH	2.3	300	7. 6E-03	Not available	POTW
Daramic LLC, Corydon, IN	2.3	300	0.01	Not available	Surface Water
PPG Industries Inc Barberton, Barberton, OH	1.4	300	4.5E-3	OH0123897	POTW
Stepan Co Millsdale Road, Elwood, IL	0.2	300	5.5E-04	IL0002453	Surface Water

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

2.16 Commercial Printing and Copying

2.16.1 Facility Estimates

There are 25,688 establishments in the United States under the following NAICS codes: 323111, Commercial Printing (except Screen and Books); 323113, Commercial Screen Printing; 323117, Books Printing; and 323120, Support Activities for Printing (U.S. Census Bureau, 2015). However, the systematic literature review of uses of and exposure to TCE (Bakke et al., 2007) indicate TCE use in printing was rare by the 1970s. The TCE Market and Use Report indicates approximately 1.7% of the TCE manufactured/imported into the U.S. is for uses considered "other uses," which would include all other uses other than as a chemical intermediate or as a degreaser (U.S. EPA, 2017d). Also, there is no information on the market share of TCE for this OES. Therefore, there is not enough information to quantify the number of facilities using TCE in commercial printing and copying.

2.16.2 Process Description

The *Scoping Document for Emission Scenario Document on Manufacture and Use of Printing Inks*(OECD, 2010) provides general process descriptions and worker activities for industrial commercial printing/copying uses.

Printing processes can be sheet-fed or web-fed. Web presses are used for larger printing runs and print images onto a continuous roll (web) of paper. After printing, the web is cut to a preferred size. Sheet-fed presses print on individual sheets of paper or other substrate. Most commercial printing is done on sheet-fed presses while long runs for newspapers, magazines, and books are usually printed on web-fed. There is an additional distinction between web-fed printing processes. Non-heat-set printing refers to continuous processes without the application of heat. In heat-set web printing a continuous roll of paper or other substrate material is printed with the application of heat. Several types of printing processes include:

- Lithography – this process is based on the principle that oil and water are not miscible. The image area on the printing plates is photochemically treated to absorb an oil-based ink in the image areas and to absorb only water in the non-image areas. At the printing facility, the ink paste is unloaded from a container into an ink tank on the printing machine. The machine is set in motion and ink is transferred first to the ink rollers, then to the printing cylinder, then to the intermediate blanket roll, and finally to the paper. The blanket imparts the image to the substrate. Lithography presses may be sheet-fed, non-heat-set-fed, or heat-set-fed. Web-fed lithography is used in the production of articles such as periodicals, newspapers, advertising, and books.
- Gravure - is a printing process in which the image is etched or engraved below the surface of a plate or cylinder. The printing image consists of millions of minute cells etched or engraved into copper cylinders or plates plated with chrome. Gravure processes using cylinders are referred to as rotogravure. Engraving cylinders is a relatively complex and expensive task. As a result, rotogravure is typically used for long printing jobs where engraving new printing images is not frequently required.
- Flexography - is an example of relief printing where the image area is raised relative to the non-image area. The inks must be very fluid to print properly and include both water-borne and solvent-borne systems. Flexographic printing can be sheet or web-fed. The major uses of flexographic printing are for flexible and rigid packaging, newspapers, magazines, and directories, and consumer paper products such as paper towels and tissues.
- Letterpress - uses a relief printing plate or cylinder like flexography. The plates differ from flexographic plates because they use a raised metal image. Viscous inks similar to lithographic

inks are used. Sheet-fed, heat-set web, and non-heat-set web presses are currently used. Letterpress is used to print newspapers, magazines, books, stationary, and advertising.

- Digital Printing - refers to any printing completed via digital files. It is not limited by short runs and is capable of incorporating data directly for compact database and printing to a digital press not using traditional methods of film or printing plates.
- Screen Printing - ink is transferred to the substrate through a porous screen marked with a stencil. Screen printing inks include ultra-violet cure, water-borne, solvent-borne, and plastisol. Plastisol is mainly used in textile printing. Both sheet-fed and web-fed presses are used. Depending on the substrate printed, it can be dried after each color application or, for absorbent substrates, after all colors have been printed. Solvent- and water-borne inks are dried in hot air or infrared drying ovens. Screen printing is used for short print runs of artistic images, especially on objects that cannot be printed by other means, such as signs, displays, electronics, wall paper, greeting cards, ceramics, decals, banners, and textiles.

2.16.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for the use of TCE in commercial printing and copying.

2.16.3.1 Worker Activities

The worker activity, use pattern, and associated exposure will vary depending on the type of printing/copying employed. However, in general, workers may be exposed to mists generated during the ink application process.

2.16.3.2 Number of Potentially Exposed Workers

The HHE (Finely and Page, 2005) summarized 44 workers potentially exposed and 74 ONUs at one site. The *Scoping Document for Emission Scenario Document on Manufacture and Use of Printing Inks* (OECD, 2010) provides the estimated number of workers per site to vary from 16 to 43 based on the type of printing involved. Further, the scenario estimates an industry average of 18 workers per site. However, without an estimate for the number of sites using TCE in printing, there is not enough data to quantify the total number of exposed workers or ONUs for this OES.

2.16.3.3 Occupational Exposure Results

EPA identified inhalation exposure monitoring data from a NIOSH a Health Hazard Evaluation report (HHE) (Finely and Page, 2005) using TCE in high speed printing presses. The following details the results of EPA's occupational exposure assessment for printing applications based on inhalation exposure monitoring data. Table 2-51 summarizes the 8-hr TWA monitoring data for the use of TCE in printing. The data were obtained from a HHE (Finely and Page, 2005).

EPA considered the assessment approach, the quality of the data, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data. For the inhalation air concentration data, the primary strengths include the assessment approach, which is the use of monitoring data, the highest of the inhalation approach hierarchy. These monitoring data include 20 data points from 1 source, and the data quality ratings from systematic review for these data were medium. The primary limitations of these data include a limited dataset, and the uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by this scenario.

Based on these strengths and limitations of the inhalation air concentration data, the overall confidence for these 8-hr TWA data in this scenario is medium to low.

Table 2-51. Summary of Worker Inhalation Exposure Monitoring Data for High Speed Printing Presses

Scenario	8-hr TWA (ppm)	AC (ppm)	ADC (ppm)	LADC (ppm)	Number of Data Points	Confidence Rating of Air Concentration Data
High-End	2.1	0.7	0.5	0.2	20	Medium
Central Tendency	0.1	0.03	0.02	8.0E-3		

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

No monitoring data were reasonably available to estimate ONU exposures. EPA estimates that ONU exposures are lower than worker exposures, since ONUs do not typically directly handle the chemical.

2.16.4 Water Release Assessment

The following sections detail EPA's water release assessment for use of TCE in commercial printing and copying.

2.16.4.1 Water Release Sources

A potential source of water releases from Printing/copying use would come from clean-out of printing equipment if the ink is water-based (OECD, 2010). Based on the use in printing/copying and the amount of TCE used for this OES, EPA expects minimal sources of TCE release to water.

2.16.4.2 Water Release Assessment Results

Water releases during use in printing and copying were assessed using data reported in the 2016 DMR. One site provided water releases. EPA assessed annual releases as reported in the 2016 DMR and assessed daily releases by assuming 250 days of operation per year. A summary of the water releases reported to the 2016 DMR can be found in Table 2-52.

Table 2-52. Reported Water Releases of Trichloroethylene from Commercial Printing and Copying

Site Identity	Annual Release (kg/site-yr)[a]	Annual Release Days (days/yr)	Daily Release (kg/site-day)[a]	NPDES Code	Release Media
Printing and Pub Sys Div, Weatherford, OK	0.05	250	2.0E-4	OK0041785	Surface Water

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

As only one site was identified with water releases for this OES, EPA acknowledges this site does not represent the entirety of commercial printing and copying sites using TCE. However, data was not reasonably available to estimate water releases from additional sites. Based on EPA models, releases from containers may be up to: 1) 0.3% to 0.6% for small containers (<20 gal) or drums that are emptied via pouring; or 2) 2.5% to 3% for drums emptied via pumping; however, not all sites are expected to dispose of container residues to water. Additional water release sources of TCE at these sites may exist and will vary depending on the use rate of the TCE-based products.

2.17 Other Commercial Uses

2.17.1 Estimates of Number of Facilities

EPA did not identify information to estimate the number of sites using TCE for other commercial uses. EPA did identify nine facilities in the 2016 DMR where EPA could not determine the OES or the use falls into a commercial use discussed in Section 2.17.2. However, due to the large variety of TCE-based products and uses of TCE, these nine sites are not expected to represent the entirety of sites using TCE in other commercial applications.

2.17.2 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 TCE may exist. Examples of these uses include, but are not limited to, mold cleaning, release, and protectant products, shoe polish, hoof polish, pepper spray, lace wig and hair extension glue, gun scrubber, and operation of nonresidential buildings. For many of these uses TCE is expected to act similar to a cleaning solvent used to remove dirt or other contaminates from substrates (e.g., mold cleaning, release and protectant products, shoe polish, hoof polish, and gun scrubber). However, TCE utilizes its adhesive properties when used as a component of lace wig and hair extension glue.

2.17.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for other commercial uses of TCE.

2.17.3.1 Worker Activities

The worker activity, use pattern, and associated exposure will vary for each OES. For polishes and gun scrubbers, EPA expects workers may be exposed to TCE vapors that evaporate from the application material (rag, brush, etc.) or the substrate surface during use. For lace wig and hair extension glue, workers may be exposed to TCE that evaporates from the application process or through absorption into the skin upon application of the lace wig or hair extensions.

2.17.3.2 Number of Potentially Exposed Workers

Table 2-53 summarizes SIC codes (and the corresponding NAICS codes) reported by the sites in the 2016 DMR (U.S. EPA, 2016a). EPA has not identified information on the number of sites and potentially exposed workers associated with these uses. The use of TCE for these conditions of use is expected to be minimal.

Table 2-53. Crosswalk of Other Industrial Use SIC Codes in DMR to NAICS Codes

SIC Code	Corresponding NAICS Code
6512 – Operation of Nonresidential Buildings	531120 - Lessors of Nonresidential Buildings (except Miniwarehouses)
9999 – Nonclassifiable Establishments	No NAICS listed in the crosswalk

SIC Code	Corresponding NAICS Code
1799 – Special Trade Contractors, NEC[a]	230000 - Construction
1794 – Excavation Work	238910 – Site Preparation Contractors

[a] The SIC code 1799 may map to any of the following NAICS codes: 236220, 237990, 238150, 238190, 238290, 238310, 238320, 238350, 238390, 238910, 561790, 562910. There is not enough information in the DMR data to determine the appropriate NAICS for each site; therefore, EPA uses data for the 2-digit NAICS, 230000, rather than a specific 6-digit NAICS.

EPA does not have data to estimate the total workers and ONUs exposed to TCE from other commercial uses as this information was not available in BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015).

2.17.3.3 Occupational Exposure Results

EPA did not identify any inhalation exposure monitoring data related to TCE use in other commercial uses. See Section 2.14.3 for the assessment of worker exposure during spot cleaning activities. EPA assumes the exposure sources, routes, and exposure levels are similar to those for spot cleaners.

2.17.4 Water Release Assessment

The following sections detail EPA's water release assessment for other commercial uses of TCE.

2.17.4.1 Water Release Sources

Specifics of the processes and potential sources of release for these uses are unknown. Based on the volatility of TCE, EPA expects the majority of TCE 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.

2.17.4.2 Water Release Assessment Results

Table 2-54 summarizes non-zero water releases from sites using TCE in other commercial uses reported in the 2016 DMR. To estimate the daily release for the sites in Table 2-54, EPA assumed a default of 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.

Table 2-54. Reported Water Releases of Trichloroethylene from Other Commercial Uses in the 2016 DMR

Site Identity	Annual Release (kg/site-yr)	Annual Release Days (days/yr)	Daily Release (kg/site-day)	NPDES Code	Release Media
Corning Hospital, Corning, NY	3.2	250	0.013	NY0246701	Surface Water
Water Street Commercial Bldg, Dayton, OH	0.7	250	2.8E-03	OH0141496	Surface Water
Union Station North Wing Office Building, Denver, CO	1.0E-01	250	4.0E-04	COG315293	Surface Water

Confluence Park Apartments, Denver, CO	7.1E-02	250	2.8E-04	COG315339	Surface Water
Park Place Mixed Use Development, Annapolis, MD	6.7E-02	250	2.7E-04	MD0068861	Surface Water
Tree Top Inc Wenatchee Plant, Wenatchee, WA	9.0E-03	250	3.6E-05	WA0051527	Surface Water
Wynkoop Denver LLCP St, Denver, CO	7.8E-03	250	3.1E-05	COG603115	Surface Water
Greer Family LLC, South Burlington, VT	1.3E-03	250	5.0E-06	VT0001376	Surface Water
John Marshall III Site, Mclean, VA	4.7E-04	250	1.9E-06	VA0090093	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, 2016a)

2.18 Process Solvent Recycling and Worker Handling of Wastes

2.18.1 Facility Estimates

To determine the number of sites that recycle/dispose of TCE, EPA considered 2016 TRI data, and 2016 DMR data. Based on the activities and NAICS codes reported in the 2016 TRI, EPA identified 28 facilities where the primary OES is expected to be disposal or recycling of TCE-containing wastes (U.S. EPA, 2017c). Two sites were identified for this OES in the 2016 DMR data. Based on the TRI and DMR data, EPA assesses a total of 30 sites for the disposal/recycling of TCE.

2.18.2 Process Description

Each of the conditions of use of TCE 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 OES assessment in Sections 2.1 through 2.17. Similarly, point source discharges of TCE to surface water are assessed in each OES assessment in Sections 2.1 through 2.17 (point source discharges are exempt as solid wastes under RCRA).Wastes of TCE that are generated during an OES and sent to a third-party site for treatment, disposal, or recycling may include the following:

- Wastewater: TCE may be contained in wastewater discharged to POTW or other, non-public treatment works for treatment. Industrial wastewater containing TCE 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 TCE is included in each of the OES assessments in Sections 2.1 through 2.17.

- 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.

