United States
Environmental Protection Agency

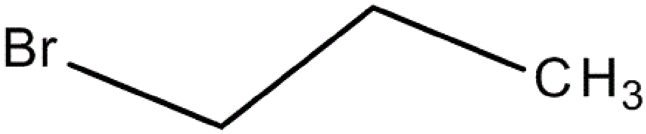
Office of Chemical Safety and
Pollution Prevention

Final Risk Evaluation for 1-Bromopropane (*n*-Propyl Bromide)

1-BP Supplemental File:

Information on Occupational Exposure Assessment

CASRN: 106-94-5



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ABBREVIATIONS

1-BP	1-Bromopropane
AC	Acute Concentration
ACGIH	American Conference of Government Industrial Hygienists
ADC	Average Daily Concentration
APF	Assigned Protection Factor
BLS	Bureau of Labor Statistics
CARB	California Air Resources Board
CBI	Confidential Business Information
CDC	Centers for Disease Control
CDR	Chemical Data Reporting
CEHD	Chemical Exposure Health Data
CFR	Code of Federal Regulations
COU	Conditions of Use
CSHO	Chemical Safety and Health Officer
DCM	Dichloromethane
DOD	Department of Defense
EC	Engineering Control
EPA	Environmental Protection Agency
ESD	Emission Scenario Documents
HHE	Health Hazard Evaluation
HSIA	Halogenated Solvents Industry Association
IRTA	Institute for Research and Technical Assistance
LADC	Lifetime Average Daily Concentration
LEV	Local Exhaust Ventilation
MassDEP	Massachusetts Department of Environmental Protection
MWC	Municipal Waste Combustor
NAICS	North American Industry Classification System
NEI	National Emissions Inventory
NEWMOA	Northeast Waste Management Officials' Association
NKRA	Not Known or Reasonably Ascertainable
NIOSH	National Institute of Occupational Safety and Health
OCSPP	Office of Chemical Safety and Pollution Prevention
OECD	Organisation for Economic Co-operation and Development
OES	Occupational Employment Statistics
ONU	Occupational Non-User
OPPT	Office of Pollution Prevention and Toxics
OSHA	Occupational Safety and Health Administration
OTVD	Open-Top Vapor Degreaser
PAPR	Power Air-Purifying Respirator
Perc	Perchloroethylene
PBZ	Personal Breathing Zone
PEL	Permissible Exposure Limit
PESS	Potentially Exposed Susceptible Subpopulation
PPE	Personal Protective Equipment
ppm	Part(s) per Million

QC	Quality Control
RCRA	Resource Conservation and Recovery Act
SAR	Supplied-Air Respirator
SCBA	Self-Contained Breathing Apparatus
SNAP	Significant New Alternatives Policy
SUSB	Statistics of US Businesses
TCE	Trichloroethylene
TLV	Threshold Limit Value
TSCA	Toxic Substances Control Act
TWA	Time-Weighted Average
U.S.	United States
VOC	Volatile Organic Compound

1 INTRODUCTION

This engineering report presents the occupational exposures to 1-Bromopropane (1-BP), and supplements the final risk evaluation of 1-BP under the Frank R. Lautenberg Chemical Safety for the 21st Century Act. The Frank R. Lautenberg Chemical Safety for the 21st Century Act amended the Toxic Substances Control Act (TSCA), the Nation's primary chemicals management law, on June 22, 2016. The new law includes statutory requirements and deadlines for actions related to conducting risk evaluations of existing chemicals.

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). EPA's designation of the first 10 chemical substances constituted the initiation of the risk evaluation process for each of these chemical substances, pursuant to the requirements of TSCA § 6(b)(4). The scope documents for all first 10 chemical substances were issued on June 22, 2017, and the problem formulation documents were issued on May 31, 2018. The risk evaluation for each chemical will be completed on or before December 2019. This engineering report is being issued separately from the risk evaluation report for 1-BP.

1.1 Background and Scope

This report addresses all conditions of use and pathways associated with industrial and commercial activities, as described in EPA's May 2018 Problem Formulation Document for 1-BP. TSCA § 3(4) defines the conditions of use as ''the circumstances, as determined by the Administrator, under which a chemical substance is intended, known, or reasonably foreseen to be manufactured, processed, distributed in commerce, used, or disposed of.'' This report assesses dermal and inhalation exposure in occupational settings.

1.2 General Approach and Methodology for Number of Sites and Workers

Where possible, EPA determined the number of sites and workers using data reported under the Chemical Data Reporting (CDR) Rule. The CDR Rule, issued under the TSCA, requires manufacturers and importers to report certain information on the chemicals they produce domestically or import into the United States. For the 2016 CDR cycle, manufacturers and importers of chemicals listed on the TSCA inventory were required to report if their production volume exceeded 25,000 pounds at a single site during any of the calendar years 2012, 2013, 2014 or 2015.

For conditions of use where CDR data are insufficient, EPA determined the number of sites that manufacture, process, and use 1-BP using reasonably available market data and data from Section 3 of the Toxics Release Inventory (TRI), "Activities and Uses of the Toxic Chemical at the Facility." In addition, EPA determined the number of workers by analyzing Bureau of Labor Statistics (BLS) and U.S. Census data using the methodology described in Appendix A. This methodology was previously described in the 2016 draft Risk Assessment of 1-BP.

1.3 General Approach and Methodology for Occupational Exposures

EPA assessed occupational exposures following the analysis plan published in the May 2018 Problem Formulation Document. Specific assessment methodology is described in further detail below for each type of assessment.

1.3.1 Inhalation Exposure Assessment Approach and Methodology

To assess inhalation exposure, EPA reviewed reasonably available exposure monitoring data and mapped them to specific conditions of use. The monitoring data used in the assessment include data collected by government agencies such as OSHA and NIOSH, and data found in published literature. For each exposure scenario and worker job category ("worker" or "occupational non-user"), where available, EPA calculated the 95th and 50th percentile exposure levels from the observed data set. The 95th percentile exposure concentration represents high-end exposure to 1-BP across the distribution of available exposure data. The 50th percentile exposure concentration represents a typical exposure level. For this assessment, only personal breathing zone (PBZ) monitoring data were used to determine the time-weighted average (TWA) exposure concentration. TWA exposure concentrations are then used to calculate the Acute Concentration (AC), Average Daily Concentrations (ADC) and Lifetime Average Daily Concentration (LADC) using the approach and equations described in Appendix B.

For several conditions of use, EPA modeled exposure in occupational settings. The models were used to either supplement existing exposure monitoring data or to provide exposure estimates where data are insufficient. For example, EPA used the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* to estimate worker exposure during container and truck unloading activities that occur at industrial facilities. EPA also refined its exposure models from the 2016 draft Risk Assessment to address peer review comments.

1.3.2 Dermal Exposure Assessment Approach and Methodology

Although inhalation pathway is expected to be the most important route for 1-BP, dermal exposure may be important in contributing to the overall exposure. During the 2016 peer review of the draft 1-BP Risk Assessment, peer reviewers recommended that quantitative estimates of dermal exposure be included to address this pathway. Peer reviewers also noted the possible occupational exposure scenarios where dermal contact is occluded.

EPA assessed dermal exposure to workers by modifying the *EPA/OPPT 2-Hand Dermal Exposure to Liquids Model*. The report presents several occupational dermal exposure scenarios, accounting for the potential for evaporation, glove use, and occlusion. Dermal exposure assessment is described in more detail in Section 2.18.

1.3.3 Respiratory Protection

OSHA's Respiratory Protection Standard (29 CFR 1910.134) provides a summary of respirator types by their assigned protection factor (APF). APF means the workplace 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 according to the requirements of OSHA's Respiratory Protection Standard. Respirators, and any personal protective equipment, is the last mean of worker protection, and should only be considered when process design and engineering control cannot reduce workplace exposure to an acceptable level.

Exposure to 1-BP can cause irritation and can damage the nervous system. 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 which have the appropriate APF. Respirators that meet these criteria include air-purifying respirators with organic vapor cartridges. Respirators must meet or exceed the required level of protection listed in Table 1-1. Based on the protection standards, inhalation exposures may be reduced by a factor of 5 to 10,000, assuming workers and occupational non-users are complying with the standard.

Table 1-1. 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: 1910.134(d)(3)(i)(A)

1.4 Peer Review Comments

Prior to the Lautenberg Act, EPA completed a draft risk assessment for 1-BP, addressing occupational and consumer uses in spray adhesives, dry cleaning (including spot cleaning), vapor degreasing, aerosol degreasing, and cold cleaning. The draft assessment was published in February 2016 and peer reviewed in May 2016.

EPA has reviewed and evaluated public and peer review comments provided on the 2016 draft risk assessment as well as the 2019 draft Risk Evaluation. Where appropriate, EPA made editorial changes to improve the clarity and flow of the assessment. EPA also reviewed additional data and information provided by the commenters and considered changes to enhance the assessment approach. As part of this process, EPA updated the dry cleaning (including spot cleaning), vapor degreasing, aerosol degreasing, and cold cleaning models to address peer review comments and to incorporate latest available data. Example model updates include truncating the upper-bound of certain model input parameters (e.g., air speed) to a reasonable high-end value and changing the exposure averaging period from 8-hr TWA to 12-hr TWA in the dry cleaning model.

This report also includes a quantitative assessment of dermal exposure, including assessment of potential for occlusion in select conditions of use, in response to the 2016 peer review comments as well as peer review and public comments on the 2019 draft Risk Evaluation.

2 Engineering Assessment

The following sections will contain process descriptions and the specific details (worker activities, analysis for determining number of workers, exposure assessment approach and results) from the assessment for each exposure scenario.

2.1 Manufacture

2.1.1 Process Description

1-BP is produced by reacting n-propyl alcohol with hydrogen bromide and then removing the excess water that forms in the process (NTP, 2013). The reaction product may then be distilled, neutralized with sodium hydrogen carbonate, stored, and packaged (Ichihara et al., 2004). The purity of the final product may range from 96 percent (Li et al., 2010) to over 99.9 percent (OSHA, 2013a).

The manufacturing process may be either batch or continuous. Based on a site visit in 2013 conducted by PEC, Icarus Environmental, and OSHA representatives, one major U.S. manufacturer of 1-BP operates a continuous, closed production process for 24 hours per day and 7 days per week (OSHA, 2013a).

2.1.2 Number of Sites and Potentially Exposed Workers

The CDR Rule requires manufacturers and importers to provide EPA information on the chemicals they produce domestically or import into the United States. Based on CDR data, EPA identified two domestic 1-BP manufacturers, Albemarle Corporation and Chemtura Corporation, for calendar year 2015. Table 2-1 below summarizes the number of workers reasonably likely to be exposed to 1-BP at the two manufacturing facilities, as reported in the 2016 CDR (U.S. EPA, 2017a)[1]. The term "reasonably likely to be exposed," for the purpose of CDR, means "an exposure to a chemical substance which, under foreseeable conditions of manufacture, processing, distribution in commerce, or use of the chemical substance, is more likely to occur than not to occur." These exposures would include activities such as charging reactor vessels, drumming, bulk loading, cleaning equipment, maintenance operations, materials handling and transfer, and analytical operations. The estimate also includes persons whose employment requires them to pass through areas where chemical substances are manufactured, processed, or used, i.e., those who may be considered "occupational non-users," such as production workers, foremen, process engineers, and plant managers. There are at least 35 to less than 75 potentially exposed workers and ONUs at the two manufacturing sites.

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[1] No further information regarding these facilities were provided during the comment period; therefore, EPA is relying on CDR data.

Table 2-1. Number of Potentially Exposed Workers at Manufacturing Facilities (2016 CDR)

Company	Facility	Facility Location		Number of Workers [a] Likely to be Exposed	Basis for Manufacturing Determination
		City	State		
Albemarle Corporation	Albemarle Corp South Plant	Magnolia	AR	25 – <50	2016 CDR (Sec. 2.B.4)
Chemtura Corporation	Great Lakes Chemical - Central	El Dorado	AR	10 – <25	2016 CDR (Sec. 2.B.4)
Total				**35 – 73**	

Source: (U.S. EPA, 2017a)
[a] May include both workers and ONUs

2.1.3 Exposure Assessment

2.1.3.1 Worker Activities

Typical worker activities at a manufacturing facility include: 1) collecting and analyzing quality control (QC) samples; 2) routine monitoring of the process, making process changes, or responding to process upsets; and 3) loading finished products containing 1-BP into containers and tank trucks. The specific activity and the potential exposure level may differ substantially depending on the facility's operation, process enclosure, level of automation, engineering control, and personal protective equipment (PPE). For example, at a U.S. manufacturing facility, workers were observed to spend most of their time in a control room monitoring the production process via a computerized system. QC samples are taken and analyzed inside a laboratory fume hood, and in some cases, in a nitrogen purge dry box. Product loading is controlled using a computerized system; smart-hoses and a vent line are used to minimize leaks and to capture vapors generated during loading. At this facility, employees wear safety glasses, nitrile gloves, and steel toe shoes when performing product sampling and laboratory analysis. In addition, operators wear a full chemical suit[2] during truck loading, including a full-face respirator equipped with organic vapor cartridges (OSHA, 2013a). The company has an industrial hygiene program where all employees are trained on PPE and work practices according to their job duties.