- TCE is both a listed and a characteristic hazardous waste. TCE is a non-specific-source listed hazardous waste under waste numbers F001 (spent halogenated degreasing solvents) and F002 (spent halogenated solvents) (40 CFR § 261.31). TCE is also a specific-source listed hazardous waste under number K030 (Column bottoms or heavy ends from the combined production of trichloroethylene and perchloroethylene) (40 CFR § 261.32). Discarded, commercial-grade TCE is a listed hazardous waste under waste number U228 (40 CFR § 261.33).
- TCE is a toxic contaminant under RCRA with waste number D040. A solid waste can be a hazardous waste due to its toxicity characteristic if its extract following the Toxicity Characteristic Leaching Procedure (TCLP) (or the liquid waste itself if it contains less than 0.5% filterable solids) contains at least 0.5 mg/L of TCE (40 CFR § 261.24).

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

2016 TRI data lists off-site transfers of TCE to land disposal, wastewater treatment, incineration, and recycling facilities. About 68% of off-site transfers were incinerated, 26% is recycled off-site, 2% sent to land disposal, 1% sent to wastewater treatment, and about 3% is classified as “other” (U.S. EPA, 2017c). See Figure 2-20 for a general depiction of the waste disposal process.

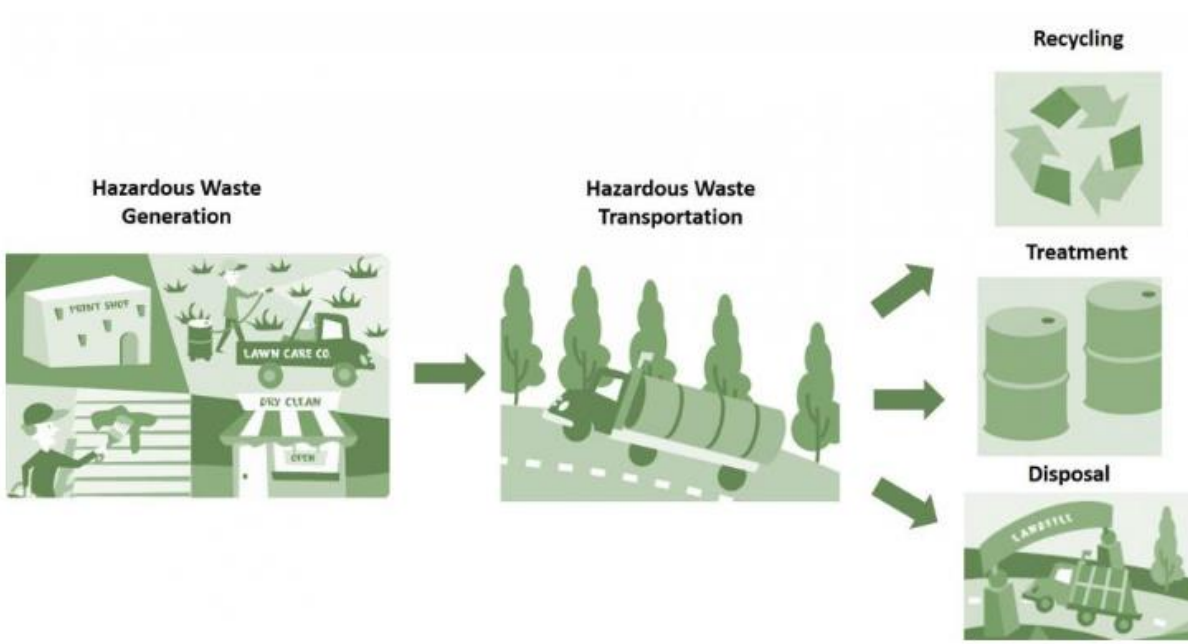

Figure 2-20. Typical Waste Disposal Process

Source: EPA, 2017 (https://www.epa.gov/hw/learn-basics-hazardous-waste)

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.[9]

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.[10,11]

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 (See Figure 2-21).

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.

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[9] J.B. Kitto, Eds., *Steam: Its Generation and Use*, 40th Edition, Babcock and Wilcox/American Boiler Manufacturers Association, 1992.
[10] Environmental Technology Council's Hazardous Waste Resource Center; http://www.etc.org/advanced-technologies/high-temperature-incineration.aspx
[11] *Incineration Services*; Heritage; https://www.heritage-enviro.com/services/incineration/

In incineration, complete combustion is necessary to prevent phosgene formation and acid scrubbers must be used to remove any haloacids produced (ATSDR, 2014).

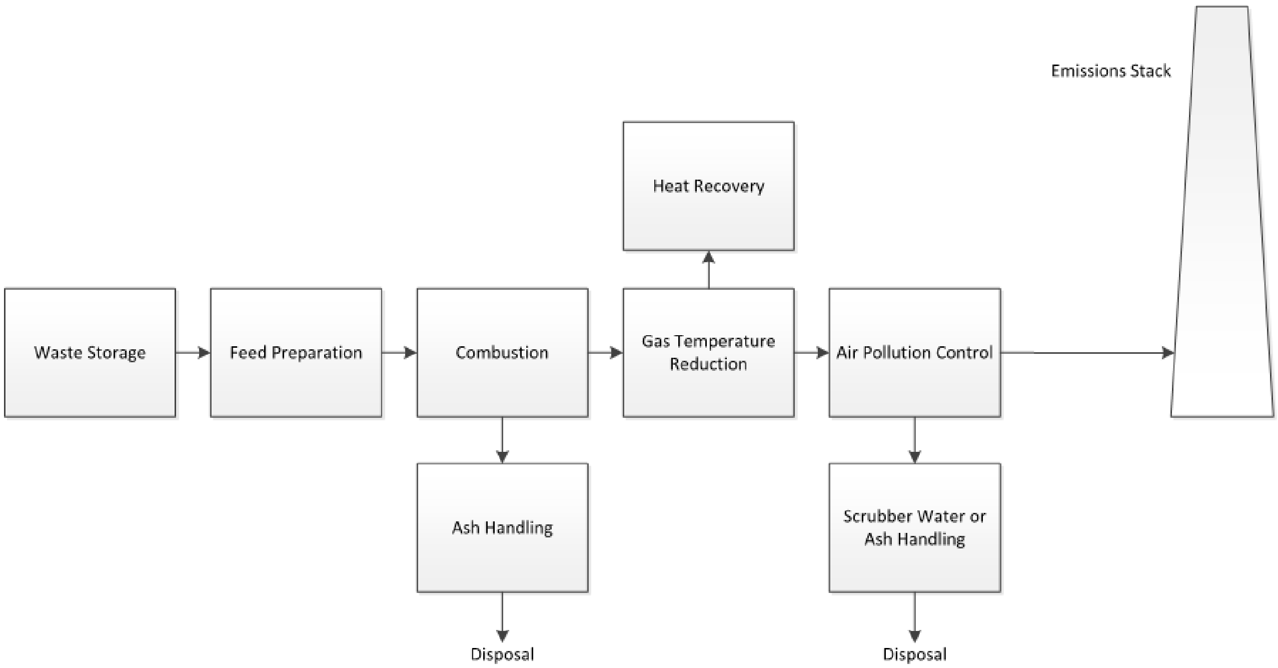

Figure 2-21.Typical Industrial Incineration Process

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 states 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[12]. 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

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

standards and requirements prevent potential contamination of groundwater and nearby surface water resources. Hazardous waste landfills are regulated under Part 264/265, Subpart N.

TCE is listed as a hazardous waste under RCRA and federal regulations prevent land disposal of various chlorinated solvents that may contain TCE (ATSDR, 2014). TCE may be disposed of by absorption in vermiculite, dry sand, earth, or other similar material and then buried in a secured sanitary landfill or incinerated (NIH, 2012).

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 2-22 illustrates a typical solvent recovery process flow diagram (U.S. EPA, 1980).

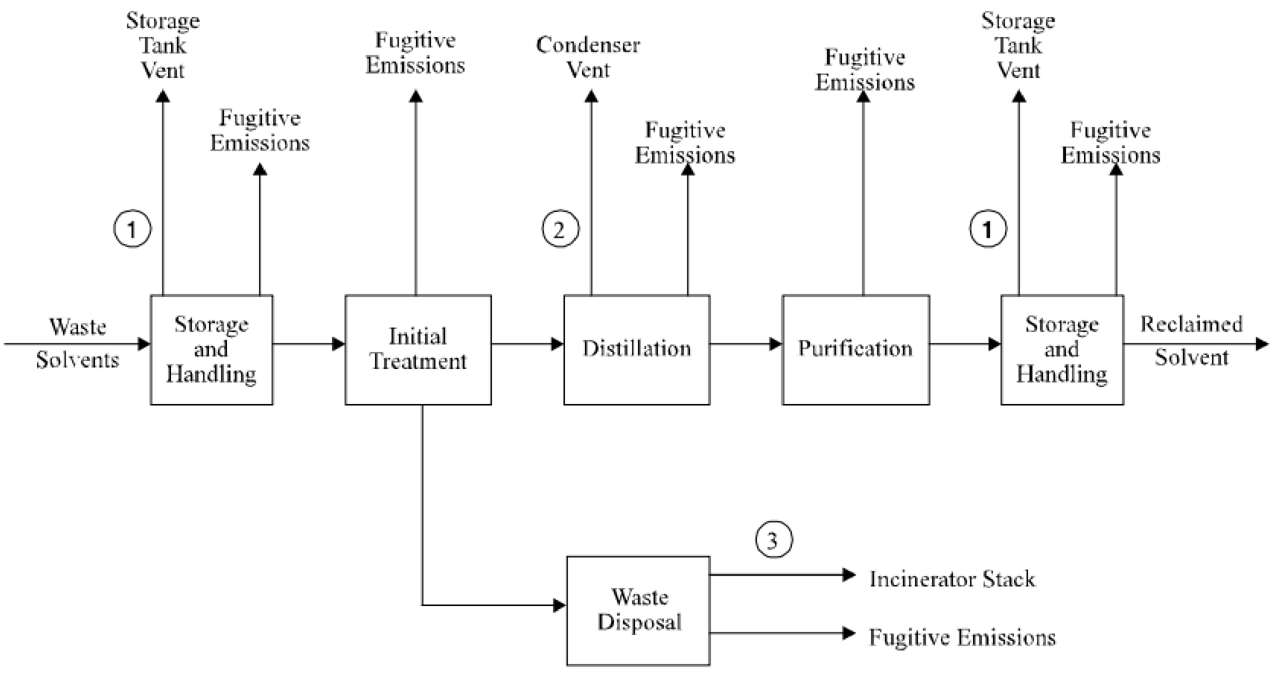

Figure 2-22. General Process Flow Diagram for Solvent Recovery Processes (U.S. EPA, 1980)

2.18.3 Exposure Assessment

The following sections detail EPA's occupational exposure assessment for disposal/recycling of TCE wastes.

2.18.3.1 Worker Activities

At waste disposal sites, workers are potentially exposed via inhalation of TCE vapor. Depending on the concentration of TCE in the waste stream, the route and level of exposure may be similar to that associated with container unloading activities. See Section 2.4.3 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[13].

2.18.3.2 Number of Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed during use of TCE during recycling and waste handling using BLS Data (U.S. BLS, 2016) and the U.S. Census' SUSB (U.S. Census Bureau, 2015) as well as the NAICS codes reported by the sites in the 2016 TRI (U.S. EPA, 2017c) . There were two discernable recycling and waste handling sites in the 2016 DMR data (U.S. EPA, 2016a). These sites did not report a relevant SIC/NAICS code,but based on research of the site and/or company, both were determined to be Recycling/Waste Handling sites. To estimate the number of workers, both sites were grouped under NAICS code 562211. 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. Table 2-55 provides the results of the number of worker analysis. There are approximately 380 workers and 140 ONUs potentially exposed during use of TCE during recycling/waste disposal.

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

Table 2-55. Estimated Number of Workers Potentially Exposed to Trichloroethylene During Recycling/Waste Handling

NAICS Code	Number of Sites	Total Exposed Workers	Total Exposed Occupational Non-Users	Total Exposed[b]	Exposed Workers per Site[a]	Exposed Occupational Non-Users per Site[a]
562211	19	171	98	269	9	5
562920	1	2	2	4	2	2
562213	1	13	8	21	13	8
327310	9	196	30	226	22	3
Total[c]	30	380	140	520	13	5

[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. [b] Totals may not add exactly due to rounding.
[c] Values rounded to two significant figures.
Sources: (U.S. EPA, 2017c) and (U.S. EPA, 2016a)

2.18.3.3 Occupational Exposure Results

EPA did not identify any inhalation exposure monitoring data related to waste handling/recycling. See Section 2.4.3 for the assessment of worker exposure from chemical unloading activities. EPA assumes the exposure sources, routes, and exposure levels are similar to those at a repackaging facility.

2.18.4 Water Release Assessment

The following sections detail EPA's water release assessment for disposal/treatment of TCE wastes.

2.18.4.1 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.

2.18.4.2 Water Release Assessment Results

EPA assessed water releases using the values reported to the 2016 TRI and DMR by the 30 disposal/recycling sites. In the 2016 TRI, three of sites reported non-zero indirect discharges to off-site wastewater treatment; one site reported discharges to both off-site wastewater treatment as well as discharge to a POTW. All sites in TRI for this OES reported zero direct discharges to surface water.

To estimate the daily release, EPA used a default assumption of 250 days/yr of operation as and averaged the annual release over the operating days. Table 2-56 summarizes the water releases from the 2016 DMR and 2016 TRI for sites with non-zero discharges.