In contrast, a recent study among three 1-BP manufacturing facilities in China indicate that none of the workers were observed to wear PPE. These workers manually add chemicals into reaction pots, pour final product into drums, and adjust the final drum volume with hand scoops (Li et al., 2010).

2.1.3.2 Occupational Exposure Assessment Methodology

1-BP exposure monitoring data were identified for one manufacturing facility in the U.S. (OSHA, 2013a) and a facility in China. Although the Chinese study may not be representative of work practices and exposure levels at U.S. facilities, data from this study are presented for comparison purposes, and may be indicative of potential exposure levels in the absence of adequate engineering controls and workplace protection.

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[2] Chemical resistant pants and jacket with hood, steel-toed rubber boots, chemical resistant gloves, and full-face respirator equipped with organic vapor cartridges.

2.1.3.3 Occupational Exposure Results

Table 2-2 presents the exposure levels from an OSHA site visit to a U.S. manufacturing facility. The purpose of the site visit was to collect information on 1-BP production process, engineering controls, and potential exposures. OSHA performed personal sampling on two operators during two consecutive shifts and on one laboratory technician; the company also collected simultaneous samples for result comparison and verification. In the table, the high-end exposure value represents the maximum TWA exposure among the three workers sampled, and the central tendency value represents the median exposure. EPA assumed the TWA exposures approximate 8-hr TWA because actual sampling time ranged from 429 to 449 minutes (7.2 to 7.5 hour). Exposure was highest during truck loading, which occurs once every 24 hours, with the night shift operator having an exposure of 2.61 ppm during a 78-minute personal breathing zone sample. The operator wore a full-face respirator during this activity (OSHA, 2013a).

Table 2-3 presents the 95th and 50th percentile exposures surveyed by Ichihara et al. (2004) at a factory located in Jiangsu province, China. As most employees at this facility also worked 12-hour shifts, the data are assumed to represent 12-hr TWA. In comparison to the U.S. facility, exposure levels in China are more than two orders of magnitude higher, and the authors/investigators themselves complained of nasal and conjunctival irritation following visits to the facility. Exposure concentration was highest when workers transferred produced solvents into containers.

Table 2-2. Statistical Summary of 8-hr 1-BP TWA Exposures (AC, ADC and LADC) for Manufacturing Based on Monitoring Data (U.S. Facility, Closed System)

Category	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** **AC$_{\text{1-BP, 8-hr TWA}}$** and **ADC$_{\text{1-BP, 8-hr TWA}}$**		**Chronic, Cancer Exposures (ppm)** **LADC$_{\text{1-BP, 8-hr TWA}}$**		Data Points
	High-end (Maximum)	Central tendency	High-end (Maximum)	Central tendency	
Worker [a]	0.27	0.09	0.14	0.04	3

Source: (OSHA, 2013a) (U.S. facility)

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

a – Because OSHA and the company took simultaneous samples, two sets of exposure monitoring data are available for each worker. For the same worker, EPA used the higher of the two TWA exposure results. For the lab technician and the day shift operator, EPA used company results (OSHA experienced a pump malfunction while performing sampling on the lab technician, and OSHA results for the day shift operator were below the reporting limit of 0.007 ppm of OSHA's sampling and analytical method PV2061). For the night shift operator, EPA used OSHA results. The workers worked 12-hour shifts but were not exposed to 1-BP for the entire shift; exposure data are available as 8-hr TWA exposures.

Table 2-3. Statistical Summary of 12-hr 1-BP TWA Exposures (AC, ADC and LADC) for Manufacturing Based on Monitoring Data (Chinese Facility, Open System)

Category	Acute, Non-Cancer Exposures (12-Hour TWAs in ppm) $AC_{1\text{-}BP,\ 12\text{-}hr\ TWA}$		Chronic, Non-Cancer Exposures (24-Hour TWAs in ppm) $ADC_{1\text{-}BP,\ 24\text{-}hr\ TWA}$		Chronic, Cancer Exposures (ppm) $LADC_{1\text{-}BP,\ 24\text{-}hr\ TWA}$		Data Points
	95th Percentile	50th Percentile	95th Percentile	50th Percentile	95th Percentile	50th Percentile	
Worker	167.9	45.2	59.8	16.1	30.7	6.39	26

Source: (Ichihara et al., 2004)

2.2 Import

2.2.1 Process Description

Commodity chemicals such as 1-BP may be 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. The type and size of container will vary depending on customer requirement. In some cases, QC samples may be taken at import sites for analyses. Some import facilities may only serve as storage and distribution locations, and repackaging/sampling may not occur at all import facilities.

1-BP may be imported neat or as a component in a formulation. In the 2016 CDR, most companies reported importing 1-BP at concentrations greater than 90 percent; one company reported importing a formulation containing 1 to 30 percent 1-BP.

The total 1-BP import volume is claimed CBI in the 2016 CDR. However, recent data from other sources estimate an import volume of 10.3 million pounds of brominated derivatives of acrylic hydrocarbons, which includes 1-BP and other chemicals. (ATSDR, 2016)

2.2.2 Number of Sites and Potentially Exposed Workers

In the 2016 CDR, seven companies reported importing 1-BP into the United States during calendar year 2015. In addition, Superior Oil Company, Inc. reported to the CDR but withheld its activity information in Section 2.B.4 of CDR Form U (U.S. EPA, 2017a). Based on its facility address, it is likely an import office, rather than industrial manufacturing facility.

Table 2-4 below summarizes the number of persons (including workers and ONUs) reasonably likely to be exposed to 1-BP at the import facilities, as reported in the 2016 CDR (where available). Of these import facilities, six facilities estimated that fewer than 10 employees per site are likely to be exposed, and one facility estimated 25 to up to 50 employees are likely to be exposed.

Table 2-4. Number of Potentially Exposed Workers at Import Facilities

Company	Facility	Facility Location		Number of Workers [a] Likely to be Exposed	Basis for Import Determination
		City	State		
PHT International	PHT International, Inc.	Charlotte	NC	<10	2016 CDR (Sec. 2.B.4)
Custom Synthesis, LLC	Custom Synthesis LLC	Anderson	SC	25 - <50	2016 CDR (Sec. 2.B.4)
Enviro Tech International Inc	Enviro Tech International Inc	Melrose Park	IL	<10	2016 CDR (Sec. 2.B.4)
ICL North America	ICL-IP America Inc.	St. Louis	MO	<10	2016 CDR (Sec. 2.B.4)
MC International, LLC	MC International, LLC	Miami	FL	<10	2016 CDR (Sec. 2.B.4)
Phoenix Chemical Co Inc	Phoenix Chemical Co	Calhoun	GA	<10	2016 CDR (Sec. 2.B.4)
Superior Oil Company, Inc.	Superior Oil Company, Inc.	Indianapolis	IN	Withheld	2016 CDR (Address)
WEGO Chemical Group	WEGO Chemical & Mineral Corp	Great Neck	NY	<10	2016 CDR (Sec. 2.B.4)
Total				**31 - 103**	

Source: (U.S. EPA, 2017a)
a - May include both workers and ONUs

2.2.3 Exposure Assessment

2.2.3.1 Worker Activities

Workers are potentially exposed during repackaging and sampling, if these activities occur at import sites. Workers near loading racks and container filling stations are potentially exposed to fugitive emissions as containers are filled. They are also potentially exposed via dermal contact with liquid.

ONUs are employees who work at the facility where 1-BP is handled, but who do not directly perform the repackaging and sampling activity. ONUs are expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs include supervisors, managers, and tradesmen.

2.2.3.2 Occupational Exposure Assessment Methodology

EPA has not identified exposure monitoring data for import. Therefore, EPA assessed exposure using the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*. Based on data reported in the 2016 CDR, the model assumes 1-BP is present at 30 and 100 percent concentration in the import formulation for the central tendency and high-end exposure scenario, respectively. The model provides inhalation exposure estimates to volatile liquid chemicals during outdoor loading and unloading activities at an industrial facility. The model accounts for the emissions of saturated air containing the chemical of interest that remains in the loading arm, transfer hose, and related equipment, and emissions from equipment leaks from processing units such as pumps, seals, and valves. The model assumes industrial facilities use a vapor recovery system to minimize air emissions, such that vapor losses from displacement of saturated air inside the container is mitigated using such systems. See Appendix D for detailed description of this model.

For the high-end scenario, the model assumes the use of an engineered loading system, such as a loading arm, and that the operation occurs outdoor with a wind speed of 5 miles per hour (mph). For the central tendency scenario, the model assumes the use of a 12-foot transfer hose with two-inch diameter, with an average outdoor wind speed of 9 mph. For the purpose of this assessment, loading/unloading event is assumed to occur once per work shift. Combining published EPA emission factors and engineering calculations with the *EPA/OPPT Mass Balance Inhalation Model* (peer reviewed), this model estimates central tendency and high-end exposure concentrations for chemical unloading scenarios at industrial facilities.

2.2.3.3 Occupational Exposure Results

As shown in Table 2-5, the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* estimates a high-end and central tendency exposure level of 0.06 ppm and 0.004 ppm as 8-hr TWA, respectively, during container unloading activities. The "high-end" exposure represents a railcar loading scenario, and the "central tendency" exposure represents a tank truck loading scenario. Note the model does not estimate separate exposure levels for workers and ONUs for this activity.

Table 2-5. Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Import and Repackaging Based on Modeling

Category	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** $\mathbf{AC_{1\text{-}BP,\ 8\text{-}hr\ TWA}}$ and $\mathbf{ADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}}$		**Chronic, Cancer Exposures (ppm)** $\mathbf{LADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}}$	
	High-end	Central tendency	High-end	Central tendency
Worker	5.67E-2	3.83E-3	2.91E-2	1.52E-3

2.3 Processing as a Reactant

2.3.1 Process Description

Processing as a reactant or intermediate is the use of 1-BP as a raw material in the production of another chemical, in which 1-BP is reacted and consumed. In the early to mid-1990s, 1-BP was used as an intermediate in the production of pesticides, quaternary ammonium compounds, flavors and fragrances, pharmaceuticals, and other chemicals (HSIA, 2010). In the present day, 1-BP is used as an intermediate in the production of other organic chemicals, inorganic chemicals, pharmaceuticals, pesticides, fertilizers, and other agricultural chemicals (Enviro Tech International, 2017a). The extent of these uses is not known, as the volumes are claimed CBI in the 2016 CDR (HSIA, 2010).

2.3.2 Number of Sites and Potentially Exposed Workers

EPA identified the number of sites and workers using downstream industrial processing and use information reported by manufacturers and importers in Part III, Section A of the CDR Form U. As shown in Table 2-6, 1-BP is potentially used as a chemical intermediate at between three and

27 sites, where 30 to 72 workers and ONUs are potentially exposed. CDR does not differentiate between workers and ONUs. CDR also does not provide the identity of these downstream sites. Information reported under the TRI program indicates Dow Chemical's Midland, MI facility is a processing site (U.S. EPA, 2016b).

Table 2-6. Estimated Number of Sites and Workers for Industrial Intermediate Uses (2016 CDR)

Reporting Company	Type of Process	NAICS code	Industrial Sector	Industrial Function Category	Number of Sites	Number of Workers	Basis for Processing Determination
Albemarle Corporation	Processing as a reactant	32518	All Other Basic Inorganic Chemical Manufacturing	Intermediates	<10	10 - <25	2016 CDR
Chemtura Corporation	Processing as a reactant	32519	All Other Basic Organic Chemical Manufacturing	Intermediates	<10	10 - <25	2016 CDR
Chemtura Corporation	Processing as a reactant	3253	Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing	Intermediates	<10	10 - <25	2016 CDR
Total					**3 - 27**	**30 - 72**	

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

2.3.3 Exposure Assessment

2.3.3.1 Worker Activities

At industrial facilities, workers are potentially exposed when unloading 1-BP from transport containers into intermediate storage tanks and process vessels. Workers may be exposed via inhalation of vapor or via dermal contact with liquids while connecting and disconnecting hoses and transfer lines. Once 1-BP is unloaded into process vessels, it is consumed as a chemical intermediate.

ONUs are employees who work at the facilities that process 1-BP, but who do not directly handle the material. ONUs may also be exposed to 1-BP but are expected to have lower inhalation exposures and are not expected to have dermal exposures. ONUs for this condition of use may include supervisors, managers, engineers, and other personnel in nearby production areas.

2.3.3.2 Occupational Exposure Assessment Methodology

See Section 2.2.3.2 for the assessment of worker exposure from chemical unloading activities. EPA assumes the exposure sources, routes, and exposure levels are similar to those at an import/repackaging facility. The exposure results are presented in Table 2-7.

Table 2-7. Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Processing as a Reactant Based on Modeling

	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $AC_{1\text{-BP, 8-hr TWA}}$ and $ADC_{1\text{-BP, 8-hr TWA}}$		Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 8-hr TWA}}$	
Category	High-end	Central tendency	High-end	Central tendency
Worker	5.67E-2	3.83E-3	2.91E-2	1.52E-3

2.4 Processing – Incorporation into Formulation, Mixture, or Reaction Product

2.4.1 Process Description

After manufacture, 1-BP may be supplied directly to end-users, or may be incorporated into various products and formulations at varying concentrations for further distribution. Incorporation into a formulation, mixture, or reaction product refers to the process of mixing or blending several raw materials to obtain a single product or preparation. For example, formulators may add stabilizing packages to 1-BP for specialized vapor degreasing uses (Enviro Tech International, 2017a) or mix 1-BP with other additives to formulate adhesives, sealants, and other products.

In a 2010 study, Hanley et al. describes the process of formulating adhesive products containing 1-BP at one facility:

> *"…a large variety of glues, sealants, and coatings were manufactured for a multitude of commercial and industrial applications using water-, epoxy-, and organic solvent-based formulas. When charging the batch mixers, large volume solvents (e.g., 1-BP) were dispensed through an enclosed piping manifold system. Solid chemicals were added manually through hatch openings, which otherwise remained closed during mixing. After blending, the finished product was pumped into buckets, drums, or bulk tanks using semi-enclosed methods. Local exhaust ventilation was not provided for the mixing vessels or packaging locations. Instead, each bay on the charging and packing floors were serviced with high volume dilution ventilation consisting of air supply and exhaust system located on opposite walls to produce directional air flow. A solvent blend containing over 96 percent 1-BP was used as the principal solvent in one product line. This adhesive was made approximately once every 45 days*." (Hanley et al., 2010)

It is not known whether the specific equipment and engineering controls cited by Hanley et al. (Hanley et al., 2010) is representative of other facilities. However, the general process activities (e.g., unloading of raw materials into mixing vessels) are likely similar across different formulation facilities.

2.4.2 Number of Sites and Potentially Exposed Workers

EPA identified the number of sites and workers using downstream industrial processing and use information reported by manufacturers and importers in Part III, Section A of the CDR Form U.

As shown in Table 2-8, the number of 1-BP formulation sites ranges from 33 to 99[3]. This range is consistent with the estimate provided in the *Analysis of Economic Impacts of Final nPB [1-bromopropane] rulemaking for Cleaning Solvent Sector* of the SNAP program, which estimated that in 2007, there were seven companies that formulated solvent-based products containing 1-BP, three companies that formulated adhesive products containing 1-BP, an additional 60 small providers of specialty products[4] that contained 1-BP, and approximately 20 or 25 companies that prepared aerosol formulations with 1-BP (U.S. EPA, 2007a). The number of workers and ONUs likely exposed ranges from 220 to 1,046. CDR does not differentiate between workers and ONUs.

Table 2-8. Estimated Number of Sites and Workers for Processing – Incorporation into Formulation, Mixture or Reaction Product (2016 CDR)

Reporting Company	Type of Process	NAICS code	Industrial Sector	Industrial Function Category	Number of Sites	Number of Workers [a]
Albemarle Corporation	Processing - incorporation into formulation, mixture, or reaction product	325998	All Other Chemical Product and Preparation Manufacturing	Solvents (for cleaning or degreasing)	<10	10 - <25
Chemtura Corporation	Processing - incorporation into formulation, mixture, or reaction product	3256	Soap, Cleaning Compound, and Toilet Preparation Manufacturing	Solvents (for cleaning or degreasing)	10 - <25	100 - <500
Custom Synthesis, LLC	Processing - incorporation into formulation, mixture, or reaction product	335	Electrical Equipment, Appliance, and Component Manufacturing	Solvents (for cleaning or degreasing)	10 - <25	100 - <500
ICL	Processing - incorporation into formulation, mixture, or reaction product	334	Computer and Electronic Product Manufacturing	Solvents (for cleaning or degreasing)	10 - <25	NKRA
MC International, LLC	Processing - incorporation into formulation, mixture, or reaction product	32552	Adhesive Manufacturing	Solvents (which become part of product formulation or mixture)	<10	NKRA
PHT International	Processing - incorporation into formulation, mixture, or reaction product	11	Agriculture, Forestry, Fishing and Hunting	Agricultural chemicals (non pesticidal)	NKRA	NKRA

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[3] CDR does not provide the identity of these formulation sites.

[4] In a 2017 public comment, Enviro Tech stated that most of these additional companies merely market the same products produced by one of the seven major solvent manufacturers, sometimes under a private label. Enviro Tech International is a major supplier of 1-BP and fluorinated solvents. (Enviro Tech International, 2017a)

Reporting Company	Type of Process	NAICS code	Industrial Sector	Industrial Function Category	Number of Sites	Number of Workers [a]
Wego Chemical and Mineral Corp.	Processing - incorporation into formulation, mixture, or reaction product	51, 52, 53, 54, 55, 56, 61, 62, 71, 72, 81, 92	Services	Solvents (for cleaning or degreasing)	<10	10 - <25
Total					**33 - 99**	**220 – 1,046**

[a] May include both workers and ONUs
Source: (U.S. EPA, 2017a)

2.4.3 Exposure Assessment

2.4.3.1 Worker Activities

At formulation facilities, workers are potentially exposed when unloading 1-BP into mixing vessels, taking QC samples, and packaging formulated products into containers and tank trucks. The exact activities and associated level of exposure will differ depending on the degree of automation, presence of engineering controls, and use of PPE at each facility.

2.4.3.2 Occupational Exposure Assessment Methodology

For formulation of 1-BP into products, EPA assessed exposure using personal air monitoring data from a formulation facility submitted by Enviro Tech. The facility is dedicated to the production of 1-BP based products; a batch of product containing 80 to 96 percent 1-BP is produced during a single eight-hour shift per year, and production takes place twice per weeks for 50 weeks per year in a closed system with mechanized filling operations.

2.4.3.3 Occupational Exposure Results

Table 2-9 presents the central tendency and high-end exposure levels for employees at this facility. The worker exposure level represents employee exposure when working as the mixing room operator; the mixing room is where all mixing, decanting, and filling operations occur. Employees at this facility work once during the work week as the mixing room operator, and performs other work for the remainder of the week. Exposure levels for occupational non-user represent employee exposure when performing other job duties, primarily in the warehouse, storage, office, areas of the facility where they do not directly handle 1-BP (Enviro Tech International, 2020).

In a separate study, Hanley et al. (2010) measured exposure at an adhesive manufacturing facility. The study did not provide detailed data to allow determination of 50th and 95th percentile exposures, but stated that the geometric mean full-shift (8 to 10 hour) TWA measurement was 3.79 ppm for those who handled 1-BP products (workers), and 0.33 ppm for those who did not use 1-BP (i.e., ONUs). The maximum exposure value was 18.9 ppm TWA for those who directly used 1-BP, and 1.59 ppm TWA for those who did not use 1-BP. This facility does not have local exhaust ventilation, but uses high volume general dilution ventilation to provide directional air flow in the production area (Hanley et al., 2010).

Table 2-9. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Processing/Formulation Based on Monitoring Data

Category	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $AC_{1\text{-}BP,\ 8\text{-}hr\ TWA}$ and $ADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}$		Chronic, Cancer Exposures (ppm) $LADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}$		Data Points
	Central tendency	High-end	Central tendency	High-end	
Worker	7.20		2.86		1
ONU	0.16	0.28	0.06	0.14	10

Source: (Enviro Tech International, 2020)

2.5 Processing – Incorporation into Articles

2.5.1 Process Description

According to EPA's Use Dossier, 1-BP is present at less than 5 percent concentration in the THERMAX$^{\text{TM}}$ brand insulation manufactured by Dow Chemical (EPA-HQ-OPPT-2016-0741-0003). THERMAX$^{\text{TM}}$ is a polyisocyanurate rigid board insulation for interior and exterior applications, and can be used on walls, ceilings, roofs, and crawl spaces in commercial and residential buildings. The product is marketed to have superior durability and fire performance over generic polyisocyanurate insulations.[5] EPA does not have information on the exact process for producing THERMAX$^{\text{TM}}$ and the function of 1-BP in the insulation material (Dow, 2018).

2.5.2 Number of Sites and Potentially Exposed Workers

Dow's website indicates insulation products containing 1-BP are produced at its Pennsauken, NJ facility (Dow, 2018). The number of potentially exposed workers at this specific facility is not known; however, EPA estimated the number of workers at facilities characterized under NAICS 326150[6], "Urethane and Other Foam Product (except Polystyrene) Manufacturing" using Bureau of Labor Statistics' OES data (2015) and U.S. Census SUSB (2012). The method for estimating number of workers is detailed in Appendix A. The analysis indicates an average of 15 potentially exposed workers and 4 ONUs per site.

Table 2-10. Estimated Number of Workers Potentially Exposed during Incorporation of 1-BP into Articles for NAICS 326150

Exposed Workers	Exposed Occupational Non-Users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational Non-Users per Site
15	4	19	1	15	4

2.5.3 Exposure Assessment

2.5.3.1 Worker Activities

The exact process and worker activity at the Dow facility is not known; however, workers at this site may be potentially exposed when unloading 1-BP from transport containers into mixing vessels and taking QC samples. Actual levels of exposure will depend on the degree of automation, presence of engineering controls, and use of PPE.

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[5] https://www.dow.com/en-us/products/thermaxbrandinsulation#sort=%40gtitle%20ascending

[6] The Dow facility reports a primary NAICS of 326150 in the 2016 and 2017 TRI

2.5.3.2 Occupational Exposure Assessment Methodology

EPA did not find monitoring data for this condition of use. EPA modeled exposure using the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*, which estimates high-end and central tendency exposure concentrations for chemical unloading scenarios at industrial setting. See Section 2.2.3.2 for the assessment of worker exposure from chemical unloading activities. The exposure results are presented in Table 2-11.

Table 2-11. Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Processing – Incorporation into Articles Based on Modeling

	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $\mathbf{AC}_{\mathbf{1\text{-}BP,\ 8\text{-}hr\ TWA}}$ and $\mathbf{ADC}_{\mathbf{1\text{-}BP,\ 8\text{-}hr\ TWA}}$		**Chronic, Cancer Exposures (ppm)** $\mathbf{LADC}_{\mathbf{1\text{-}BP,\ 8\text{-}hr\ TWA}}$	
Category	High-end	Central tendency	High-end	Central tendency
Worker	5.67E-2	3.83E-3	2.91E-2	1.52E-3

2.6 Repackaging

2.6.1 Process Description

Chemicals shipped in bulk containers may be repackaged into smaller containers for resale, such as drums or bottles. The type and size of container will vary depending on customer requirement. In some cases, QC samples may be taken at repackaging sites for analyses. Repackaging could occur for both domestic and imported shipments of 1-BP; repackaging activities that occur at import facilities are addressed in Section 2.2.

2.6.2 Number of Sites and Potentially Exposed Workers

EPA identified the number of sites and workers using downstream industrial processing and use information reported by manufacturers and importers in Part III, Section A of the CDR Form U. As shown in Table 2-12, one company reported up to 10 downstream repackaging sites with 10 to up to 25 workers. Another company reported downstream repackaging activities but indicated the number of sites and workers were not known or reasonably ascertainable (U.S. EPA, 2017a). EPA does not know the identity of these sites. In addition, EPA does not know whether these sites are exclusive repackaging sites or whether they also fall under other 1-BP conditions of use.

Table 2-12. Number of Sites and Potentially Exposed Workers for Repackaging (2016 CDR)

Reporting Company	**Type of Process**	**NAICS code**	**Industrial Sector**	**Industrial Function Category**	**Number of Sites**	**Number of Workers** [a]
Albemarle Corporation	Processing – repackaging	325998	All other chemical product and preparation manufacturing	Solvents (for cleaning and degreasing)	<10	10 - <25

Reporting Company	Type of Process	NAICS code	Industrial Sector	Industrial Function Category	Number of Sites	Number of Workers [a]
Phoenix Chemical Co Inc	Processing – repackaging	NKRA	NKRA	NKRA	NKRA	NKRA
Total					**<10**	**10 - <25**

Source: (U.S. EPA, 2017a)
a - May include both workers and ONUs
NKRA – Not known or reasonably ascertainable

2.6.3 Exposure Assessment

2.6.3.1 Worker Activities

During repackaging, workers are potentially exposed while connecting and disconnecting hoses and transfer lines to import bulk containers (e.g., railcars, tank trucks, totes), intermediate storage vessels (e.g., storage tanks, pressure vessels), and final packaging containers (e.g., drums, bottles). Workers near loading racks and container filling stations are potentially exposed to fugitive emissions as containers are filled. They are also potentially exposed via dermal contact with liquid.

ONUs are employees who work at the facility where 1-BP is repackaged, but who do not directly perform the repackaging activity. ONUs are 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.

2.6.3.2 Occupational Exposure Assessment Methodology

EPA has not identified exposure monitoring data for repackaging. Therefore, EPA assessed exposure using the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model*. See Section 2.2.3.2 for the assessment of worker exposure from chemical unloading activities.

2.6.3.3 Occupational Exposure Results

As shown in Table 2-13, the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* estimates a high-end and central tendency exposure level of 0.06 ppm and 0.004 ppm as 8-hr TWA, respectively, during container unloading activities. The "high-end" exposure represents a railcar loading scenario, and the "central tendency" exposure represents a tank truck loading scenario. The model does not estimate separate exposure levels for workers and ONUs for this activity.