Table 2-56. Estimated Water Releases of Trichloroethylene from Disposal/Recycling of TCE

Site Identity	Annual Release	Annual Release Days (days/yr)	Daily Release (kg/site-day)[a]	NPDES Code	Release Media

	(kg/site-yr)[a]				
Veolia Es Technical Solutions LLC, Middlesex, NJ	6035	250	24.1	Not available	POTW WWT (0.02%) and Non-POTW WWT (99.98%)
Clean Harbors Deer Park LLC, La Porte, TX	87.1	250	0.3	TX0005941	Non-POTW WWT
Clean Harbors El Dorado LLC, El Dorado, AR	9.1	250	0.04	AR0037800	Non-POTW WWT
Clean Water Of New York Inc, Staten Island, NY	0.9	250	3.8E-03	NY0200484	Surface Water
Reserve Environmental Services, Ashtabula, OH	3.9E-04	250	1.6E-06	OH0098540	Surface Water

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 250 days of operation per year.
Sources: (U.S. EPA, 2017c) and (U.S. EPA, 2016a)

2.19 Dermal Exposure Assessment

EPA estimated workers' dermal exposure to TCE for the industrial and commercial use scenarios considering evaporation of liquid from the surface of the hands and conditions of use with and without gloves. The OSHA recommends employers utilize the hierarchy of controls for reducing or removing hazardous exposures. The most effective controls are elimination, substitution, or engineering controls. Gloves are the last course of worker protection in the hierarchy of controls and should only be considered when process design and engineering controls cannot reduce workplace exposure to an acceptable level.

Vapor absorption during dermal exposure requires that TCE be capable of achieving a sufficient concentration in the media at the temperature and atmospheric pressure of the scenario under evaluation to provide a significant driving force for skin penetration. Because TCE is a volatile liquid (VP = 73.46 mmHg and 25℃), the dermal absorption of TCE depends on the type and duration of exposure. Where exposure is not occluded, only a fraction of TCE that comes into contact with the skin will be absorbed as the chemical readily evaporates from the skin. 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 TCE liquids trapped inside the gloves, inhibiting the evaporation of TCE and increasing the exposure duration. See Appendix E for more information about occlusion and the incorporation of gloves in the dermal exposure assessment. EPA collected and reviewed reasonably available SDSs (Safety Data Sheets) to inform the evaluation of gloves used with TCE in liquid and aerosol form at varying concentrations.

Trichloroethylene in liquid form at 99-100% concentration is expected to be used in both industrial and commercial settings. For industrial scenarios using this form of TCE, the following Conditions of Use are expected; Manufacture of TCE, Processing as a Reactant, Industrial Processing Aid, Formulation of Aerosol and Non Aerosol Products, Repackaging, Process Solvent Recycling, Batch Open Top Vapor Degreasing, Batch Closed-Loop Vapor Degreasing, Conveyorized Vapor Degreasing, and Web Vapor Degreasing. For trichlorethylene in liquid form at 99-100% concentration an SDS from Mallinckrodt

Baker Inc. recommended neoprene gloves and an SDS from Solvents Australia PTY. LTD. recommended the use of gloves made from rubber, PVC, or nitrile (U.S. EPA, 2017b). Commercial conditions of use where TCE in liquid form at 99-100% concentration is expected includes Spot Cleaning, Wipe Cleaning, and Carpet Cleaning. An SDS for an R.R. Street & Co. cleaning agent recommended wearing Viton ® [Butyl-rubber], PVA, or Barrier ™ gloves. Two gun wipe cleaning agent manufacturers A.V.W. Inc. and G.B. Distributors recommend Viton or Neoprene gloves and polyethylene, neoprene, or PVA gloves, respectively (U.S. EPA, 2017b).

For Aerosol Degreasing and Aerosol Lubricants applications, TCE is used in a range of concentrations in aerosol form. An SDS for a 90-100% TCE aerosol degreasing agent from Brownells, Inc. recommended using PVA gloves and an SDS for a 45-55% TCE aerosol brake parts cleaner from Zep Manufacturing Co. recommended using Viton® gloves (U.S. EPA, 2017b).

Metalworking Fluids and Adhesives, Sealants, Paints, and Coatings typically contain a maximum TCE concentration of 80-90%. An SDS from LPS Laboratories presented a tap and die fluid at 80-90% TCE concentration and recommended using Viton® [Butyl-rubber], Silver Shield®[PE and EVOH laminate] and PVA gloves. An SDS for a 75-90% TCE adhesive from Rema Tip Top recommended using Neoprene, Butyl-rubber, or nitrile rubber (U.S. EPA, 2017b).

EPA did not find any SDSs with applicable use towards commercial printing and copying applications.

To assess exposure, EPA used the *Dermal Exposure to Volatile Liquids* Model (see **Equation 1**) to calculate the dermal retained dose for both non-occluded and occluded scenarios. The equation modifies the *EPA 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 in occupational settings. Default PF values, which vary depending on the type of glove used and the presence of employee training program, are shown in Table 2-57:

Equation 1. Dermal Dose Equation

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

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 TCE: 0.08 for industrial facilities and 0.13 for commercial facilities)
PF is the glove protection factor (Default: see Table 2-57)

The steady state fractional absorption (f_{abs}) for TCE is estimated to be 0.08 in industrial facilities with higher indoor wind flows or 0.13 in commercial facilities with lower indoor wind speeds based on a theoretical framework provided by Kasting and Miller (2006) (Kasting and Miller, 2006), meaning approximately 8 or 13 percent of the applied dose is absorbed through the skin following exposure, from industrial and commercial settings, respectively. However, there is a large standard deviation in the experimental measurement, which is indicative of the difficulty in spreading a small, rapidly evaporating dose of TCE evenly over the skin surface.

Table 2-57. 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 2-58 presents the estimated dermal retained dose for workers in various exposure scenarios. The dose estimates assume one exposure event (applied dose) per work day and that approximately eight to thirteen percent[14] of the applied dose is absorbed through the skin. Table 2-58 also includes estimated dermal retained dose for occluded scenarios for conditions of use where EPA determined occlusion was reasonably expected to occur. Occluded scenarios are generally expected where workers are expected to come into contact with bulk liquid TCE during use in open systems (e.g., during solvent changeout in vapor degreasing) and not expected in closed-type systems (e.g., during connection/ disconnection of hoses used in loading of bulk containers in manufacturing). See discussion on occlusion in Appendix H.7 for further description of these scenarios. The exposure estimates are provided for each OES, where the conditions of use are "binned" based on the maximum possible exposure concentration (Y_{derm}), the likely level of exposure, and potential for occlusion. The exposure concentration is determined based on EPA's review of currently available products and formulations containing TCE. For example, EPA found that TCE concentration in degreasing formulations such as C-60 Solvent Degreaser can be as high as 100 percent.

To streamline the dermal exposure assessment, the conditions of use were grouped based on characteristics known to effect dermal exposure such as the maximum weight fraction of TCE could be present in that OES, open or closed system use of TCE, and large or small-scale use. Four different groups or "bins" were created to group conditions of use based on this analysis.

- **Bin 1** covers industrial uses that generally occur in closed systems. For these uses, dermal exposure is likely limited to chemical loading/unloading activities (e.g. connecting hoses) and taking quality control samples. EPA assesses the following glove use scenarios for Bin 1 conditions of use:

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

  - 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.
  - Scenarios not assessed: EPA does not assess occlusion as workers in these industries are not likely to come into contact with bulk liquid TCE that could lead to chemical permeation under the cuff of the glove or excessive liquid contact time leading to chemical permeation through the glove.
- **Bin 2** covers industrial degreasing uses, which are not closed systems. For these uses, there is greater opportunity for dermal exposure during activities such as charging and draining degreasing equipment, drumming waste solvent, and removing waste sludge. 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 equipment, drumming waste solvent, and removing waste sludge. EPA assumes gloves may offer a range of protection, depending on the type of glove and employee training provided.
  - Occluded Exposure: Occlusion may occur when workers are handling bulk liquid TCE when charging and draining degreasing equipment, drumming waste solvent, and removing waste sludge that could lead to chemical permeation under the cuff of the glove or excessive liquid contact time leading to chemical permeation through the glove.
- **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 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. EPA does not assess occlusion for aerosol applications because TCE formulations are often supplied in an aerosol spray can and contact with bulk liquid is unlikely. EPA also does not assess occlusion for non-aerosol niche uses because the potential for occlusion is unknown

- **Bin 4** covers commercial activities of similar maximum concentration. Most of these uses are uses as spot cleaners or in wipe cleaning, and/or uses expected to have direct dermal contact with bulk liquids. 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.
    - Occluded Exposure: Occlusion may occur when workers are handling bulk liquid TCE when charging and draining solvent to/from machines, removing and disposing sludge, and maintaining equipment that could lead to chemical permeation under the cuff of the glove or excessive liquid contact time leading to chemical permeation through the glove.
    - 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.

As shown in Table 2-58, the calculated absorbed dose is low for all non-occluded scenarios as TCE evaporates quickly after exposure. Dermal exposure to liquid is not expected for occupational non-users, as they do not directly handle TCE.

Table 2-58. Estimated Dermal Absorbed Dose (mg/day) for Workers in All Conditions of Use

Occupational Exposure Scenario	Bin	Max Y_{derm}	Non-Occluded Exposure				Occluded Exposure
			No Gloves (PF = 1)	Protective Gloves (PF = 5)	Protective Gloves (PF = 10)	Protective Gloves (Industrial uses, PF = 20)	
Manufacturing	Bin 1	1.0	184.36	36.87	18.44	9.22	N/A – occlusion not expected
Processing as a Reactant		1.0	184.36	36.87	18.44	9.22	
Formulation of Aerosol and Non-Aerosol Products		1.0	184.36	36.87	18.44	9.22	
Repackaging		1.0	184.36	36.87	18.44	9.22	
Other Industrial Uses		1.0	184.36	36.87	18.44	9.22	
Industrial Processing Aid		1.0	184.36	36.87	18.44	9.22	
Process Solvent Recycling and Worker Handling of Wastes		1.0	184.36	36.87	18.44	9.22	
Batch Open Top Vapor Degreasing	Bin 2	1.0	184.36	36.87	18.44	9.22	2,247
Batch Closed-Loop Vapor Degreasing		1.0	184.36	36.87	18.44	9.22	2,247
Conveyorized Vapor Degreasing		1.0	184.36	36.87	18.44	9.22	2,247
Web Vapor Degreasing		1.0	184.36	36.87	18.44	9.22	2,247
Cold Cleaning		1.0	184.36	36.87	18.44	9.22	2.247
Aerosol Applications: Spray Degreasing/Cleaning, Automotive Brake and Parts Cleaners, Penetrating Lubricants, and Mold Releases	Bin 3	1.0	184.36	36.87	18.44	Not Assessed	N/A – occlusion not expected

Occupational Exposure Scenario	Bin	Max Y_{derm}	Non-Occluded Exposure				Occluded Exposure
			No Gloves (PF = 1)	Protective Gloves (PF = 5)	Protective Gloves (PF = 10)	Protective Gloves (Industrial uses, PF = 20)	
Adhesives, Sealants, Paints, and Coatings (Industrial)		0.9	165.92	33.18	16.59		
Adhesives, Sealants, Paints, and Coatings (Commercial)		0.9	260.50	52.10	26.05		
Metalworking Fluids	Bin 4	0.8	147.49	29.50	14.75	Not Assessed	1,798
Spot Cleaning		1.0	289.44	57.89	28.94		2,247
Wipe Cleaning		1.0	289.44	57.89	28.94		2,247
Carpet Cleaning		1.0	289.44	57.89	28.94		2,247
Commercial Printing and Copying		0.35	101.30	20.26	10.13		786
Other Commercial Uses		1.0	289.44	57.89	28.94		2,247

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 reasonably available.

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). 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 TCE, as outlined below. Most are unlikely to result in a systematic underestimate or overestimate, but could result in an inaccurate estimate.

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 TCE. Manufacturers and importers are only required to report if they manufactured or imported TCE in excess of 25,000 pounds at a single site during any calendar; as such, CDR may not capture all sites and workers associated with any given chemical.

There are also uncertainties with BLS data, which are used to estimate the number of workers for the remaining conditions of use. First, BLS Data 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 TCE for the assessed applications. 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 TCE 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 TCE 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

This report uses existing worker exposure monitoring data to assess exposure to TCE during several conditions of use. To analyze the exposure data, EPA categorized each PBZ data point 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 TCE are categorized as "worker" and samples for employees that are expected to have the lower exposure and do not directly handle TCE 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 TCE 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. Also, there is uncertainty in the ONU risk estimates since in some instances the data or modeling used worker exposure estimates where no data or models were reasonably available for ONU exposure estimates.

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. Similarly, OSHA CEHD are obtained from OSHA inspections, which may be the result of worker complaints, and may provide exposure results that may generally exceed the industry average.

Some scenarios have limited exposure monitoring data in literature, if any. Where there are few data points reasonably available, it is unlikely the results will be representative of worker exposure across the industry. 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 that the results will be fully representative of worker exposure across different conditions of use.

Where sufficient data were reasonably available, the 95th and 50th percentile exposure concentrations were calculated using reasonably available data. The 95th percentile exposure concentration is intended to represent a high-end exposure level, while the 50th percentile exposure concentration represents typical exposure level. The underlying distribution of the data, and the representativeness of the data, are not known. Where discrete data was not reasonably 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.

EPA calculated ADC and LADC values assuming workers and ONUs are regularly exposed during their entire working lifetime, which likely results in an overestimate. Individuals may change jobs during the course of their career such that they are no longer exposed to TCE, and that actual ADC and LADC values become lower than the estimates presented.

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 reasonably 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. 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 TCE applications (e.g. vapor degreasing and cold cleaning), TCE 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 TCE OES. 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 Vapor Degreasing and Cold Cleaning Models

The OTVD, conveyorized vapor 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 eight 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 TCE in air.

3.2.3.2 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 degreasing applications involving TCE.
- The TCE Use Dossier (U.S. EPA, 2017b) presented 16 different aerosol degreasing formulations containing TCE. For each Monte Carlo iteration, the model determines the TCE concentration in product by selecting one of 16 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 TCE Use Dossier (U.S. EPA, 2017b) were provided as ranges. For each Monte Carlo iteration the model selects a TCE concentration within the range of concentrations using a uniform distribution. In reality, the TCE concentration in the formulation may be more consistent than the range provided.

3.2.3.3 Spot Cleaning Model

The multi-zone spot cleaning model also uses a near-field/far-field approach. Specific uncertainties associated with the spot cleaning scenario are presented below:

- The model assumes a use rate based on estimates of the amount of TCE-based spot cleaner sold in California and the number of textile cleaning facilities in California (IRTA, 2007). It is uncertain if this distribution is representative of other geographic locations in the U.S.
- The model assumes a facility floor area based on data from (CARB, 2006) and King County (Whittaker and Johanson, 2011). It is unknown how representative the area is of "typical" spot cleaning facilities. Therefore, these assumptions may result in an overestimate or underestimate of worker exposure during spot cleaning.
- Many of the model input parameters were obtained from (Von Grote et al., 2003), which is a German study. Aspects of the U.S. spot cleaning facilities may differ from German facilities. However, it is not known whether the use of German data will under- or over-estimate exposure.

3.2.4 Modeled Dermal Exposures

The *Dermal Exposure to Volatile Liquids Model* is used to estimate dermal exposure to TCE 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.

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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 TCE 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 OES.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics data (U.S. BLS, 2016).
3. Refine the BLS OES Occupational Employment Statistics estimates where they are not sufficiently granular by using the U.S. Census' (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 TCE instead of other chemicals (i.e., the market penetration of TCE in the OES).
5. Estimate the number of sites and number of potentially exposed employees per site.
6. Estimate the number of potentially exposed employees within the OES.

Step 1: Identifying Affected NAICS Codes

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

- Querying the U.S. Census Bureau's *NAICS Search* tool using keywords associated with each OES to identify NAICS codes with descriptions that match the OES.
- Referencing EPA Generic Scenarios (GS's) and Organisation for Economic Co-operation and Development (OECD) Emission Scenario Documents (ESDs) for an OES 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 OES section in the main body of this report identifies the NAICS codes EPA identified for the respective OES.

Step 2: Estimating Total Employment by Industry and Occupation

BLS's (U.S. BLS, 2016) Occupational Employment Statistics 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 TCE. Table A-1 shows the SOC codes EPA classified as occupations potentially exposed to TCE. 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 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 OES. Table A-2 summarizes the SOC codes with worker and ONU designations used for dry cleaning facilities.

Table 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

SOC	Occupation	Designation
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's (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 TCE 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 A-3 illustrates this granularity adjustment for NAICS 812320.

Table 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 TCE 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 TCE may be only one of multiple chemicals used for the applications of interest. EPA did not identify market penetration data any conditions of use. In the absence of market penetration data for a given OES, EPA assumed TCE 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 OES 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's SUSB (U.S. Census Bureau, 2015) 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 OES

EPA estimated the number of workers and occupational non-users potentially exposed to TCE and the number of sites that use TCE in a given OES through the following steps:

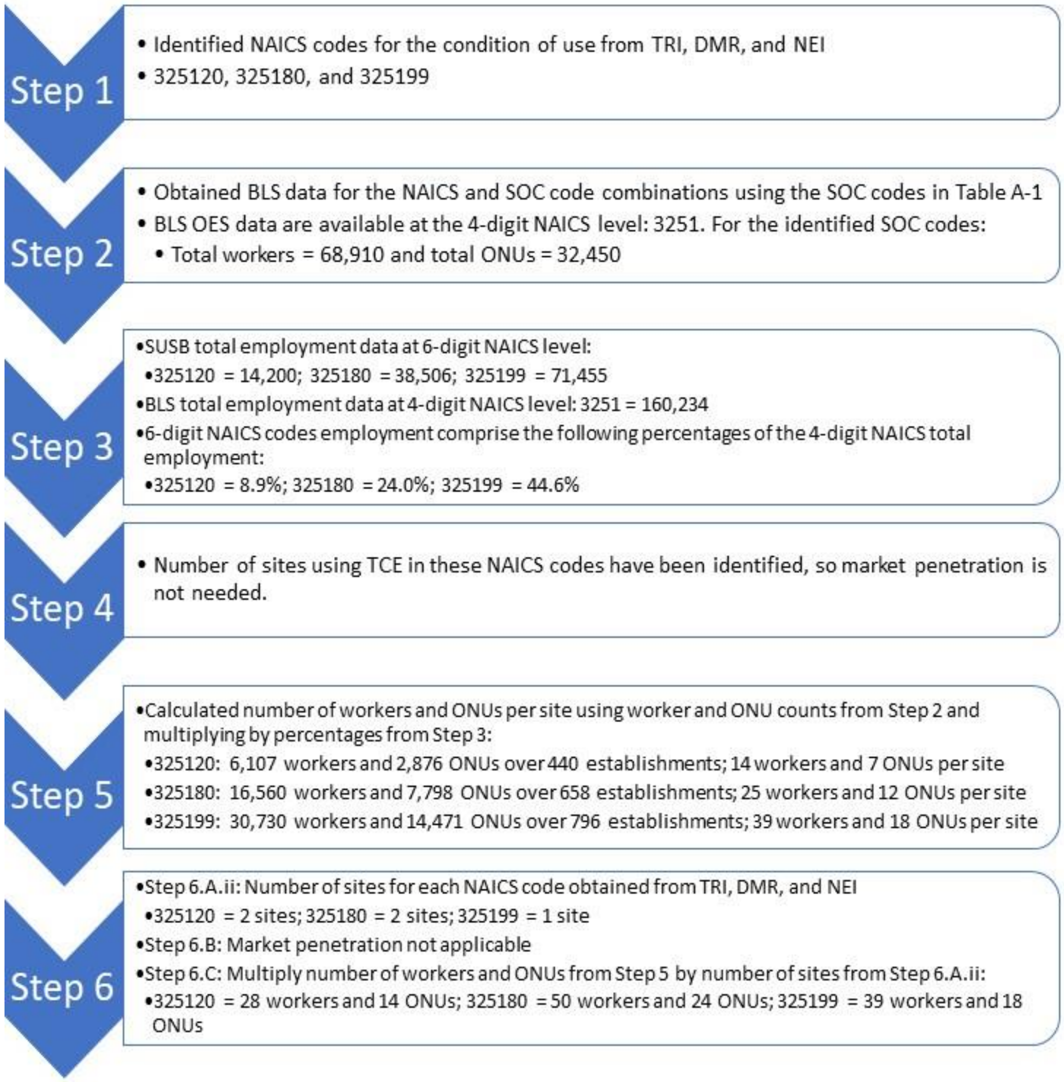
6.A. Obtaining the total number of establishments by:
   i. Obtaining the number of establishments from SUSB (U.S. Census Bureau, 2015) at the 6-digit NAICS level (Step 5) for each NAICS code in the OES and summing these values; or
   ii. Obtaining the number of establishments from the Toxics Release Inventory (TRI), Discharge Monitoring Report (DMR) data, National Emissions Inventory (NEI), or literature for the OES.

6.B. Estimating the number of establishments that use TCE 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 TCE 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.

Figure A-1 presents a graphical example of the steps followed to determine the number of workers for the Processing as a Reactant OES.

Figure A-1. Graphical Example for the Approach for Estimating Number of Workers and Occupational Non-Users



Appendix B Equations for Calculating Acute and Chronic (Non-Cancer and Cancer) Inhalation Exposures

This report assesses TCE 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 B-1.

Equation 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 B-2

$$\text{ADC or LADC} = \frac{\text{C} \times \text{ED} \times \text{EF} \times \text{WY}}{\text{AT or AT}_\text{c}}$$

Equation B-3

$$\text{AT} = \text{WY} \times 365\frac{\text{day}}{\text{yr}} \times 24\frac{\text{hr}}{\text{day}}$$

Equation B-4

$$\text{AT}_\text{C} = \text{LT} \times 365\frac{\text{day}}{\text{yr}} \times 24\frac{\text{hr}}{\text{day}}$$

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 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 B-1. Parameter Values for Calculating Inhalation Exposure Estimates

Parameter Name	Symbol	Value	Unit
Exposure Duration	ED	8 or 24	hr/day
Exposure Frequency	EF	250	days/yr
Working years	WY	31 (50^{th} percentile) 40 (95^{th} 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 50^{th} percentile value for working years (WY)
[b] Calculated using the 95^{th} percentile value for working years (WY)

<u>Exposure Duration (ED)</u>

EPA generally uses an exposure duration of 8 hours per day for averaging full-shift exposures with an exception of spot-cleaning. Operating hours for spot cleaning were assessed a 2 to 5 hours/day.

<u>Exposure Frequency (EF)</u>

EPA generally uses an exposure frequency of 250 days per year with the following exception: spot cleaning. EPA assumed spot 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 249 at the 50^{th} percentile and 313 at the 95^{th} percentile.

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 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)

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 TCE-specific data, EPA assumes the parameter *f* is equal to one for all conditions of use.

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 BLS (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' (U.S. Census Bureau, 2019) 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, 2019). 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, 2019). 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.[15] 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 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 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

[15] 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
Manufacturing sectors (NAICS 31-33)	35.7	36	39	40
Non-manufacturing sectors (NAICS 42-81)	36.1	36	39	44

Source: Census Bureau, 2016a.
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 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 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 exposure concentrations for one setting, Manufacturing, are demonstrated below. The explanation of the equations and parameters used is provided in Appendix B. The final values will have two significant figures since they are based on values from modeling.

C.1 Example High-End AC, ADC, and LADC

Calculate AC_{HE}:

$$AC_{HE} = \frac{C_{HE} \times ED}{AT_{acute}}$$

$$AC_{HE} = \frac{2.6\ ppm \times 8\ hr/day}{24\ hr/day} = 0.87\ ppm$$

Calculate ADC_{HE}:

$$\boldsymbol{ADC_{HE} = \frac{C_{HE} \times ED \times EF \times EWY}{AT}}$$

$$\boldsymbol{ADC_{HE} = \frac{2.6\ ppm \times 8\frac{hr}{day} \times 250\frac{days}{year} \times 40\ years}{\left(40\ years \times 365\frac{days}{year} \times 24\frac{hours}{day}\right)} = 0.59\ ppm}$$

Calculate $LADC_{HE}$:

$$\boldsymbol{LADC_{HE} = \frac{C_{HE} \times ED \times EF \times EWY}{AT_{LADC}}}$$

$$\boldsymbol{LADC_{HE} = \frac{2.6\ ppm \times 8\frac{hr}{day} \times 250\frac{days}{year} \times 40\ years}{\left(78\ years \times 365\frac{days}{year} \times 24\frac{hours}{day}\right)} = 0.30\ ppm}$$

C.2 Example Central Tendency AEC, ADC, and LADC

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 $LADC_{CT}$:

$$LADC_{CT} = \frac{C_{CT} \times ED \times EF \times WY}{AT_c}$$

$$\boldsymbol{LADC_{CT} = \frac{0.03\ ppm \times 8 \frac{hr}{day} \times 250 \frac{days}{year} \times 31\ years}{78\ years \times 365 \frac{days}{year} \times 24\ hr/day} = 2.8 \times 10^{-3}\ ppm}$$

Appendix D Approach for Estimating Water Releases from Manufacturing Sites Using Effluent Guidelines

This appendix presents a methodology for estimating water releases of TCE 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, 2019g). 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 TCE 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 TCE 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, 2019g). 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 TCE in each of the Subparts are provided in Table D-1.

Table D-1. Summary of OCPSF Effluent Guidelines for Trichloroethylene

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	54	21	BAT effluent limitations and NSPS
Subpart J – Direct Discharge Point Sources That Do Not Use End-of-Pipe Biological Treatment	69	26	BAT effluent limitations and NSPS
Subpart K – Indirect Discharge Point Sources	69	26	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, 2019g)

To estimate daily releases from the EG, EPA used Equation D-1 to estimate daily releases and Equation D-2 to estimate annual releases using the parameters in Table 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 (26 g/L) from Subparts J and K, a high-end daily release using the limit for the maximum for any one day (69 g/L) from Subparts J and K, and an annual release using the maximum monthly average from Subparts J and K.

Equation D-1

$$DR = \frac{DL \times PW \times PV}{1{,}000{,}000{,}000 \times OD}$$

Equation D-2

$$AR = \frac{DL \times PW \times PV}{1{,}000{,}000{,}000}$$

Table D-2. Default Parameters for Estimating Water Releases of Trichloroethylene 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: 69 Average Daily: 26 Annual: 26	µg/L
PW	Produced water[b]	10	L/kg
PV	Annual TCE 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 TCE 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 (ESIG, 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 TCE-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) (ESIG, 2012). In lieu of TCE-specific information, EPA estimated wastewater flow using the SpERC specified wastewater production volume and the annual TCE production rates for each facility. Table D-3 provides estimated daily production volume and wastewater flow for each facility that EPA used the EG to assess water releases.

Table D-3. Summary of Facility Trichloroethylene 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)
Solvents & Chemicals, Pearland, TX[a]	20,382,094	350	58,234	582,345
Occidental Chemical Corp. Wichata, KS[a]	20,382,094	350	58,234	582,345

[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 TCE for maximum on any one day and maximum for any monthly average, respectively. Prevalence of end-of-pipe biological treatment at TCE 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 TCE at manufacturing sites based on the estimated production volume for Solvents & Chemicals (44,934,862 lbs/yr or 20,382,094 kg/yr)[16]:

$$Max\ DR = \frac{69\frac{\mu g}{L} \times 10\frac{L}{kg} \times 20{,}382{,}094\frac{kg}{yr}}{1{,}000{,}000{,}000\frac{\mu g}{kg} \times 350\frac{days}{yr}} = 0.04\frac{kg}{day}$$

$$Average\ DR = \frac{26\frac{\mu g}{L} \times 10\frac{L}{kg} \times 20{,}382{,}094\frac{kg}{yr}}{1{,}000{,}000{,}000\frac{\mu g}{kg} \times 350\frac{days}{yr}} = 0.015\ \frac{kg}{day}$$

$$AR = \frac{26\frac{\mu g}{L} \times 10\frac{L}{kg} \times 20{,}382{,}094\frac{kg}{yr}}{1{,}000{,}000{,}000\frac{\mu g}{kg}} = 5.3\frac{kg}{yr}$$

16 This estimated production volume is equal to the estimated production volume assessed for all manufacturing sites.

Appendix E 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:

- Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model;
- 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 TCE 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 reasonably 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.