Table 2-13. Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Repackaging Based on Modeling

Category	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** **$AC_{1\text{-BP, 8-hr TWA}}$ and $ADC_{1\text{-BP, 8-hr TWA}}$** High-end	Central tendency	**Chronic, Cancer Exposures (ppm)** **$LADC_{1\text{-BP, 8-hr TWA}}$** High-end	Central tendency
Worker	5.67E-2	3.83E-3	2.91E-2	1.52E-3

2.7 Batch Vapor Degreaser (Open-Top)

2.7.1 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 (Enviro Tech International, 2017a):

- 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.

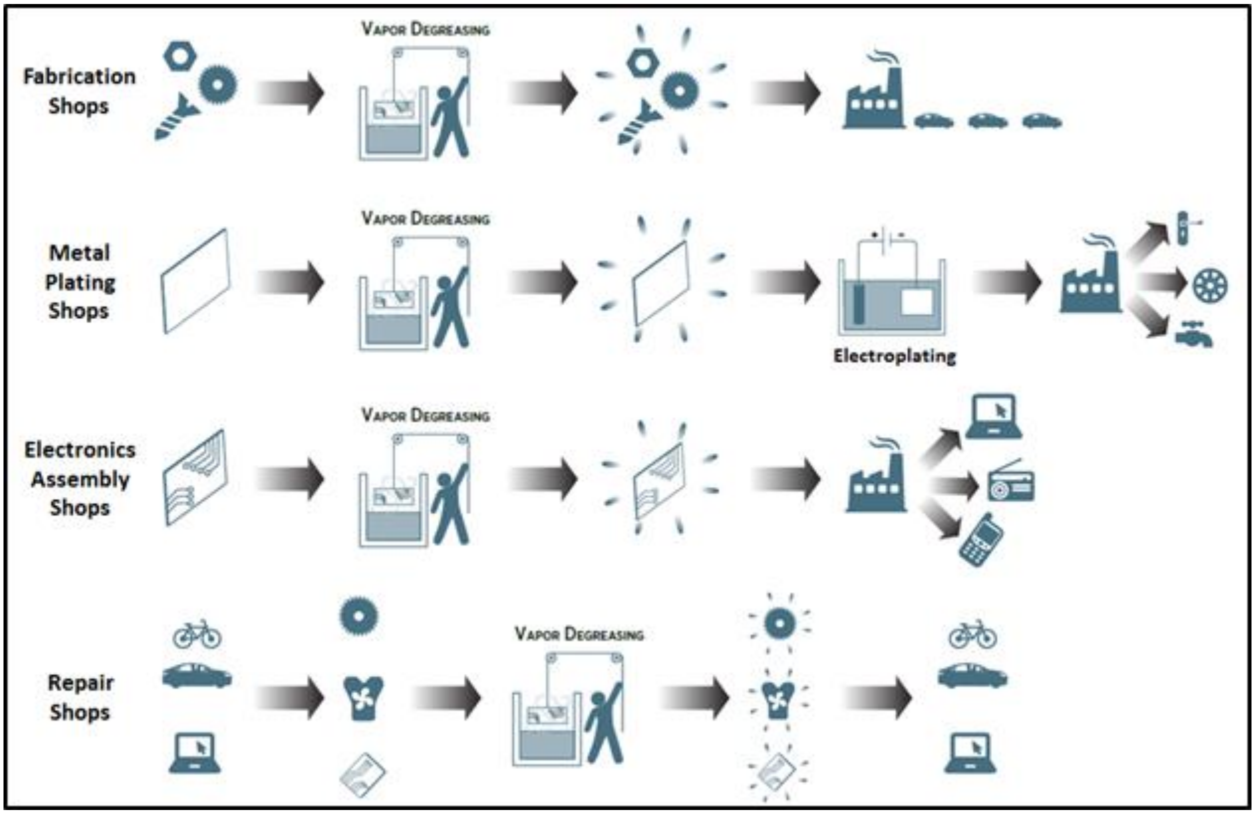

Figure 2-1. Use of Vapor Degreasing in a Variety of Industries

1-BP is often used to replace chlorinated solvents, especially in applications where flammability is a concern (CRC Industries Inc., 2017). 1-BP is also desirable because of its low corrosivity, compatibility with many metals, and suitability for use in most modern vapor degreasing equipment. Vapor degreasing may take place in batches or as part of an in-line (i.e., continuous) system. In batch machines, each load (parts or baskets of parts) is loaded into the machine after the previous load is completed. With in-line systems, parts are continuously loaded into and through the vapor degreasing equipment as well as the subsequent drying steps. Vapor degreasing equipment can generally be categorized into one of the three categories: (1) batch vapor degreasers, (2) conveyorized vapor degreasers and (3) web vapor degreasers.

In batch open-top vapor degreasers (OTVDs), a vapor cleaning zone is created by heating and volatilizing the liquid solvent in the OTVD. Workers manually load or unload fabricated parts directly into or out of the vapor cleaning zone. The tank usually has chillers along the side of the tank to prevent losses of the solvent to the air. However, these chillers are not able to eliminate emissions, and throughout the degreasing process air emissions of the solvent can occur. Additionally, the cost of replacing solvent lost to emissions can be expensive (NEWMOA, 2001). Figure 2-2 illustrates a standard OTVD. The use of 1-BP in OTVD has been previously described in EPA's 2016 Draft Risk Assessment (U.S. EPA, 2016c).

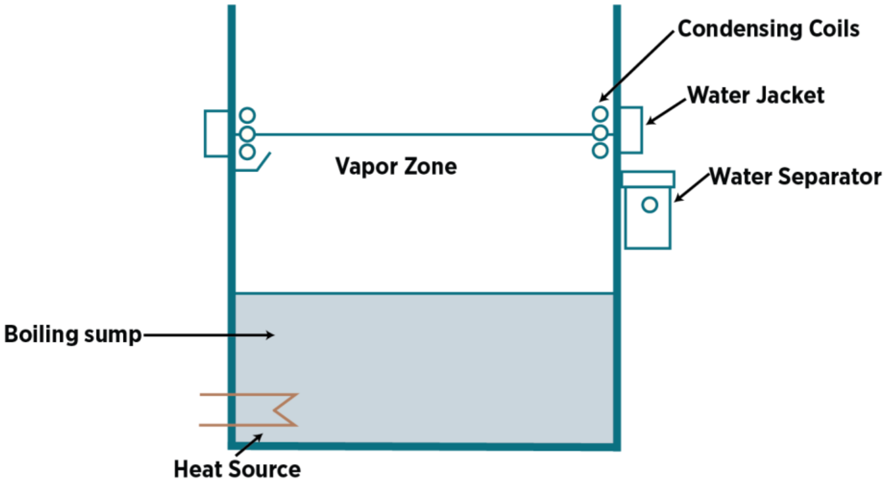

Figure 2-2. Batch Open-Top Vapor Degreaser

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

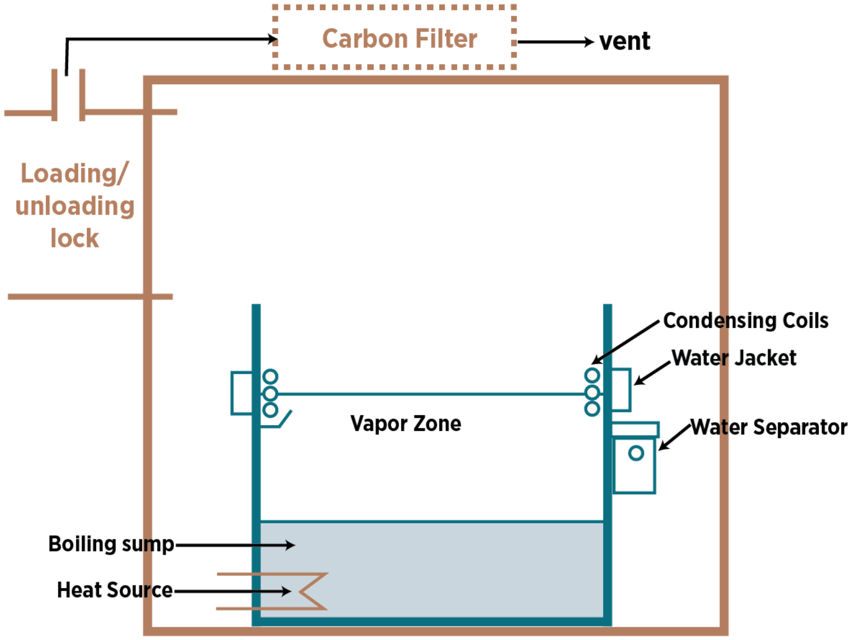

Figure 2-3. Open-Top Vapor Degreaser with Enclosure

2.7.2 Number of Sites and Potentially Exposed Workers

EPA estimated the number of workers potentially exposed to 1-BP in vapor degreasing using Bureau of Labor Statistics' OES data (2015) and U.S. Census SUSB (2012). The method for estimating number of workers is detailed in Appendix A and the 2016 Draft Risk Assessment (U.S. EPA, 2016c). Table 2-14 presents the estimated number of workers and occupational non-users based on industry- and occupational-specific employment data.

The number of businesses that use 1-BP for vapor degreasing is estimated at 500 to 2,500 businesses (CDC, 2016). EPA assumes each business equates to one site and that each site has one degreasing unit. The total number of potentially exposed workers and occupational non-users is estimated at 4,712 to 23,558. Because EPA was unable to determine which industry sectors and occupations perform specific degreasing types (e.g., OTVD, conveyorized vapor degreasing, cold cleaning), these estimates likely cover a range of degreasing operations and are not specific to OTVD.

Table 2-14. Estimated Number of Workers Potentially Exposed to 1-BP in Degreasing Uses

Exposed Workers	Exposed Occupational non-users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational non-users per Site
Low-end					
3,245	1,466	4,712	500	6	3
High-end					
16,226	7,332	23,558	2,500	6	3

Note: 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. Values are rounded to the nearest integer.

2.7.3 Exposure Assessment

2.7.3.1 Worker Activities

When operating a batch vapor degreaser, 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). Worker exposure is also possible while charging new solvent or disposing spent solvent.

2.7.3.2 Occupational Exposure Assessment Methodology

For vapor degreasing, EPA assessed exposure using available monitoring data and model results.

2.7.3.3 Occupational Exposure Results

Monitoring Data

Table 2-15 summarizes the 1-BP exposure data for vapor degreasing operations. EPA obtained exposure monitoring data from several sources, including journal articles (e.g., (Hanley et al., 2010)), public comments, NIOSH Health Hazard Evaluations (HHEs), the OSHA Chemical Exposure Health Data (CEHD) database, and data submitted to EPA's SNAP program. 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. OSHA CEHD are workplace monitoring data from OSHA inspections; EPA SNAP program data are collected as part of the EPA's effort to identify substitutes for ozone-depleting substances. Some of these data, such as monitoring data conducted during OSHA inspections, are not intended to be representative of typical exposure levels.

Data from these sources cover exposure at a variety of industries that conduct vapor degreasing, including telecommunication device manufacturing, aerospace parts manufacturing, electronics parts manufacturing, helicopter transmission manufacturing, hydraulic power control component manufacturing, metal product fabrication, optical prism and assembly, and printed circuit board manufacturing. It should be noted that sources that only contain a statistical summary of worker exposure monitoring, but exclude the detailed monitoring results, are not included in EPA's analysis below.

Most of the gathered data were for batch open-top vapor degreasers, except for data from OSHA and EPA's SNAP program, where the type of degreaser is typically not specified. EPA included these data in the analysis despite uncertainty in the degreaser type.

Monitoring data show exposure levels can vary widely depending on several factors, including facility ventilation, degreaser design (e.g., freeboard ratio), or the presence of an enclosure. The 2016 draft Risk Assessment previously categorized data as either pre- or post-Engineering Control. After further evaluation, EPA removed these categories because we determined there is insufficient information on engineering control at all facilities to accurately characterize the dataset.

EPA defined a vapor degreasing "worker" as an employee who operates or performs maintenance tasks on the degreaser, such as draining, cleaning, and charging the degreaser bath tank. EPA defined “occupational non-user” as an employee who does not handle 1-BP but performs work in the surrounding area. Some data sources do not describe their work activities in detail, and the exact proximity of these occupational non-users to the degreaser is unknown. As shown in the table, workers are exposed to 1-BP, with 95th and 50th percentile exposures of 49.4 and 6.70 ppm as 8-hr TWA, respectively. For occupational non-users, the 95th and 50th percentile exposure levels are below 3 ppm as 8-hr TWA.

Table 2-15. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Vapor Degreasing Based on Monitoring Data

	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $\mathbf{AC_{1\text{-}BP,\ 8\text{-}hr\ TWA}}$ and $\mathbf{ADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}}$		**Chronic, Cancer Exposures (ppm)** $\mathbf{LADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}}$		
Category	95th Percentile	50th Percentile	95th Percentile	50th Percentile	Data Points
Worker	49.3	6.70	25.3	2.66	155
ONU	0.46	0.10	0.24	0.04	75

Source: (OSHA, 2013b; NIOSH, 2001) (OSHA, 2019) (U.S. EPA, 2006b) (Miller, 2019).