E.1 Model Design Equations

Figure E-1. The Near-Field/Far-Field Model as Applied to the Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model and the Cold Cleaning Near-Field/Far-Field Inhalation

Exposure Model Figure E-1 through Figure E-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 TCE vapors evaporate into the near-field, resulting in worker exposures at a TCE concentration C_{NF}. The concentration is directly proportional to the evaporation rate of TCE, 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 TCE dissipates into the far-field, resulting in occupational non-user exposures to TCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the TCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly TCE dissipates out of the surrounding space and into the outside air.

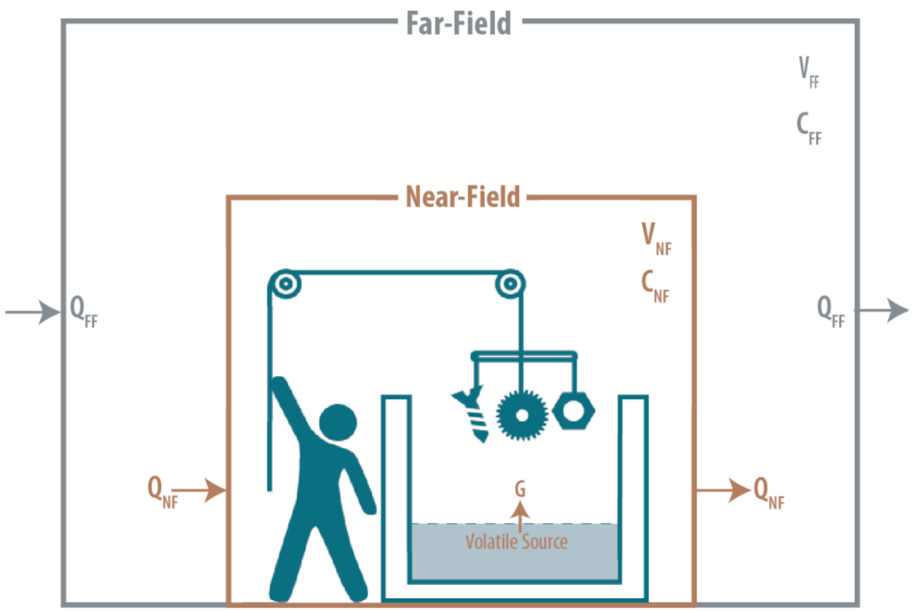


Figure E-1. The Near-Field/Far-Field Model as Applied to the Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model and the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model

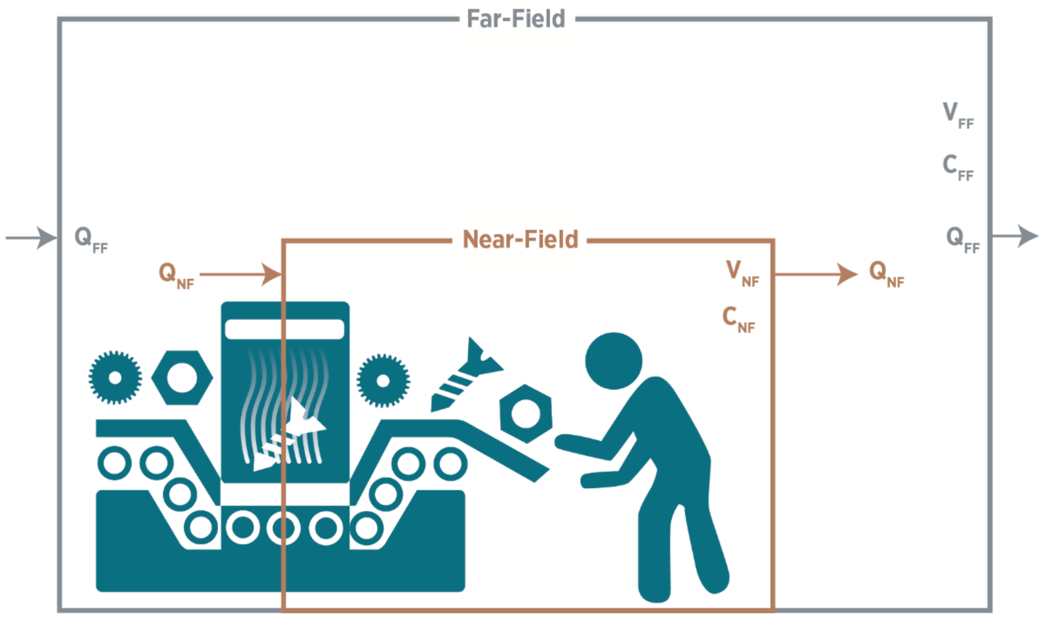


Figure E-2. The Near-Field/Far-Field Model as Applied to the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model

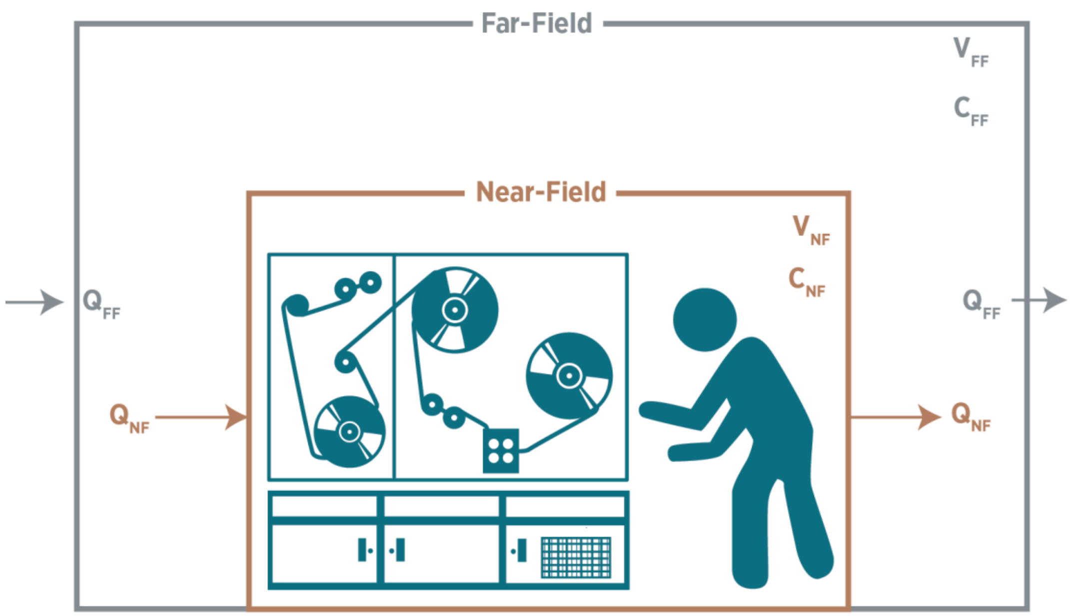


Figure E-3. The Near-Field/Far-Field Model as Applied to the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model

The model design equations are presented below in Equation G-1 through Equation G-. Note the design equations are the same for each of the models discussed in this appendix.

Near-Field Mass Balance

Equation E-3

$$V_{NF}\frac{dC_{NF}}{dt} = C_{FF}Q_{NF} - C_{NF}Q_{NF} + G$$

Far-Field Mass Balance

Equation E-4

$$V_{FF}\frac{dC_{FF}}{dt} = C_{NF}Q_{NF} - C_{FF}Q_{NF} - C_{FF}Q_{FF}$$

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 E-5

$$C_{NF} = G\left(k_1 + k_2 e^{\lambda_1 t} - k_3 e^{\lambda_2 t}\right)$$

Equation E-6

$$C_{FF} = G\left(\frac{1}{Q_{FF}} + k_4 e^{\lambda_1 t} - k_5 e^{\lambda_2 t}\right)$$

Where:

Equation E-7

$$k_1 = \frac{1}{\left(\frac{Q_{NF}}{Q_{NF} + Q_{FF}}\right) Q_{FF}}$$

Equation E-8

$$k_2 = \frac{Q_{NF}Q_{FF} + \lambda_2 V_{NF}(Q_{NF} + Q_{FF})}{Q_{NF}Q_{FF}V_{NF}(\lambda_1 - \lambda_2)}$$

Equation E-9

$$k_3 = \frac{Q_{NF}Q_{FF} + \lambda_1 V_{NF}(Q_{NF} + Q_{FF})}{Q_{NF}Q_{FF}V_{NF}(\lambda_1 - \lambda_2)}$$

Equation E-10

$$k_4 = \left(\frac{\lambda_1 V_{NF} + Q_{NF}}{Q_{NF}}\right) k_2$$

Equation E-11

$$k_5 = \left(\frac{\lambda_2 V_{NF} + Q_{NF}}{Q_{NF}}\right) k_3$$

Equation E-12

$$\lambda_1 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) + \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

Equation E-13

$$\lambda_2 = 0.5\left[-\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right) - \sqrt{\left(\frac{Q_{NF}V_{FF} + V_{NF}(Q_{NF} + Q_{FF})}{V_{NF}V_{FF}}\right)^2 - 4\left(\frac{Q_{NF}Q_{FF}}{V_{NF}V_{FF}}\right)}\right]$$

EPA calculated the hourly TWA concentrations in the near-field and far-field using Equation G-1221 and Equation G-13, respectively. Note that the numerator and denominator of Equation G-1221 and Equation G-132 use two different sets of time parameters. The numerator is based on operating times for the scenario (e.g., two or eight hours for OTVDs, 8 to 24 hours for conveyorized degreasers, 8 hours for web degreasers, and 3 to 8 hours for cold cleaning, see Appendix 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 E-14

$$C_{NF,TWA} = \frac{\int_{t_1}^{t_2} C_{NF}dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(k_1 + k_2e^{\lambda_1 t} - k_3e^{\lambda_2 t}\right)dt}{t_{avg}} =$$

$$\frac{G\left(k_1t_2 + \frac{k_2e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_3e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(k_1t_1 + \frac{k_2e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_3e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

Equation E-15

$$C_{FF,TWA} = \frac{\int_{t_1}^{t_2} C_{FF}dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(\frac{1}{Q_{FF}} + k_4e^{\lambda_1 t} - k_5e^{\lambda_2 t}\right)dt}{t_{avg}} =$$

$$\frac{G\left(\frac{t_2}{Q_{FF}} + \frac{k_4e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_5e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(\frac{t_1}{Q_{FF}} + \frac{k_4e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_5e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

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 G-23, below:

Equation E-16

$$FSA = 2(L_{NF}H_{NF}) + 2(W_{NF}H_{NF}) + (L_{NF}W_{NF})$$

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 G-154 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 E-17

$$Q_{NF} = \frac{1}{2} v_{NF} FSA$$

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 G-25:

Equation E-18

$$Q_{FF} = V_{FF} AER$$

Using the model inputs described in Appendix E.2, EPA estimated TCE 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.

E.2 Model Parameters

Table G-1 through Table E-4 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 E-1. Summary of Parameter Values and Distributions Used in the Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	ft^3	10,594	Midpoint	10,594	70,629	17,657	Triangular	See Section E.2.1
Air exchange rate	AER	hr^{-1}	2	Mode	2	20	3.5	Triangular	See Section E.2.2
Near-field indoor wind speed	v_{NF}	ft/hr	1,181	50th percentile	154	23,882	—	—	See Section E.2.3
		cm/s	10	50th percentile	1.3	202.2	—	—	
Near-field length	L_{NF}	ft	10	—	—	—	—	Constant Value	See Section E.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	—	2	8	—	--	See Section E.2.5
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	See Section E.2.6
Vapor generation rate	G	mg/hr	2.34E+07	Average	4.54E+02	4.67E+07	—	Discrete	See Section E.2.7
		lb/hr	51.50	Average	0.001	103.00	—	Discrete	
Operating hours per day	OH	hr/day	8	—			—	Discrete	See Section E.2.8

Table E-2. Summary of Parameter Values and Distributions Used in the Conveyorized Degreasing Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	ft^3	10,594	Midpoint	10,594	70,629	17,657	Triangular	See Section E.2.1
Air exchange rate	AER	hr^{-1}	2	Mode	2	20	3.5	Triangular	See Section E.2.2
Near-field indoor wind speed	v_{NF}	ft/hr	1,181	50th percentile	154	23,882	—	—	See Section E.2.3
		cm/s	10	50th percentile	1.3	202.2	—	—	
Near-field length	L_{NF}	ft	10	—	—	—	—	Constant Value	See Section E.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	24	—	24	8	—	Constant Value	See Section E.2.5
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	See Section E.2.6
Vapor generation rate	G	mg/hr	1.6E+07	Average	3.63E+05	3.29E+07	—	Discrete	See Section E.2.7
Operating hours per day	OH	hr/day	24	—	—	—	—	Constant	See Section E.2.8

Table E-3. Summary of Parameter Values and Distributions Used in the Web Degreasing Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	ft^3	10,594	Midpoint	10,594	70,629	17,657	Triangular	See Section E.2.1
Air exchange rate	AER	hr^{-1}	2	Mode	2	20	3.5	Triangular	See Section E.2.2
Near-field indoor wind speed	v_{NF}	ft/hr	1,181	50th percentile	154	23,882	—	—	See Section E.2.3
		cm/s	10	50th percentile	1.3	202.2	—	—	
Near-field length	L_{NF}	ft	10	—	—	—	—	Constant Value	See Section E.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	—	8	8	—	Constant Value	See Section E.2.5
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	See Section E.2.6
Vapor generation rate	G	mg/hr	—	—	1.12E+05	1.12E+05	—	Discrete	See Section E.2.7; Single Data Point
Operating hours per day	OH	hr/day	24	—	—	—	—	Constant	See Section G.2.8

Table E-4. Summary of Parameter Values and Distributions Used in the Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model

Input Parameter	Symbol	Unit	Deterministic Values		Uncertainty Analysis Distribution Parameters				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Far-field volume	V_{FF}	ft^3	10,594	Midpoint	10,594	70,629	17,657	Triangular	See Section E.2.1
Air exchange rate	AER	hr^{-1}	2	Mode	2	20	3.5	Triangular	See Section E.2.2
Near-field indoor wind speed	v_{NF}	ft/hr	1,181	50th percentile	154	23,882	—	—	See Section E.2.3
		cm/s	10	50th percentile	1.3	202.2	—	—	
Near-field length	L_{NF}	ft	10	—	—	—	—	Constant Value	See Section E.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	—	—	3	8	—	Discrete	See Section E.2.5
Averaging Time	t_{avg}	hr	8	—	—	—	—	Constant Value	See Section E.2.6
Vapor generation rate	G	mg/hr	5.14E+05	Average	6.28E+02	1.02E+06	—	Discrete	See Section E.2.7
		lb/hr	1.13	Average	0.001	2.26	—	Discrete	
Operating hours per day	OH	hr/day	—	—	—	—	—	—	See Section E.2.8

E.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 et al., 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 et al., 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).