Model Data

The Vapor Degreasing model, including all model input parameters, was previously peer reviewed as part of the 2016 draft 1-BP Risk Assessment. 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 vapor degreasing (Keil, 2009). As the figure shows, volatile 1-BP 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 1-BP, 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 1-BP dissipates into the far-field, resulting in occupational non-user exposures to 1-BP at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the 1-BP dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly 1-BP dissipates out of the surrounding space and into the outside air.

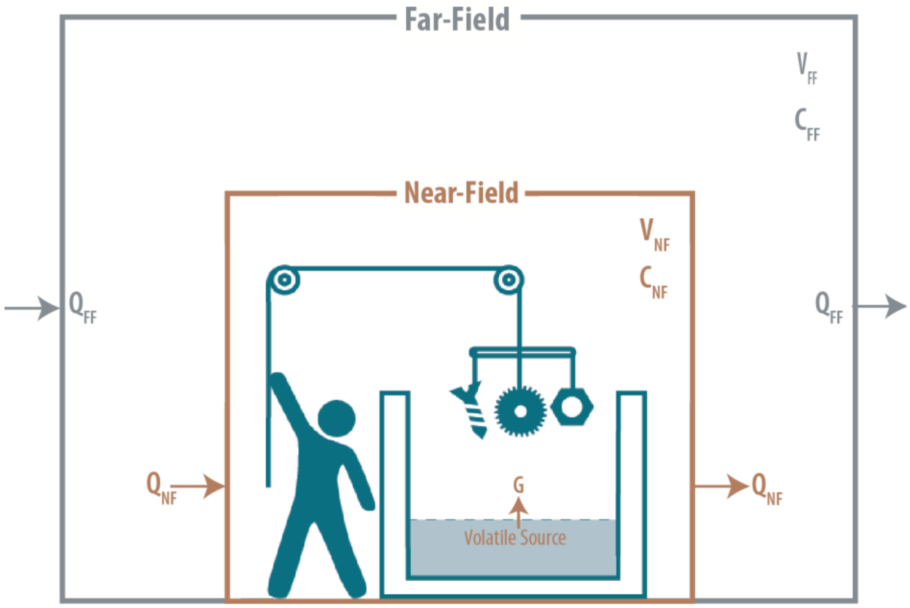

Figure 2-4. Schematic of the Near-Field/Far-Field Model for Vapor Degreasing

Appendix E presents the equations, model parameters, parameter distributions, and assumptions for the 1-BP vapor degreasing model. To estimate the 1-BP vapor generation rate, the model references an emission factor developed by the California Air Resources Board (CARB) for the California Solvent Cleaning Emissions Inventories (CARB, 2011). CARB surveyed facilities that conduct solvent cleaning operations and gathered site-specific information for 213 facilities. CARB estimated a 1-BP emission factor averaging 10.43 lb/employee-yr, with a standard deviation of 17.24 lb/employee-yr, where the basis is the total number of employees at a facility. The majority of 1-BP emissions were attributed to the vapor degreasing category.

The “vapor degreasing” category in CARB’s study includes the batch-loaded vapor degreaser, aerosol surface preparation process, and aerosol cleaning process. It is not known what percentage, if any, of the 1-BP emission factor is derived from aerosol applications. This modeling approach assumes the 1-BP emission factor is entirely attributed to vapor degreasing applications. The emission factor is expected to represent emissions from batch-loaded degreasers used in California at the time of study. It is not known whether these are specifically open-top batch degreasers, although open-top is expected to be the most common design. The CARB survey data did not include emissions for conveyorized vapor degreasers.

The CARB emission factor is then combined with U.S. employment data for vapor degreasing industry sectors from the Economic Census[7]. The 1-BP RA identified 78 NAICS industry codes that are applicable to vapor degreasing. For these industry codes, the Census data set indicates a minimum industry average of 8 employees per site, with a 50th percentile and 90th percentile of

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[7] For the purpose of modeling, EPA/OPPT used data from the 2007 Economic Census for the vapor degreasing NAICS codes as identified in the TCE RA (U.S. EPA, 2014b). The 2012 Economic Census did not have employment data (average number of employees per establishment) for all vapor degreasing NAICS codes of interest.

25 and 61 employees per site, respectively. A lognormal distribution is applied to the Census data set to model the distribution of the industry-average number of employees per site for the NAICS codes applicable to vapor degreasing.

These nationwide Census employment data are comparable to the 2008 California employment data cited in CARB's study. According to the CARB study, approximately 90 percent of solvent cleaning facilities in California had less than 50 employees (whereas the national Census data estimate 90 percent of facilities have less than or equal to 61 employees). Census data report an average number of employees per site for each NAICS code. The number of employees for each individual site within each NAICS code is not reported. Therefore, the distribution EPA calculated represents a population of *average* facility size for each NAICS code, and not the population of *individual* facility sizes over all NAICS codes.

The vapor generation rate, G (kg/unit-hr), is calculated *in-situ* within the model, as follows:

Equation 2-1 for Calculating Vapor Degreasing Vapor Generation Rate

$$G = EF \times EMP / (2.20462 \times OH \times OD \times U)$$

Where EF = emission factor (lb/employee-yr)
EMP = Number of employees (employee/site)
OH = Operating hours per day (hr/day)
OD = Operating days per year (day/yr)
U = Number of degreasing units (unit/site)
2.20462 = Unit conversion from lb to kg (lb/kg)

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[8] 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 8-hr acute exposure, ADC, and LADC.

Table 2-16 presents a statistical summary of the exposure modeling results. These exposure estimates represent modeled exposures for the workers and occupational non-users. For workers, the baseline (pre-engineering control) 50th percentile exposure is 1.89 ppm 8-hr TWA, with a 95th percentile of 23.9 ppm 8-hr TWA. Compared to literature studies:

- Hanley et al. (2010) reported a geometric mean of 2.63 ppm 8-hr TWA exposure with a range of 0.078 to 21.4 ppm 8-hr TWA among 44 samples;
- NIOSH (2001) reported a range of 0.01 to 0.63 ppm 8-hr TWA among 20 samples; and

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[8] A risk analysis software tool (Microsoft Excel add-in) using Monte Carlo simulation.

- A 2003 EPA analysis suggested that 87 percent of the samples were less than 25 ppm 8-hr TWA among 500 samples at vapor degreasing facilities (U.S. EPA, 2003).

The modeled mean near-field exposure is found to be generally comparable to the exposures reported in literature. For occupational non-users, the modeled far-field exposure has a 50th percentile value of 0.99 ppm and a 95th percentile of 13.5 ppm 8-hr TWA. These modeled far-field results are somewhat higher than reported literature values. (Hanley et al., 2010) reported workers away from the degreasers are exposed at concentrations of 0.077 to 1.69 ppm 8-hr TWA, with a geometric mean of 0.308 ppm 8-hr TWA. The modeled exposures represent the potential exposure associated with batch-loaded degreasers, which could include both OTVD and batch-loaded, closed-loop vapor degreasers.

The model also presents a “post-Engineering Control” (post-EC) scenario by applying a 90 percent emission reduction factor to the baseline, pre-EC scenario. The estimate is based on a Wadden et al. (1989) study, which indicates a LEV system for an open-top vapor degreaser (lateral exhaust hoods installed on two sides of the tank) can be 90 percent effective (Wadden et al., 1989). This assumption is likely an overestimate because the study covered only reductions in degreaser machine emissions due to LEV and did not address other sources of emissions such as dragout, fresh and waste solvent storage and handling. Furthermore, a caveat in the study is that most LEV likely do not achieve ACGIH design exhaust flow rates, indicating that the emission reductions in many units may not be optimized. Actual exposure reductions from added engineering controls can be highly variable.

Table 2-16. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Vapor Degreasing Based on Modeling

	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) **$AC_{1\text{-BP, 8-hr TWA}}$** and **$ADC_{1\text{-BP, 8-hr TWA}}$**		**Chronic, Cancer Exposures (ppm)** **$LADC_{1\text{-BP, 8-hr TWA}}$**	
Category	95th Percentile	50th Percentile	95th Percentile	50th Percentile
Worker, Pre EC	23.9	1.89	9.19	0.70
Worker, Post EC 90%	2.39	0.19	0.92	0.07
ONU, Pre EC	13.5	0.99	5.23	0.37
ONU, Post EC 90%	1.35	0.10	0.52	0.04

Pre-EC: refers to modeling where no reduction due to engineering controls was assumed
Post-EC: refers to modeling where engineering controls with 90% efficiency were implemented

2.8 Batch Vapor Degreaser (Closed-Loop)

2.8.1 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.

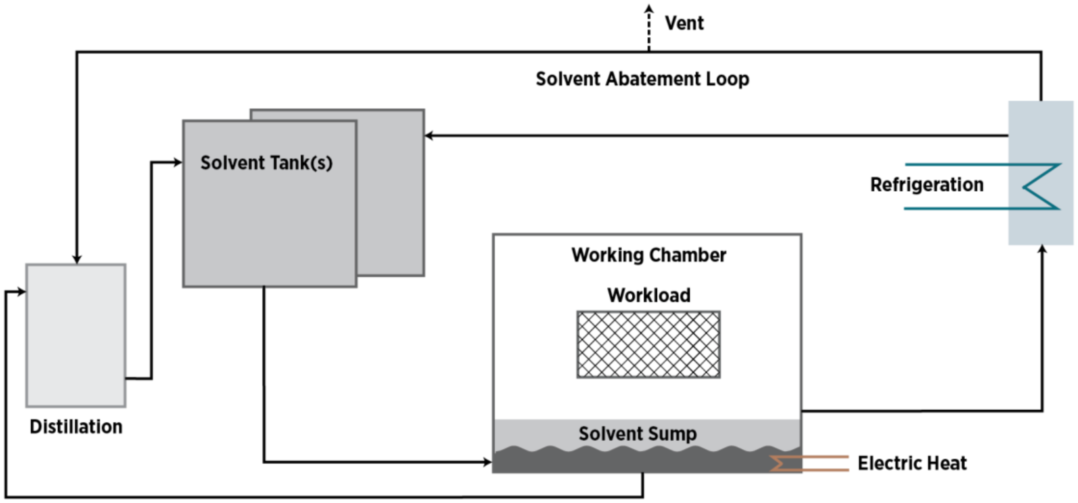

Figure 2-5. Closed-loop/Vacuum vapor Degreaser

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.

2.8.2 Number of Sites and Potentially Exposed Workers

According to IRTA, there may be as many as 2,000 vacuum degreasers in the U.S., of which approximately 100 systems use 1-BP (IRTA, 2016)[9]. Table 2-17 presents the estimated number of workers and ONUs at 100 facilities, assuming one unit per facility. It is unclear whether these approximately 100 facilities are a subset of those facilities presented in Section 2.7.2.

Table 2-17. Estimated Number of Workers Potentially Exposed to 1-BP in Batch Closed-Loop Degreasing

Exposed Workers	Exposed Occupational non-users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational non-users per Site
649	293	942	100	6	3

Note: 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. Values are rounded to the nearest integer.

2.8.3 Exposure Assessment

2.8.3.1 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.

2.8.3.2 Occupational Exposure Assessment Methodology

There are no 1-BP monitoring data specific to closed-loop degreasers. A NEWMOA study states air emissions can be reduced by 98 percent or more when a closed-loop degreaser is used instead of an open-top vapor degreaser (NEWMOA, 2001). This reduction factor is applied to the vapor degreasing model results presented in Section 2.7.3.3 to estimate exposure to batch closed-loop vapor degreasers. The approach assumes the CARB emission factor primarily represents emissions from OTVDs, rather than other types of batch-loaded degreasers.

2.8.3.1 Occupational Exposure Results

Table 2-18 presents the exposure model results for batch closed-loop vapor degreasers. For workers, the 95th and 50th percentile exposure levels are 0.48 and 0.04 ppm as 8-hr TWA. For occupational non-users, the 95th and 50th percentile exposure levels are 0.27 and 0.02 ppm as 8-hr TWA, respectively.

Table 2-18. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Batch Closed-Loop Vapor Degreasing Based on Modeling

Category	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** **$AC_{1\text{-BP, 8-hr TWA}}$** and **$ADC_{1\text{-BP, 8-hr TWA}}$**		**Chronic, Cancer Exposures (ppm)** **$LADC_{1\text{-BP, 8-hr TWA}}$**	
	95th Percentile	50th Percentile	95th Percentile	50th Percentile
Worker	0.48	0.04	0.18	0.01
ONU	0.27	0.02	0.10	0.01

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[9] It is unclear whether the IRTA estimate includes other types of closed-loop degreasers.

2.9 In-line Vapor Degreaser (Conveyorized)

2.9.1 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 large number of parts need to be 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). 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.