E.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 et al., 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 et al., 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 et al., 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 et al., 2009).

E.2.3 Near-Field Indoor Air Speed

(Baldwin and Maynard, 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 and Maynard, 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 and Maynard, 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 and Maynard, 1998) to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

(Baldwin and Maynard, 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.

E.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.

E.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 Appendix E.2.8 for discussion of operating hours).

E.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.

E.2.7 Vapor Generation Rate

For the vapor generation rate from each machine type (OTVD, conveyorized and cold), EPA used a discrete distribution based on the annual unit emission rates reported in the (U.S. EPA, 2018a). No web degreasers were reported in the 2014 NEI, therefore, (U.S. EPA, 2011) data was used for web degreasers. Annual unit emission rates were converted to hourly unit emission rates by dividing the annual reported emissions by the reported annual operating hours (see Appendix E.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 E-5 summarizes the data in the 2014 NEI.

Table E-5. Summary of Trichloroethylene 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[a]
Open-Top Vapor Degreasers	149	29	62	76
Conveyorized Degreasers	8	0	5	3
Web Degreasers[b]	1	0	0	1
Cold Cleaning Machines	17	1	6	10

a – Some units with zero emissions also did not include accompanying operating hours; therefore, subtracting the units with zero emissions and the units without operating hours from the total units does not equal the units in the analysis due to double counting.
b – No web degreasers reported in the 2014 NEI. One web degreaser reported in the (U.S. EPA, 2011) was used in this analysis.
Source: (U.S. EPA, 2018a, 2011)

Table E-6 through Table E-9 summarize the distribution of hourly unit emissions for each machine type calculated from the annual emission in the 2014 NEI.

Table E-6. Distribution of Trichloroethylene Open-Top Vapor Degreasing Unit Emissions

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
1	103.00	0.0132
1	63.95	0.0132
1	19.04	0.0132
1	13.20	0.0132
1	12.18	0.0132
1	9.47	0.0132
1	9.21	0.0132
1	8.14	0.0132
1	7.30	0.0132
1	6.93	0.0132
1	6.64	0.0132
1	6.61	0.0132
1	6.44	0.0132
1	6.40	0.0132
1	6.32	0.0132
1	5.10	0.0132
1	5.06	0.0132
1	4.89	0.0132
1	4.85	0.0132
1	4.14	0.0132
1	3.96	0.0132
1	3.82	0.0132
1	3.77	0.0132
1	3.68	0.0132
2	3.66	0.0263
1	3.64	0.0132
1	3.43	0.0132
1	3.40	0.0132
1	2.88	0.0132
1	2.79	0.0132
1	2.64	0.0132
1	2.61	0.0132
1	2.48	0.0132
1	2.37	0.0132
1	2.20	0.0132
1	1.97	0.0132
1	1.96	0.0132
1	1.73	0.0132
1	1.62	0.0132

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
1	1.59	0.0132
1	1.44	0.0132
1	1.33	0.0132
1	1.22	0.0132
1	1.09	0.0132
2	0.93	0.0263
1	0.90	0.0132
2	0.84	0.0263
1	0.83	0.0132
1	0.79	0.0132
3	0.79	0.0395
1	0.70	0.0132
1	0.62	0.0132
1	0.60	0.0132
1	0.43	0.0132
1	0.42	0.0132
1	0.39	0.0132
1	0.38	0.0132
1	0.38	0.0132
1	0.35	0.0132
1	0.23	0.0132
1	0.18	0.0132
1	0.15	0.0132
1	0.15	0.0132
1	0.14	0.0132
1	0.11	0.0132
1	0.10	0.0132
2	0.10	0.0263
1	0.07	0.0132
1	0.03	0.0132
1	0.001	0.0132

Table E-7. Distribution of Trichloroethylene Conveyorized Degreasing Unit Emissions

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
1	72.48	0.3333
1	1.51	0.3333
1	0.80	0.3333

Table E-8. Distribution of Trichloroethylene Web Degreasing Unit Emissions

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
—	0.247	1.00

Table E-9. Distribution of Trichloroethylene Cold Cleaning Unit Emissions

Count of Units	Unit Emissions (lb/unit-hr)	Fractional Probability
1.00	2.26	0.1000
1.00	0.83	0.1000
1.00	0.83	0.1000
1.00	0.83	0.1000
1.00	0.83	0.1000
1.00	0.05	0.1000
1.00	0.01	0.1000
1.00	0.01	0.1000
1.00	0.01	0.1000
1.00	0.00	0.1000

E.2.8 Operating Hours

For the operating hours of each machine type (OTVD, 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 E-10 through Table E-13 summarize the distribution of operating hours per day for each machine type.

Table E-10. Distribution of Trichloroethylene Open-Top Vapor Degreasing Operating Hours

Count of Occurrences	Operating Hours (hr/day)	Fractional Probability
—	24	0.4048
—	16	0.0952
—	8	0.2381
—	6	0.0476
—	4	0.0714
—	2	0.1429

Table E-11. Distribution of Trichloroethylene Conveyorized Degreasing Operating Hours

Count of Occurrences	Operating Hours (hr/day)	Fractional Probability
—	24	1.0000

Table E-12. Distribution of Trichloroethylene Web Degreasing Operating Hours

Count of Occurrences	Operating Hours (hr/day)	Fractional Probability
—	24	1.0000

Table E-13. Distribution of Trichloroethylene Cold Cleaning Operating Hours

Count of Occurrences	Operating Hours (hr/day)	Fractional Probability
—	24	0.4000
—	8	0.5000
—	3	0.1000

Appendix F 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 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 TCE 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 TCE 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 reasonably 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.

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

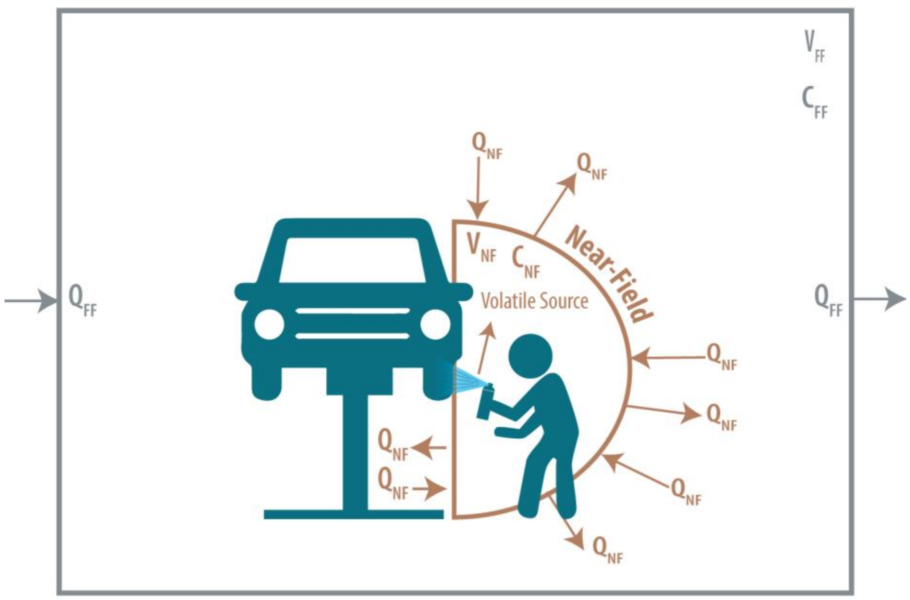


Figure F-1. The Near-Field/Far-Field Model as Applied to the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model

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 Sections F.2.5 and F.2.9 below, 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 TCE using the weight fraction of TCE in the aerosol product. EPA uses a uniform distribution of weight fractions for TCE based on facility data for the aerosol products in use (CARB, 2000).

The model design equations are presented below in Equation F-1 through Equation F-21.

Near-Field Mass Balance
Equation F-1

$$V_{NF}\frac{dC_{NF}}{dt} = C_{FF}Q_{NF} - C_{NF}Q_{NF}$$

Far-Field Mass Balance
Equation F-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 and Equation F-1 and Equation F-2 in terms of the time-varying concentrations in the near-field and far-field yields Equation F-3 and Equation F-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 TCE 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 TCE 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 F-13 and Equation F-14. The *k* coefficients (Equation F-5 through Equation F-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 F-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 F-4

$$C_{FF,t_{m,n+1}} = \left(k_{3,t_{m,n}} e^{\lambda_1 t} - k_{4,t_{m,n}} e^{\lambda_2 t}\right)$$

Where:

Equation F-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 F-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 F-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 F-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 F-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 F-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 F-11

$$C_{NF,o}(t_{m,n}) = \begin{cases} 0, \ m = 0 \\ \frac{Amt}{V_{NF}}\left(1{,}000\frac{mg}{g}\right) + C_{NF}(t_{m,n-1}), \ n > 0 \ for\ all\ m\ where\ brake\ job\ occurs \end{cases}$$

Equation F-12

$$C_{FF,o}(t_{m,n}) = \begin{cases} 0, \ m = 0 \\ C_{FF}(t_{m,n-1}), \ for\ all\ n\ where\ m > 0 \end{cases}$$

Equation F-13

$$C_{NF,\text{ 5-min TWA, }t_{m,n}} = \frac{\left(\frac{k_{1,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_2} + \frac{k_{2,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_2}\right) - \left(\frac{k_{1,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_1} + \frac{k_{2,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_1}\right)}{t_2 - t_1}$$

Equation F-14

$$C_{FF,\text{ 5-min TWA, }t_{m,n}} = \frac{\left(\frac{k_{3,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_2} + \frac{k_{4,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_2}\right) - \left(\frac{k_{3,t_{m,n-1}}}{\lambda_1}e^{\lambda_1 t_1} + \frac{k_{4,t_{m,n-1}}}{\lambda_2}e^{\lambda_2 t_1}\right)}{t_2 - t_1}$$

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 F-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 F-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 F-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 F-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 F-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 F-19, below:

Equation F-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 F-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 F-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 F-21:

Equation F-21

$$Q_{FF} = V_{FF} AER$$

Using the model inputs described in Appendix F.2, EPA estimated TCE 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.

F.2 Model Parameters

Table F-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 F-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 et al., 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 et al., 2009) identifies average AERs for occupational settings utilizing mechanical ventilation systems to be between 3 and 20 hr^{-1}. (Golsteijn et al., 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 et al., 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 and Maynard, 1998).
		cm/s	—	—	0	202.2	—	Lognormal	
Near-field radius	R_{NF}	m	1.5	—	—	—	—	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	
Starting time for each application period	t_1	hr	0	—	—	—	—	Constant Value	Constant.
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.
TCE weight fraction	wtfrac	wt frac	—	—	0.40	1.00	—	Discrete	Discrete distribution of TCE-based aerosol product formulations based on products identified in EPA's Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal for TCE (U.S. EPA, 2017b). Where the weight fraction of TCE in the formulation was given as a range, EPA assumed a uniform distribution within the reported range for the TCE 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 TCE/ application	—	—	14.8	37.1	—	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.
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

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
									operating weeks per year and 8 hours per work shift.

F.2.1 Far-Field Volume

The far-field volume is based on information obtained from (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.

F.2.2 Air Exchange Rate

The air exchange rate (AER) is based on data from (Demou et al., 2009), (Hellweg et al., 2009), (Golsteijn et al., 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 et al., 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 et al., 2009) identifies average AERs for occupational settings using mechanical ventilation systems to vary from 3 to 20 hr^{-1}. (Golsteijn et al., 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 et al., 2014) and the low end reported by (Demou et al., 2009) and (Hellweg et al., 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 et al., 2009) and a maximum of 20 hr^{-1} per (Demou et al., 2009) and (Hellweg et al., 2009).

F.2.3 Near-Field Indoor Air Speed

(Baldwin and Maynard, 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 and Maynard, 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 or other aerosol applications.

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 and Maynard, 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 and Maynard, 1998) to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

(Baldwin and Maynard, 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.

F.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 F-1). The near-field volume is calculated per Equation F-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 F-22

$$V_{NF} = \frac{1}{2} \times \frac{4}{3} \pi R_{NF}^3$$

F.2.5 Application Time

EPA assumed an average of 11 brake cleaner applications per brake job (see Section F.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.

F.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.

F.2.7 Trichloroethylene Weight Fraction

EPA reviewed the *Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: Trichloroethylene* report (U.S. EPA, 2017b) for aerosol degreasers that contain TCE. EPA (2017) identifies 16 aerosol degreaser products that overall range in TCE content from 40 to 100 weight percent. The identified aerosol degreasers include a brake cleaner as well as general purpose degreasers, machine cleaners, electronic/electrical parts cleaners, and a mold cleaner. EPA includes all of these aerosol degreasers in the estimation of TCE content as: 1) automotive maintenance and repair facilities may use different degreaser products interchangeably as observed by (CARB, 2000); and 2) EPA uses this brake servicing model as an exposure scenario representative of all commercial-type aerosol degreaser applications.

EPA used a discrete distribution to model the TCE weight fraction based on the number of occurrences of each product type. In some instances, the concentration of TCE was reported as a range. For these product types, EPA used a uniform distribution to model the TCE weight fraction within the product type. Table F-2 provides a summary of the reported TCE content reported in the safety data sheets identified in (U.S. EPA, 2017b), the number of occurrences of each product type, and the fractional probability of each product type.