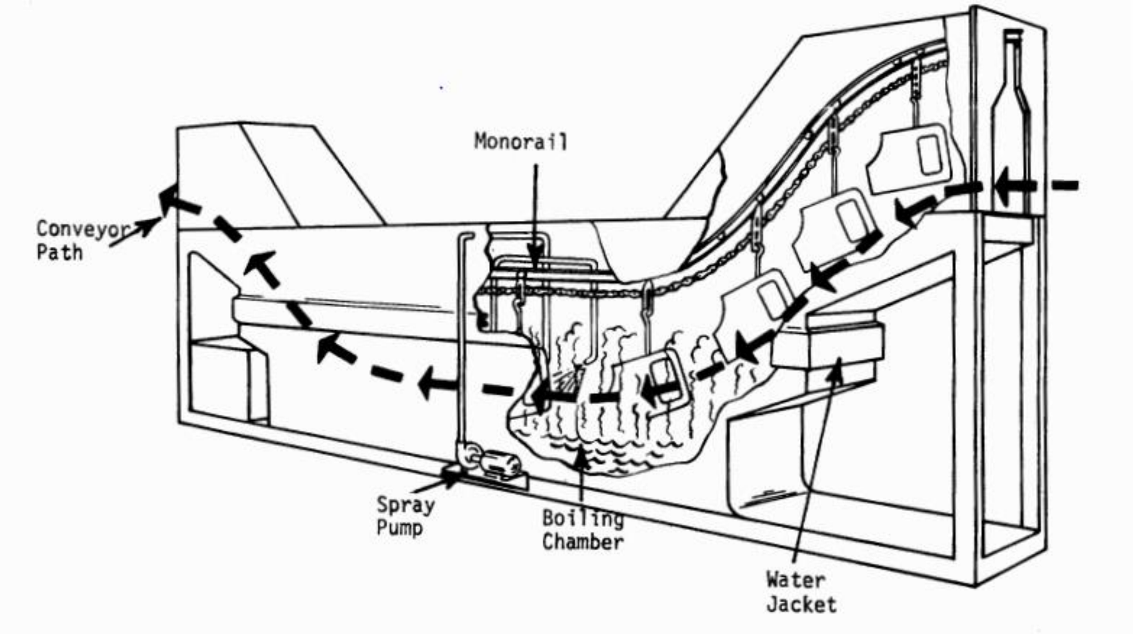

Figure 2-6. Monorail Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- 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.

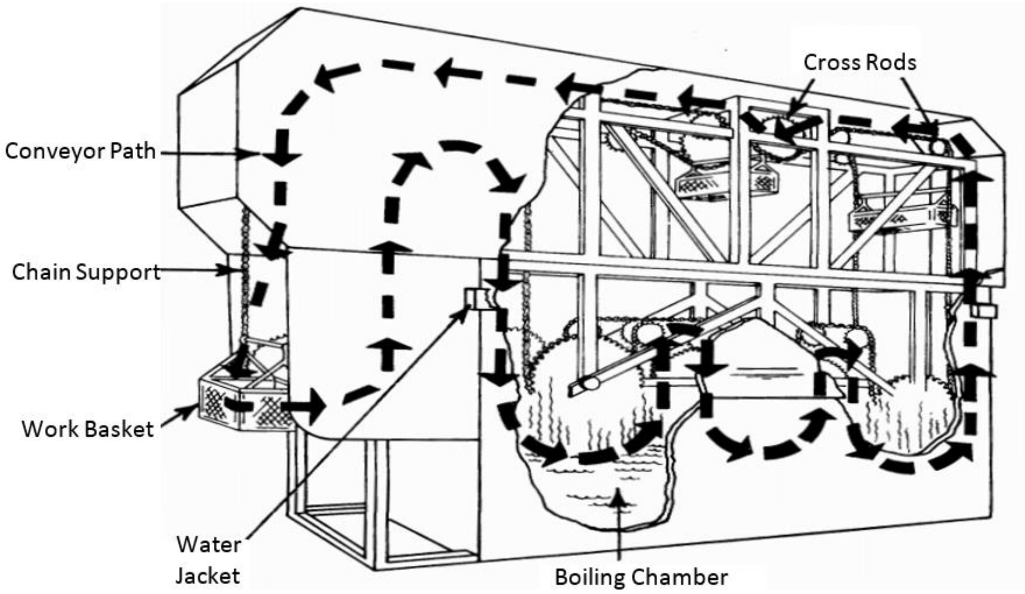

Figure 2-7. Cross-Rod Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- 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.

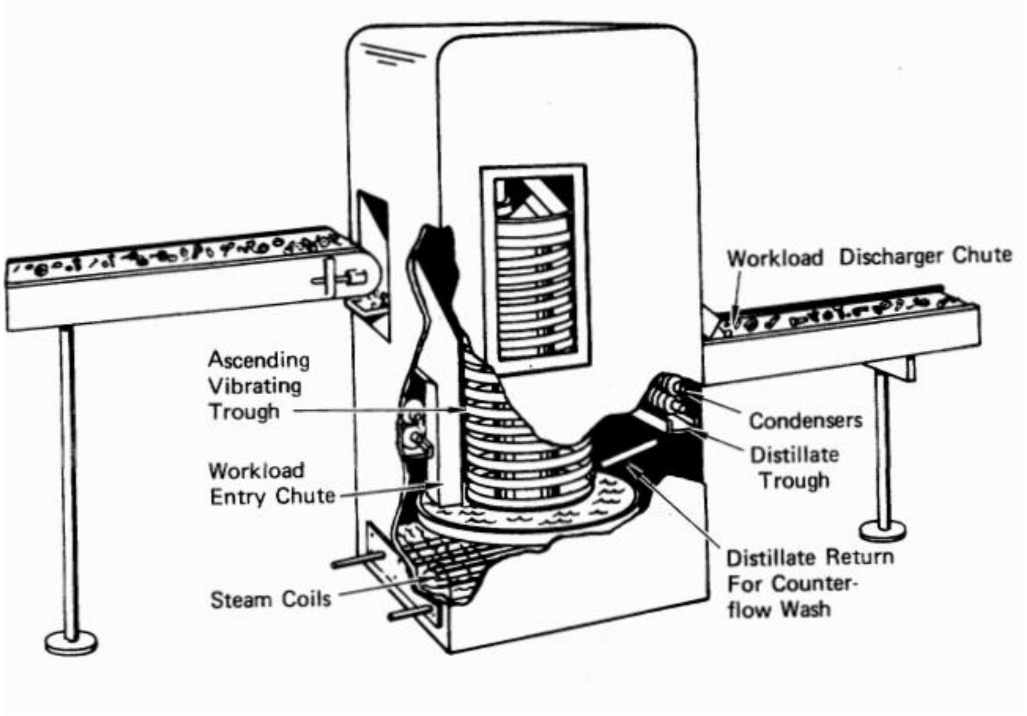

Figure 2-8. Vibra Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- Ferris wheel degreasers – Ferris wheel degreasing systems are generally the smallest of all the conveyorized degreasers. In these systems, parts are manually loaded into perforated baskets or cylinders and then rotated vertically through the cleaning zone and back out (U.S. EPA, 1977). Figure 2-9 illustrates a typical ferris wheel degreaser.

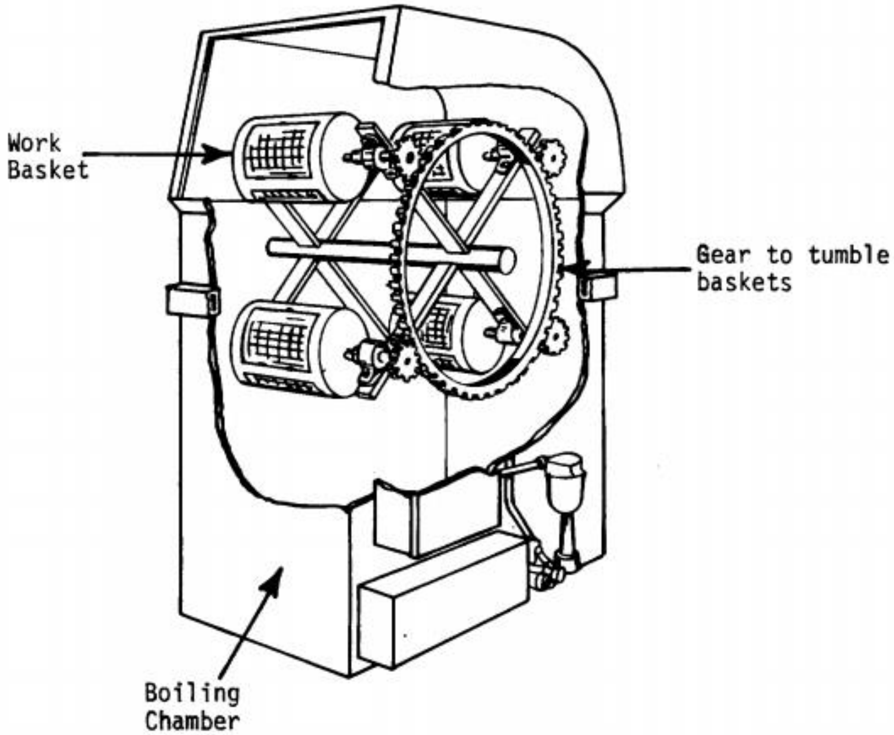

Figure 2-9. Ferris Wheel Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

- Belt degreasing systems (similar to strip degreasers; see next bullet) are used when simple and rapid loading and unloading of parts is desired. Parts are loaded onto a mesh conveyor belt that transports them through the cleaning zone and out the other side (U.S. EPA, 1977). Figure 2-10 illustrates a typical belt or strip degreaser.

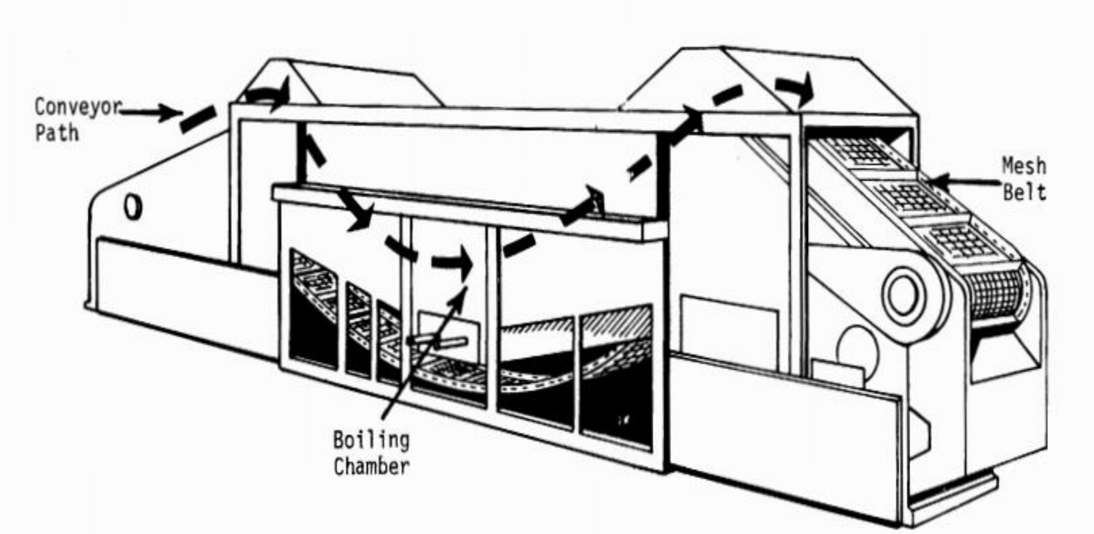

Figure 2-10. Belt/Strip Conveyorized Vapor Degreasing System (U.S. EPA, 1977)

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

- 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).

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, 2006a). 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, 2006a). The parts are then recoiled or cut after exiting the cleaning machine (Kanegsberg and Kanegsberg, 2011) (U.S. EPA, 2006a). Figure 2-11 illustrates a typical continuous web cleaning machine.

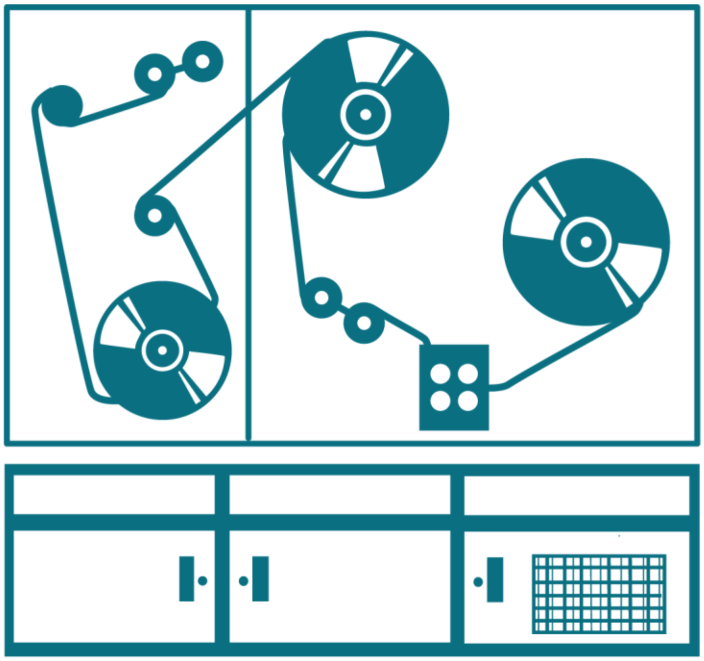

Figure 2-11. Continuous Web Vapor Degreasing System

2.9.2 Number of Sites and Potentially Exposed Workers

According to IRTA, there are likely 1,000 conveyorized systems in use, of which 80 percent (800 systems) use 1-BP (IRTA, 2016). Table 2-19 presents the estimated number of workers and ONUs for these systems, based on the average number of worker and ONU per site from the BLS data analysis.

Table 2-19. Estimated Number of Workers Potentially Exposed to 1-BP for Conveyorized Vapor Degreasers

Exposed Workers	Exposed Occupational non-users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational non-users per Site
5,192	2,346	7,538	800	6	3

Note: 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. Values are rounded to the nearest integer.

2.9.3 Exposure Assessment

2.9.3.1 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.

2.9.3.2 Occupational Exposure Assessment Methodology

There are no monitoring data specific to conveyorized degreasers that use 1-BP. Additionally, there is not sufficient data to model exposure to 1-BP from these degreasers.

Table 2-20 compares the emission rates and operating hours for OTVD and conveyorized vapor degreasers from the 2014 NEI. While NEI does not contain data specific to 1-BP, data for dichloromethane (DCM), perchloroethylene (Perc), and trichloroethylene (TCE) show that emissions from conveyorized vapor degreasers are generally similar to that from OTVDs. EPA assumed the associated worker exposure for conveyorized degreasers may be similar to the exposure levels presented in Section 2.7.3.3.

Table 2-20. Statistics of OTVD and Conveyorized Degreaser Emissions and Operating Time Data from 2014 NEI

	OTVD						Conveyor					
	DCM		Perc		TCE		DCM		Perc		TCE	
	kg/unit-hr	**Operating hr/yr**	**kg/unit-hr**	**Operating hr/yr**	**kg/unit-hr**	**Operating hr/yr**	**kg/unit-hr**	**Operating hr/yr**	**kg/unit-hr**	**Operating hr/yr**	**kg/unit-hr**	**Operating hr/yr**
Max	2.72	3,600	18.05	8,760	46.72	8,760	2.63	2,080	1.85	4,335	32.88	8,736
95th pct	2.49	3,360	11.47	8,760	5.16	8,736	2.61	2,028			29.66	8,736
50th pct	1.44	1,560	0.18	2,080	0.49	2,080	2.42	1,560			0.69	8,736
Mean	1.34	1,827	2.22	4,463	1.99	3,562	2.42	1,560			11.31	8,224
25th pct	0.81	1,176	0.02	1,000	0.05	1,028	2.31	1,300			0.52	7,968
Min	0.00	500	0.00	1	0.00	1	2.20	1,040			0.36	7,200
Count	9	9	15	15	87	87	2	2	1	1	3	3
Number of Units	18	--	23	--	149	--	3		1		8	
Number of Sites	12	--	19	--	115	--	3		1		8	
Avg Units/Site	1.50	--	1.21	--	1.30	--	1		1		1	

Source: (U.S. EPA, 2018a).

2.10 Cold Cleaner

2.10.1 Process Description

Cold cleaners are non-boiling solvent degreasing units. Cold cleaning operations include spraying, brushing, flushing, and immersion. Figure 2-12 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, 2006a). 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, 2006a).

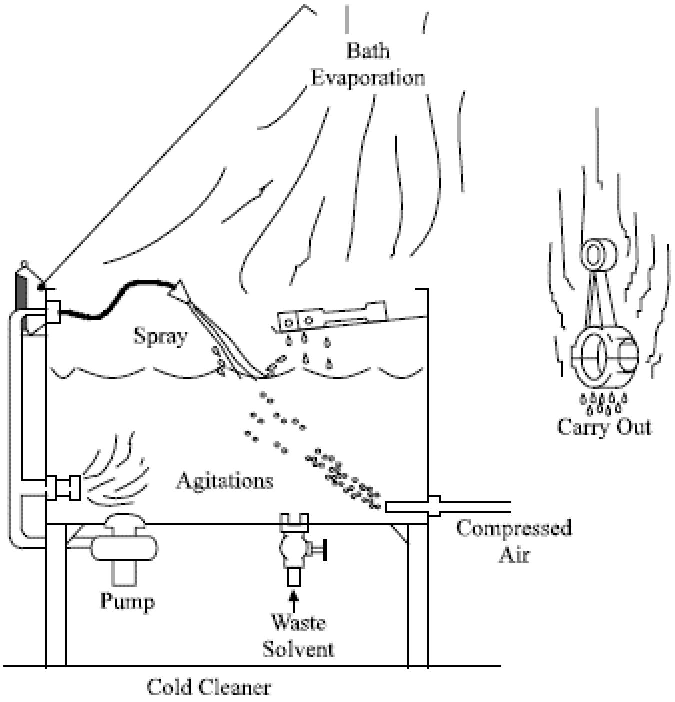

Figure 2-12. Typical Batch-Loaded, Maintenance Cold Cleaner (U.S. EPA, 1981)

2.10.2 Number of Sites Potentially Exposed Workers

There is no information to determine the number of sites that operate 1-BP cold cleaners, and the number of potentially exposed workers and occupational non-users. It is possible that some of the degreasing facilities presented in Section 2.7.2 also use 1-BP as a cold cleaning solvent.

2.10.3 Exposure Assessment

2.10.3.1 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 or 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 cleaning is performed including directly spraying, agitation, wiping or brushing (NIOSH, 2001; U.S. EPA, 1997).

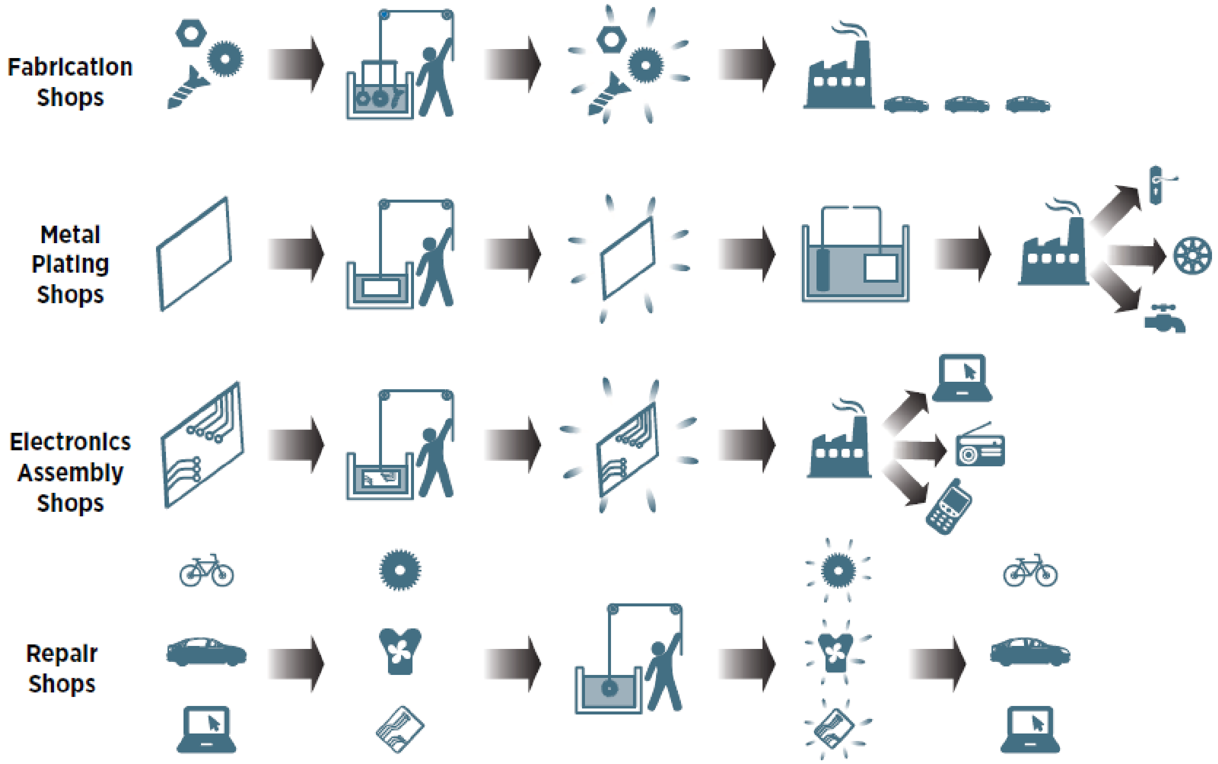

Figure 2-13. Illustration for Use of Cold Cleaner in a Variety of Industries

2.10.3.2 Occupational Exposure Assessment Methodology

Occupational exposure to 1-BP used in cold cleaning is assessed using both monitoring data and modeling results.

2.10.3.3 Occupational Exposure Results

Monitoring Data

Table 2-21 presents OSHA CEHD for two facilities. The first facility uses 1-BP to clean parts in an immersion process in an area with general ventilation. The second facility uses 1-BP in a degreasing tank equipped with a spray nozzle. The degreasing operation is conducted in an area with local exhaust ventilation. Based on available process description, EPA assumes these facilities operate a cold cleaner, even though the equipment is not described in detail in the OSHA CEHD. Among the five available data points for workers, the maximum and central tendency exposures are 7.40 and 4.30 ppm 8-hr TWA, respectively. For occupational non-users, the exposure value is based on a single data point for a Chemical Safety and Health Officer (CSHO), who is an official from OSHA or a state plan occupational safety and health program. The exposure for this individual measured 2.60 ppm 8-hr TWA. EPA presents this data point as what-if exposure for an occupational non-user; the exposure level may not be representative because the CSHO is not regularly present in the production area. It should be further noted that CEHD are obtained from OSHA inspections, and not intended to be representative of typical worker exposure.

Table 2-21. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Cold Cleaning Based on Monitoring Data

Category	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** $\mathbf{AC}_{\text{1-BP, 8-hr TWA}}$ and $\mathbf{ADC}_{\text{1-BP, 8-hr TWA}}$		**Chronic, Cancer Exposures (ppm)** $\mathbf{LADC}_{\text{1-BP, 8-hr TWA}}$		Data Points
	High-end (max)	Central tendency	High-end (max)	Central tendency	
Worker	7.40	4.30	3.79	1.71	5
ONU	2.60 (what-if)		1.33	1.0	1

Source: (OSHA, 2013b).
What-if: Represents a what-if inhalation exposure level for occupational non-user based on a single data point.

Model Data

The Cold Cleaning model, including all model input parameters, was previously peer reviewed as part of the 2016 draft 1-BP Risk Assessment. A more detailed description of the modeling approach is provided in Appendix F.

The EPA AP-42, *Compilations of Air Pollution Emission Factors* contains emission factors and process information developed and compiled from source test data, material balance studies, and engineering estimates (U.S. EPA, 1981). Chapter 4.6 provides generic, non-methane VOC emission factors for several solvent cleaning operations, including cold cleaning and vapor degreasing. These emission factors suggest that cold cleaning emissions range from 3.2 to 57.1 percent of the emissions from a traditional open-top vapor degreaser (U.S. EPA, 1981). It is not known whether the emission factors derived using VOC data would be representative of 1-BP emissions, or whether the emission reduction when switching from vapor degreasing to cold cleaning would be similar across different chemicals. To model exposures during 1-BP cold cleaning, an exposure reduction factor, RF, with uniform distribution from 0.032 to 0.571 is applied to the vapor generation rate in the vapor degreasing model.

Figure 2-14 presents the model approach for cold cleaning. Except for the exposure reduction factor, the model approach and input parameters for cold cleaning are identical to those previously presented for batch vapor degreasing. EPA performed a Monte Carlo simulation with 100,000 iterations and the Latin Hypercube sampling method in @Risk to estimate 8-hr TWA near-field and far-field exposures, acute exposures, ADCs, and LADCs. Note the cold cleaning model approach and the underlying data used (i.e., EPA AP-42) do not differentiate between a spray versus immersion cold cleaner.

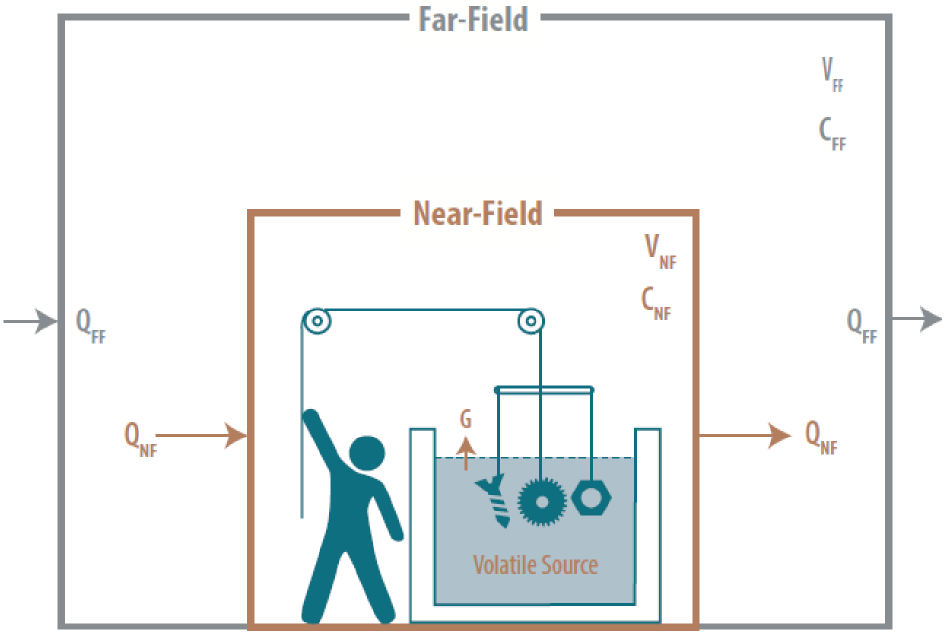

Figure 2-14. The Near-Field/Far-field Model for Cold Cleaning Scenario

Table 2-22 presents a statistical summary of the exposure modeling results. For workers, the 95th and 50th percentile exposures are 11.91 ppm and 0.55 ppm 8-hr TWA. These exposure levels are substantially lower than monitoring data. For occupational non-users, the 95th and 50th percentile exposures are 6.83 ppm and 0.29 ppm 8-hr TWA.