Table F-2. Summary of Trichloroethylene-Based Aerosol Degreaser Formulations

Name of Aerosol Degreaser Product Identified in (U.S. EPA, 2017b)	Trichloroethylene Weight Percent	Number of Occurrences	Fractional Probability
C-60 Solvent Degreaser	90-100%	1	0.063
Fusing Machine Cleaner	40-60%	1	0.063
Solvent Degreaser	> 90%	1	0.063
Electro Blast	90-100%	1	0.063
Electro Solv	90-100%	1	0.063
Pro Tools NF Solvent Degreaser	60-100%	1	0.063
Aerosolve II	>90%	1	0.063
Power Solv II	90-100%	1	0.063
Zep 45	40-50%	1	0.063
Super Solv	90-100%	1	0.063
Parts Cleaner	45-55%	1	0.063
Electronic Contact Cleaner & Protectant - Aerosol	97%	1	0.063
Flash Free Electrical Degreaser	98%	1	0.063
Chlorinated Brake & Parts Cleaner – Aerosol	98%	1	0.063
MR 351 - Mold Cleaner	69%	1	0.063
C-60 Solvent [TCE Cleaner] Degreaser	90-100%	1	0.063
	Total	**16**	**1.000**

F.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).

F.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.

F.2.10 Amount of Trichloroethylene Used per Application

EPA calculated the amount of Trichloroethylene used per application using Equation F-23. The calculated mass of Trichloroethylene used per application ranges from 14.8 to 37.1 grams.

Equation F-23

$$Amt = \frac{W_d \times wtfrac \times 28.3495 \frac{g}{oz}}{N_A}$$

Where:

Amt	=	Amount of TCE used per application (g/application);
W_d	=	Weight of degreaser used per brake job (oz/job);
Wtfrac	=	Weight fraction of TCE in aerosol degreaser (unitless); and
N_A	=	Number of degreaser applications per brake job (applications/job).

F.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).

F.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 F-24 and rounding to the nearest integer. The calculated number of brake jobs per work shift ranges from one to four.

Equation F-24

$$N_J = \frac{936 \frac{jobs}{site\text{-}year} \times 8 \frac{hours}{shift}}{52 \frac{weeks}{yr} \times OHpW}$$

Where:

N_J	=	Number of brake jobs per work shift (jobs/site-shift); and
OHpW	=	Operating hours per week (hr/week).

Appendix G Spot Cleaning Near-Field/Far-Field Inhalation Exposure Model Approach and Parameters

This appendix presents the modeling approach and model equations used in the Spot Cleaning Near-Field/Far-Field Inhalation Exposure Model. The model was developed through review of relevant literature and consideration of existing EPA/OPPT exposure models. The model uses a near-field/far-field approach (AIHA, 2009), where a vapor generation source located inside the near-field leads to the evaporation of vapors into the near-field, and indoor air movements lead to the convection of vapors between the near-field and far-field. Workers are assumed to be exposed to TCE 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;
- Spot cleaner use rate;
- Vapor generation rate;
- Weight fraction of TCE in the spot cleaner; and
- Operating hours per day.

An individual model input parameter could either have a discrete value or a distribution of values. EPA/OPPT assigned statistical distributions based on reasonably 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/OPPT 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 a high-end exposure, whereas the 50th percentile value was selected to represent a central tendency exposure level. The following subsections detail the model design equations and parameters for the spot cleaning model.

G.1 Model Design Equations

Figure G-1 illustrates the near-field/far-field modeling approach as it was applied by EPA/OPPT to spot cleaning facilities. As the figure shows, TCE 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 amount of spot cleaner 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 TCE dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational non-user exposures to TCE at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the TCE dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly TCE dissipates out of the surrounding space and into the outdoor air.

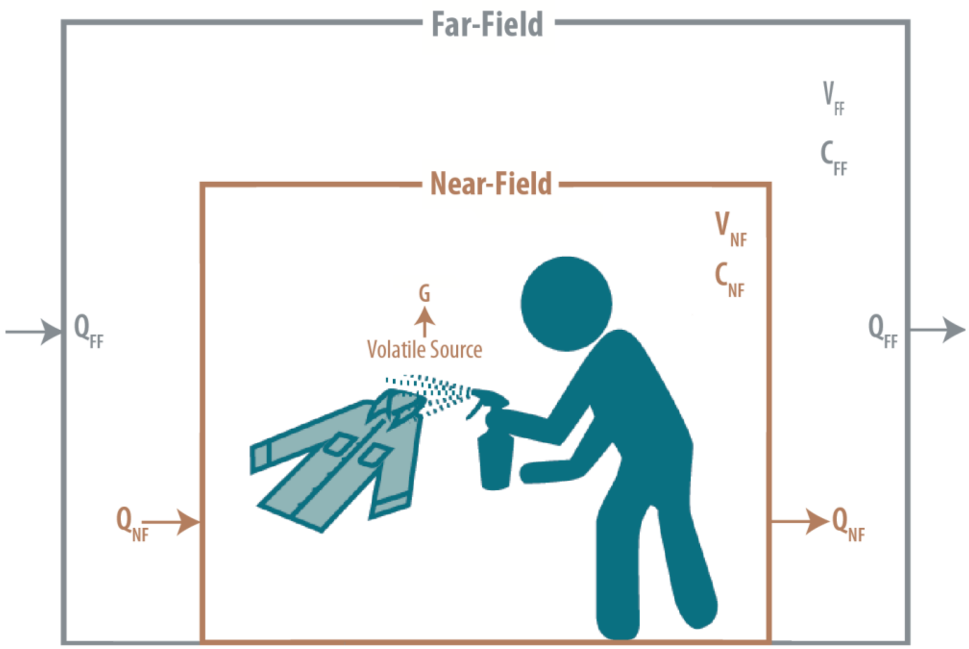


Figure G-1. The Near-Field/Far-Field Model as Applied to the Spot Cleaning Near-Field/Far-Field Inhalation Exposure Model

The model design equations are presented below in Equation G-1 through Equation G-16.

Near-Field Mass Balance

Equation G-1

$$V_{NF}\frac{dC_{NF}}{dt} = C_{FF}Q_{NF} - C_{NF}Q_{NF} + G$$

Far-Field Mass Balance

Equation 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 G-3

$$C_{NF} = G\left(k_1 + k_2 e^{\lambda_1 t} - k_3 e^{\lambda_2 t}\right)$$

Equation G-4

$$C_{FF} = G\left(\frac{1}{Q_{FF}} + k_4 e^{\lambda_1 t} - k_5 e^{\lambda_2 t}\right)$$

Where:

Equation G-5

$$k_1 = \frac{1}{\left(\frac{Q_{NF}}{Q_{NF} + Q_{FF}}\right) Q_{FF}}$$

Equation 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 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 G-8

$$k_4 = \left(\frac{\lambda_1 V_{NF} + Q_{NF}}{Q_{NF}}\right) k_2$$

Equation G-9

$$k_5 = \left(\frac{\lambda_2 V_{NF} + Q_{NF}}{Q_{NF}}\right) k_3$$

Equation 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 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/OPPT calculated the hourly TWA concentrations in the near-field and far-field using the following equations. Note that the numerator and denominator of Equation G-12 and Equation G-13, use two different sets of time parameters. The numerator is based on the operating hours for the scenario while the denominator is fixed to an averaging time span, t_avg, of 8 hours (since EPA/OPPT 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: although the spot cleaning operating hours ranges from two to five hours (as discussed in Section A.2.8), EPA/OPPT assumes exposures are equal to zero outside of the operating hours, such that the integral over the balance of the eight hours (three to six hours) is equal to zero in the numerator. Therefore, the numerator inherently includes an integral over the balance of the eight hours equal to zero that is summed to the integral from t_1 to t_2.

Equation 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 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/OPPT 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 G-14, below:

Equation 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 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 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 G-16:

Equation G-16

$$Q_{FF} = V_{FF}AER$$

Using the model inputs in Table H-1, EPA/OPPT estimated TCE inhalation exposures for workers in the near-field and for occupational bystanders in the far-field. EPA/OPPT then conducted the Monte Carlo simulations using @Risk (Version 7.0.0). The simulations applied 100,000 iterations and the Latin hypercube sampling method.

G.2 Model Parameters

Table G-1 summarizes the model parameters and their values for the Spot Cleaning Near-Field/Far-Field Exposure Model. Each parameter is discussed in detail in the following subsections.

Table G-1. Summary of Parameter Values and Distributions Used in the Spot 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	
Floor Area	A	ft^2	—	—	500	20,000	—	Beta	Facility floor area is based on data from the (CARB, 2006) and King County (Whittaker and Johanson, 2011) study. ERG fit a beta function to this distribution with parameters: α_1 = 6.655, α_2 = 108.22, min = 500 ft^2, max = 20,000 ft^2.
Far-field volume	V_{FF}	ft^3	—	—	6,000	240,000	—	—	Floor area multiplied by height. Facility height is 12 ft (median value per (CARB, 2006) study).
Near-field length	L_{NF}	ft	10	—	—	—	—	—	EPA/OPPT assumed a constant near-field volume.
Near-field width	W_{NF}	ft	10	—	—	—	—	—	
Near-field height	H_{NF}	ft	6	—	—	—	—	—	
Air exchange rate	AER	hr^{-1}	—	—	1	19	3.5	Triangular	Values based on (von Grote et al., 2006), and (SCG, 2013). The mode represents the midpoint of the range reported in (SCG, 2013).
Near-field indoor wind speed	v_{NF}	cm/s	—	—	0	202.2	—	Lognormal	Lognormal distribution fit to the data presented in (Baldwin and Maynard, 1998).
		ft/hr	—	—	0	23,882	—	Lognormal	
Starting time	t_1	hr	0	—	—	—	—	—	Constant value.
Exposure Duration	t_2	hr	—	—	2	5	—	Uniform	Equal to operating hours per day.
Averaging time	t_{avg}	hr	8	—	—	—	—	—	Constant value.

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Use rate	UR	gal/yr	8.4	—	—	—	—	—	(IRTA, 2007) used estimates of the amount of TCE-based spot cleaner sold in California and the number of textile cleaning facilities in California to calculate a use rate value.
Vapor generation rate	G	mg/hr	—	—	2.97E+03	9.32E+04	—	Calculated	G is calculated based on UR and assumes 100% volatilization and accounts for the weight fraction of TCE.
		g/min	—	—	0.05	1.55	—	Calculated	
TCE weight fraction	wtfrac	wt frac	—	—	0.1	1	—	Uniform	(IRTA, 2007) observed TCE-based spotting agents contain 10% to 100% TCE.
Operating hours per day	OH	hr/day	—	—	2	5	—	Uniform	Determined from a California survey performed by (Morris and Wolf, 2005) and an analysis of two model plants constructed by the researchers
Operating days per year	OD	days/yr	—	—	249	313	300	Triangular	Operating days/yr distribution assumed as triangular distribution with min of 250, max of 312, and mode of 300.

Input Parameter	**Symbol**	**Unit**	**Constant Model Parameter Values**		**Variable Model Parameter Values**				**Comments**
			Value	**Basis**	**Lower Bound**	**Upper Bound**	**Mode**	**Distribution Type**	
Fractional number of operating days that a worker works	*f*	Dimensionless	1	—	0.8	1.0	—	Uniform	In BLS/Census data, the weighted average worked hours per year and per worker in the dry cleaning sector is approximately 1,600 (i.e., 200 day/yr at 8 hr/day). The BLS/Census data weighted average of 200 day/yr falls outside the triangular distribution of operating days and to account for lower exposure frequencies and part-time workers, EPA/OPPT defines *f* as a uniform distribution ranging from 0.8 to 1.0. 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 1.0 is appropriate as dry cleaners may be family owned and operated and some workers may work as much as every operating day.

G.2.1 Far-Field Volume

EPA/OPPT 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 (CARB, 2006) study) as discussed in more detail below.

The 2006 CARB *California Dry Cleaning Industry Technical Assessment Report* (CARB, 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 (2006) study also provides survey data on facility height. Using survey results from both studies, EPA/OPPT composed the following distribution of floor area. To calculate facility volume, EPA/OPPT used the median facility height from the CARB (2006) study. The facility height distribution in the CARB (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 G-2. Composite Distribution of Dry Cleaning Facility Floor Areas

Floor Area Value (ft^2)	Percentile (as fraction)	Source
20,000	1	King County
3,000	0.96	King County
2,000	0.84	King County
1,600	0.5	CARB 2006
1,100	0.1	CARB 2006
500	0	CARB 2006

EPA/OPPT 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.

G.2.2 Near-Field Volume

EPA/OPPT assumed a near-field of constant dimensions of 10 ft wide by 10 ft long by 6 ft high resulting in a total volume of 600 ft^3.

G.2.3 Air Exchange Rate

(von Grote et al., 2006) indicated typical air exchange rates (AERs) of 5 to 19 hr^{-1} for dry cleaning facilities in Germany. (Klein and Kurz, 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/OPPT'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 et al. and (Klein and Kurz, 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}).

G.2.4 Near-Field Indoor Wind Speed

(Baldwin and Maynard, 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/OPPT analyzed the air speed data from Baldwin and Maynard (1998) and categorizing the air speed surveys into settings representative of industrial facilities and representative of commercial facilities. EPA/OPPT fit separate distributions for these industrial and commercial settings and used the commercial distribution for dry cleaners (including other textile cleaning facilities that conduct spot cleaning).

EPA/OPPT 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/OPPT truncated the distribution at the largest observed value among all of the survey mean air speeds from Baldwin and Maynard (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 and Maynard (1998)) to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

Baldwin and Maynard (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.2.5 Averaging Time

EPA/OPPT is interested in estimating 8-hr TWAs for use in risk calculations; therefore, a constant averaging time of eight hours was used.

G.2.6 Use Rate

EPA/OPPT used a top-down approach to estimate use rate based on the volume of TCE-based spotting agent sold in California and the number of textile cleaning facilities in California.

(IRTA, 2007) estimated 42,000 gal of TCE-based spotting agents are sold in California annually and there are approximately 5,000 textile cleaning facilities in California. This results in an average use rate of 8.4 gal/site-year of TCE-based spotting agents.

The study authors' review of safety data sheets identified TCE-based spotting agents contain 10% to 100% TCE.

G.2.7 Vapor Generation Rate

EPA/OPPT set the vapor generation rate for spot cleaning (G) equal to the use rate of TCE with appropriate unit conversions. EPA/OPPT multiplied the spotting agent use rate by the weight fraction of TCE (which ranges from 0.1 to 1) and assumed all TCE applied to the garment evaporates. EPA used a density of 1.46 g/cm^3 (U.S. EPA, 2018c). To calculate an hourly vapor generation rate, EPA/OPPT divided the annual use rate by the number of operating days and the number of operating hours selected from their respective distributions for each iteration.

G.2.8 Operating Hours

(Morris and Wolf, 2005) surveyed dry cleaners in California, including their spotting labor. The authors developed two model plants: a small PERC dry cleaner that cleans 40,000 lb of clothes annually; and a large PERC dry cleaner that cleans 100,000 lb of clothes annually. The authors modeled the small dry cleaner with a spotting labor of 2.46 hr/day and the large dry cleaner with a spotting labor of 5 hr/day. EPA/OPPT models a uniform distribution of spotting labor varying from 2 to 5 hr/day.

G.2.9 Operating Days

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[17]. 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.

G.2.10 Fractional Number of Operating Days that a Worker Works

To account for lower exposure frequencies and part-time workers, EPA/OPPT 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 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).

[17] 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.

Appendix H Dermal Exposure Assessment Method

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).

H.1 Incorporating the Effects of Evaporation

H.1.1 Modification of EPA/OPPT Models

Current EPA/OPPT 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, 2013):

Equation H-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 H-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.

H.2 Calculation of f_{abs}

(Kasting and Miller, 2006) developed a diffusion model to describe the absorption of volatile compounds applied to the skin. As of part of the model, Kasting and Miller define a ratio of the liquid evaporation to absorption, χ. They derive the following definition of χ (which is dimensionless) at steady-state:

Equation H-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 $\chi \gg 1$ will largely evaporate from the skin surface, while chemicals for which $\chi \ll 1$ will be largely absorbed; $\chi = 1$ represents a balance between evaporation and absorption. Equation H-3 is applicable to chemicals having a log octanol/water partition coefficient less than or equal to three (log Kow ≤ 3)[18]. The equations that describe the fraction of the initial mass that is absorbed (or evaporated) are rather complex (Equations 20 and 21 of (Kasting and Miller, 2006) but can be solved.

H.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, (FH, 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 H-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 H-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 (FH, 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:

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[18] For simplification, (Kasting and Miller, 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 $K_{ow} \leq 3$.

Equation H-5

$$\frac{m_{evap}(\infty)}{M_0} = 1 - f_{abs} = \frac{2\chi - f\chi}{2 + 2\chi}$$

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 H-6:

Equation H-6

$$\boldsymbol{f_{abs} = \frac{m_{abs}}{M_0} = 2\sum_{n=1}^{\infty}\frac{1}{\lambda_n}\left(1 - e^{-\lambda_n{}^2\tau}\right)\left(\frac{\chi^2 + \lambda_n{}^2}{\chi^2 + \lambda_n{}^2 + \chi}\right)\cdot\left(\frac{cos(1-f)\,\lambda_n - cos\lambda_n}{f\cdot\lambda_n}\right)}$$

where the eigenvalues λ_n are the positive roots of the equation:

Equation H-7

$$\boldsymbol{\lambda_n \cdot \cot(\lambda_n) + \chi = 0}$$

Equation H-6 and Equation H-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.

H.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 H-8:

Equation H-8

$$f_{abs}(\infty) = \frac{1}{\chi + 1}$$

Table H-1 presents the estimated absorbed fraction calculated using the steady-state approximation for large doses (Equation H-8) for TCE.

Table H-1. Estimated Fraction Evaporated and Absorbed (fabs) using Equation H-8

Chemical Name	**Trichloroethylene**
CASRN	**79-01-6**
Molecular Formula	**C_2HCl_3**
Molecular Weight (g/mol)	131.39
P_{VP} (torr)	73.46
Universal gas constant, R (L*atm/K*mol)	0.0821
Temperature, T (K)	303
Log K_{ow}	2.42
K_{oct}	263.0
S_w (g/L)	1.28
S_w (μg/cm^3)	1280
u (m/s)[a]	0.1674
Evaporative Flux, χ	11.19
Fraction Evaporated	0.92
Fraction Absorbed	**0.08**
u (m/s)[a]	0.0878
Evaporative Flux, χ	6.76
Fraction Evaporated	0.87
Fraction Absorbed	**0.13**

[a] EPA used air speeds from (Baldwin and Maynard, 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.

H.3 Comparison of f_{abs} to FR_{abs} in the Consumer Exposure Model (CEM)

The *Dermal Dose from Product Applied to Skin, Fraction Absorbed Model* (P_DER2a) within CEM Version 2.1.6 also uses a fraction absorbed parameter to estimate dermal dose. In this model, a fraction absorbed parameter (FR_{abs}) is applied to a potential dose (i.e., amount of chemical retained on the skin) to estimate the amount of chemical that penetrates the skin. P_DER2a references (Frasch and Bunge, 2015) to estimate the fraction absorbed using a simple algebraic approximation at *infinite time following a transient exposure*:

Equation H-9

$$FR_{abs} = \frac{3 + \chi\left[1 - \exp\left(-a_1 \frac{t_{exp}}{t_{lag}}\right)\right]}{3(1+\chi)}$$

Where:

χ is the ratio of the evaporation rate from the *stratum corneum* (SC) surface to the dermal absorption rate through the SC (unitless, see Equation 90 of CEM)

α is constant (2.906)
t_{exp} is the exposure time (h)
t_{lag} is the lag time for chemical transport through the SC (h, see Equation 89 of CEM)

The (Frasch and Bunge, 2015) method is one of *transient dermal exposure* where the skin is exposed to a chemical for a finite duration, after which the chemical is removed and no residue remains on the skin. At the end of the exposure period, the chemical within the skin can still enter the systemic circulation. This transient exposure model can represent exposure from bathing or showering with contaminated water, where "dermal absorption proceeds for the duration of exposure, but once the bath or shower has ended, contaminant residing within the skin may still be absorbed by the body while some may evaporate into the surrounding air" (Frasch and Bunge, 2015).

For highly volatile chemicals such as 1-BP and methylene chloride, the value of FR_{abs} varies from zero (for small value of t_{exp}) to a maximum of one-third. Figure H-1 below provides a graphical representation of fraction absorbed (FR_{abs}) over time for 1-BP. It should be noted that the steady-state fraction absorbed in this transient exposure scenario is substantially higher than the theoretical fraction absorbed for a large dose scenario presented in Figure H-1.

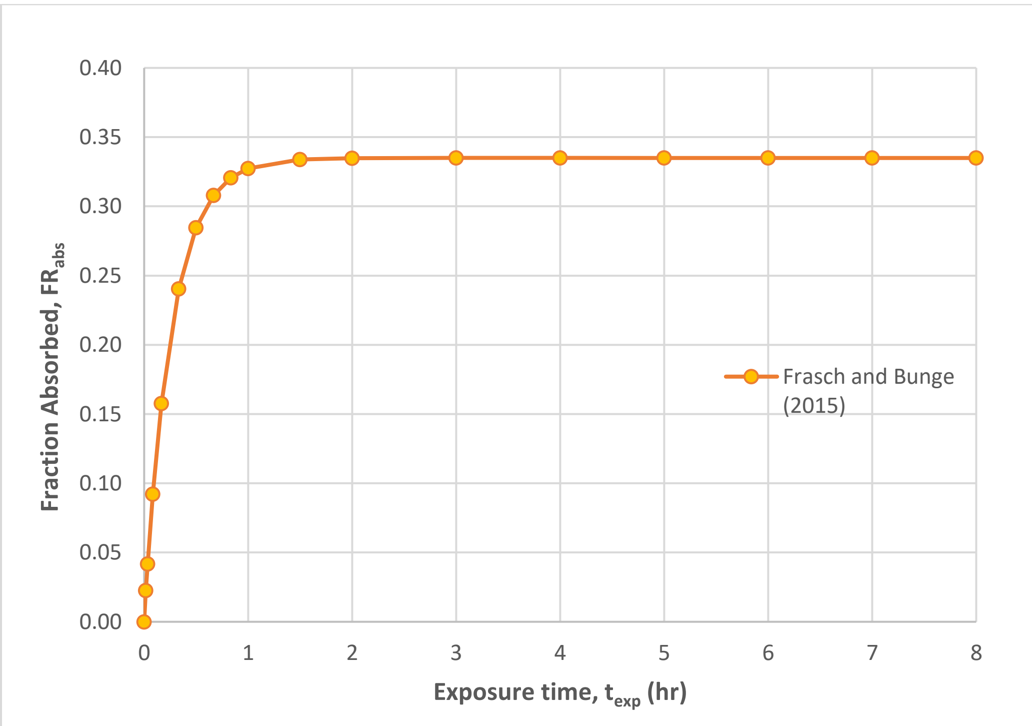

Figure H-1. Estimated Fraction Absorbed for 1-BP (CEM Equation)

It is important to note that FR_{abs} refers to the post-exposure absorbed fraction of the amount of chemical present in the skin membrane at the end of the exposure time; it does not account for the amount of chemical that has been absorbed into the body from the entire transient exposure. (Frasch and Bunge, 2015) presents equations to estimate the total mass absorbed as a function of exposure time, as an infinite series summation, when experimental values for the permeability coefficient (K_p) and lag time (t_{lag}) are available. More detailed review of this solution using measured values K_p is recommended for future work.

H.4 Comparison of f_{abs} to Experimental Values for 1-BP

Sections H.2 and H.3 present 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 reasonably available, experimental studies and actual measurements of absorbed dose are preferred over theoretical calculations.

In a 2011 study, Frasch et al. tested dermal absorption characteristics of 1-BP. For the finite dose scenario, (Frasch et al., 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 H-8. While this discrepancy is unexplained, the 2011 Frasch et al. 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 et al., 2011) also raised the possibility that 1-BP may dehydrate the *stratum corneum*, thereby decreasing the skin permeability after initial exposure.

H.5 Potential for Occlusion

Occlusion refers to skin covered directly or indirectly by impermeable films or substances. Chemical protective gloves are one of the most widely used forms of PPE intended to prevent skin exposure to chemicals. 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 H-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 H-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 protective measures could produce negative events due to the nature of occlusion, which often causes stratum corneum hyper-hydration and reduces the protective barrier properties of the skin. Many gloves do not resist the penetration of low molecular weight chemicals: those chemicals may enter the glove and become trapped on the skin under occlusion for many hours. Breakthrough times for glove materials are often underestimates of the true breakthrough times, because the measurements do not take into account increased temperature and flexing of the material during use, which is not accounted for in tests to determine breakthrough times. Occlusion by gloves raises skin temperature and hydration leading to a reduction in its natural barrier properties. 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). Wearing gloves which are internally contaminated can lead to increased systemic absorption due to increased area of contact and reduced skin barrier properties, and repeated skin contact with chemicals can give higher than expected exposure if evaporation of the carrier occurs and the concentration in contact with the skin increases. 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 H-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 H-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 $S \times Q_u$ ($cm^2 \times mg/cm^2$-event) could be replaced by a single variable representing the mass of chemical that deposits inside the glove per event, M (mg/event):

Equation H-10

$$D_{exp} = M \times Y_{derm} \times FT$$

(Garrod et al., 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 H-10, 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 $S \times Q_u$ is 2,247 mg/event) that assumes that the air within open areas of the building is well-mixed at the breathing level zone of the occupied space; environmental conditions are maintained at 50% relative humidity and 23ºC (73ºF); there are no additional sources of these pollutants; and there are no sinks or potential re-emitting sources within the space for these pollutants. The assumption is also made that the emissions are not interacting with any pre-existing air pollutants, since the chamber tests are done under clean conditions, which is not the case in the real environment. 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 of 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.

H.6 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 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 H-1) by modification of Q_u with a protection factor, PF (unitless, PF ≥ 1):

Equation H-11

$$D_{exp} = S \times \frac{Q_u}{PF} \times Y_{derm} \times FT$$

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 H-2 presents the PF values from ECETOC TRA model (version 3). In the exposure data used to evaluate the ECETOC TRA model, (Marquart et al., 2017) reported that the observed glove protection factor was 34, compared to PF values of 5 or 10 used in the model.

Table H-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

H.7 Proposed Dermal Dose Equation

Accounting for all parameters above, the proposed, overall equation for estimating dermal exposure is:

Equation H-12

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

EPA presents exposure estimates for the following deterministic dermal exposure scenarios:

- Dermal exposure without the use of protective gloves (Equation H-12, PF = 1)
- Dermal exposure with the use of protective gloves (Equation H-12, PF = 5)
- Dermal exposure with the use of protective gloves and employee training (Equation H-12, PF = 20 for industrial users and PF = 10 for professional users)
- Dermal exposure with occlusion (Equation H-10)

EPA assumes the following parameter values for Equation H-12 in addition to the parameter values presented in Table H-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 value, respectively, used in the EPA/OPPT dermal contact with liquids models (EPA, 2013).
- 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 H-12 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 H-10, 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 H.5.

H.8 Equations for Calculating Acute and Chronic (Non-Cancer and Cancer) Dermal Doses

Equation H-12 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 H-13.

Equation H-13

$$\boldsymbol{ARD = \frac{D_{\mathbf{exp}}}{BW}}$$

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 H-14

$$CRD = \frac{D_{exp} \times EF \times WY}{BW \times (AT\ or\ AT_c)}$$

Equation H-15

$$AT = WY \times 250 \frac{day}{yr}$$

Equation H-16

$$\boldsymbol{AT_c = LT \times 250 \frac{day}{yr}}$$

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 H-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_H-3

Parameter Name	Symbol	Value	Unit
Exposure Frequency	EF	250	days/yr
Working years	WY	31 (50th percentile) 40 (95th percentile)	years
Lifetime Years, cancer	LT	78	years
Body Weight	BW	80 (Average Adult Worker) 72.4 (Females of Reproductive Age)	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 H-17

$$EF = f \times AWD$$

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)

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 BLS (2014b) 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' (2016a) 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 (Census, 2016b). 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 (Census, 2016a-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.[19] 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 (Census Bureau, 2012b). 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 H-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 H-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 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: Census Bureau, 2016a.
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 H-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.

[19] 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).

Table H-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 average adult workers and 72.4 kg for females of reproductive age.