Table 2-22. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Cold Cleaning Based on Modeling

Category	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** **AC$_{\text{1-BP, 8-hr TWA}}$** and **ADC$_{\text{1-BP, 8-hr TWA}}$**		**Chronic, Cancer Exposures (ppm)** **LADC$_{\text{1-BP, 8-hr TWA}}$**	
	95th Percentile	50th Percentile	95th Percentile	50th Percentile
Worker	11.91	0.55	4.59	0.21
ONU	6.83	0.29	2.63	0.11

2.11 Aerosol Spray Degreaser/Cleaner

2.11.1 Process Description

Aerosol degreasing is a process that uses an aerosolized solvent spray, typically applied from a pressurized can, to remove residual contaminants from fabricated parts. Based on identified safety data sheets (SDS), 1-BP-based formulations typically use carbon dioxide, liquified petroleum gas (LPG) (i.e., propane and butane), 1,1,1,2-tetrafluoroethane, 1,1-difluoroethane, and pentafluorobutane as the carrier gas (U.S. EPA, 2017b). The aerosol droplets bead up on the fabricated part and then drip off, carrying away any contaminants and leaving behind a clean surface.

Figure 2-15 illustrates the typical process of using aerosol degreasing to clean components in commercial settings. One example of a commercial setting with aerosol degreasing operations is repair shops, where service items are cleaned to remove any contaminants that would otherwise compromise the service item's operation. Internal components may be cleaned in place or removed from the service item, cleaned, and then re-installed once dry (U.S. EPA, 2014a). Example uses of aerosol products containing 1-BP include brake cleaning, cable cleaning, aircraft degreasing, general purpose degreasing, and metal product cleaning applications.

Figure 2-15. Overview of Aerosol degreasing

2.11.2 Number of Sites and Potentially Exposed Workers

NAICS industry sectors relevant to aerosol degreasing and BLS occupation codes where workers are potentially exposed to degreasing solvents are detailed in the 2016 draft Risk Assessment. EPA assumed the types of occupation with potential solvent exposure are similar between vapor degreasing and aerosol degreasing.

There are 222,940 establishments among the industry sectors represented in Table 2-23. The EPA market report on 1-BP estimated that "*1,000 to 5,000 businesses used 1-BP-based aerosol solvents in 2002* (U.S. EPA, 2007b), as cited in (U.S. EPA, 2013b)." This translates to a market penetration of approximately 0.4 percent to 2.2 percent. Based on these estimates, approximately 2,466 to 12,329 workers and occupational non-users are potentially exposed to 1-BP as an aerosol degreasing solvent. It is unclear whether the number of establishments using 1-BP-based aerosol solvents has changed substantially since 2002. EPA did not receive additional information on this issue as part of the public comment on the draft Risk Evaluation.

Table 2-23. Estimated Number of Workers Potentially Exposed to 1-BP in Aerosol Degreasing

Exposed Workers	Exposed Occupational non-users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational non-users per Site
Low-end					
2,227	238	2,465	1,000	2	0.2
High-end					
11,137	1,192	12,329	5,000	2	0.2

Note: 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 0.2, as it rounds down to zero.

2.11.3 Exposure Assessment

2.11.3.1 Worker Activities

For aerosol degreasing, worker activities involve manual spraying of 1-BP products from an aerosol can onto a substrate, and then subsequently wiping of that substrate. The same worker may also perform other types of degreasing activities, if those process operations are present at the same facility.

2.11.3.2 Occupational Exposure Assessment Methodology

For aerosol degreasing, EPA assessed exposure using available exposure monitoring data and modeling results.

2.11.3.3 Occupational Exposure Results

Monitoring Data

Table 2-24 summarizes 8-hr TWA PBZ monitoring data for aerosol degreasing obtained from (Stewart, 1998) and (Tech Spray, 2003). The Stewart (1998) study measured 1-BP worker PBZ during an aerosol spray can application on a test substrate consisting of a small electric motor; the scenario was intended to simulate workers performing typical repair and maintenance work. The (Tech Spray, 2003) study measured worker exposure in a test scenario that simulated cleaning of printed circuit boards for the repair of computers and electrical systems. Among the two test studies, the 95th and 50th percentile worker exposures were 31.6 and 16.1 ppm, respectively.

The Tech Spray study tested an exposure scenario where the 1-BP aerosol degreasing occurred inside a non-vented booth. Subsequently, the company tested the same scenario in a vented booth. With a non-vented booth, worker exposure ranged from 13 to 32 ppm 8-hr TWA. With the vented booth, worker exposure was reduced to 5.50 ppm 8-hr TWA based on a single data point. The vented booth scenario has a constant draw of 0.9 cubic meters per second during the 8-hour test. The data suggest the significance of ventilation and its impact on worker exposure. The single data point for worker exposure in a vented booth represents a "what-if" exposure level for a post-EC scenario. The representativeness of this exposure level is unknown.

Table 2-24. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Aerosol Degreasing Based on Monitoring Data

Category [a]	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $AC_{1\text{-BP, 8-hr TWA}}$ and $ADC_{1\text{-BP, 8-hr TWA}}$**		**Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 8-hr TWA}}$**		Data Points
	95th Percentile	50th Percentile	95th Percentile	50th Percentile	
Worker, Pre EC	31.6	16.1	16.18	6.4	6
Worker, Post EC	5.50 (what-if)		2.82	2.2	1

Source: Stewart (1998); Tech Spray (2003), as cited in (U.S. EPA, 2006b). The vented booth scenario from Tech Spray is used as the post-EC scenario, and the remaining data points are used as the pre-EC scenario.

What-if: Represents a what-if inhalation exposure level based on a single data point.

[a] Worker includes operators, technicians, mechanics, and maintenance supervisor. Data are not available for occupational non-users.

In addition to the data summarized above, the Tech Spray study included a test scenario that measured short-term worker exposure that simulated an automotive repair shop. In this test, 1-BP was sprayed continuously over a 15-minute period. In reality, workers are only expected to spray 1-BP for a few minutes at a time; as such, the test was intended to simulate a "worst-case" scenario with heavy 1-BP usage. The 15-min short term exposure for operators ranged from 190 to 1,100 ppm. Further, the 15-minute short term exposure for a worker in an adjacent room measured 11 ppm ((Tech Spray, 2003), as cited in (U.S. EPA, 2006b)). The presence of 1-BP in the adjacent room suggests the infiltration of contaminated air into other work areas.

Model Data

As previously discussed in Section 2.11.1, a variety of workplaces can use aerosol degreaser containing 1-BP. For the purpose of modeling, EPA modeled worker exposure to 1-BP during brake servicing as a representative exposure scenario. EPA chose to model this scenario because the process of brake servicing is well understood and there is sufficient data to construct such a model. EPA believes brake servicing and engine degreasing at automotive maintenance and repair shops is a common application for products containing 1-BP, and the process is a representative aerosol degreasing scenario.

Figure 2-16 illustrates the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. The general model framework was previously peer reviewed as part of the 2016 draft 1-BP Risk Assessment; however, specific model parameters have been updated with data from a recent CARB study. As the figure shows, 1-BP 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 1-BP dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational non-user exposures to 1-BP at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the 1-BP dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly 1-BP dissipates out of the surrounding space and into the outside air.

In this scenario, 1-BP vapors 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. The product application rate is based on a 2000 CARB report for brake servicing, which estimates that each facility performs on average 936 brake jobs per year, and that each brake job requires approximately 14.4 ounces of product. For each model iteration, EPA determined the concentration of 1-BP by assuming the formulation could be one of 25 possible aerosol degreasing products identified in the Use Dossier. Detailed model parameters and assumptions are presented in Appendix G. EPA did not model a “post-EC” scenario because there is not sufficient information to determine the type and effectiveness of engineering control at automotive and other commercial degreasing facilities.

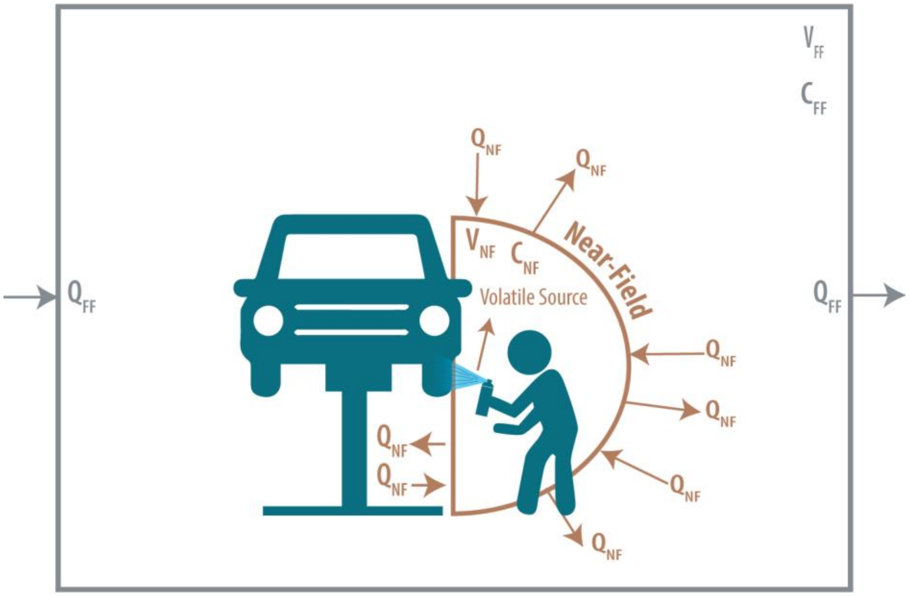

Figure 2-16. Schematic of the Near-Field/Far-Field Model for Aerosol degreasing

EPA performed a Monte Carlo simulation with 100,000 iterations and the Latin hypercube sampling method to model near-field and far-field exposure concentrations in the aerosol degreasing scenario. Table 2-25 presents a statistical summary of the exposure modeling results. The 95th and 50th percentile exposures are 22.53 ppm and 6.37 ppm 8-hr TWA for workers, and 0.93 ppm and 0.11 ppm 8-hr TWA for occupational non-users.

Table 2-25. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Aerosol Degreasing Based on Modeling

Category	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** **$AC_{1\text{-}BP,\ 8\text{-}hr\ TWA}$** and **$ADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}$**		**Chronic, Cancer Exposures (ppm)** **$LADC_{1\text{-}BP,\ 8\text{-}hr\ TWA}$**	
	95th Percentile	50th Percentile	95th Percentile	50th Percentile
Worker	22.53	6.37	9.05	2.38
ONU	0.93	0.11	0.36	0.04

2.12 Dry Cleaning

2.12.1 Process Description

1-BP is a solvent used in dry cleaning machines. There are two known 1-BP based dry cleaning formulations, DrySolv® and Fabrisolv™ XL, which were introduced beginning in 2006. These formulations are often marketed as “drop-in” replacements for perchloroethylene (Perc), which indicates they can be used in third generation or higher Perc equipment (TURI, 2012). Third generation equipment, introduced in the late 1970s and early 1980s, are non-vented, dry-to-dry machines with refrigerated condensers. These machines are essentially closed systems and are only open to the atmosphere when the machine door is opened. In third generation machines, heated drying air is recirculated back to the drying drum through a vapor recovery system (CDC, 1997).

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

Dry cleaners who opt to use 1-BP can either convert existing Perc machines or purchase a new dry cleaning machine specifically designed for 1-BP. To convert existing Perc machines to use 1-BP, machine settings and components must be changed to prevent machine overheating and solvent leaks (Blando et al., 2010). 1-BP is known to damage rubber gaskets and seals. It can also degrade cast aluminum, which is sometimes used on equipment doors and other dry cleaning machine components. In addition, 1-BP is not compatible with polyurethane and silicone (TURI, 2012). Enviro Tech International, Inc. (Enviro Tech), a major 1-BP supplier, recently ceased selling DrySolv® to users of converted Perc machines (Enviro Tech International, 2017).

While conversion of a Perc machine to 1-BP is no longer recommended by the manufacturer, 1-BP remains the only drop-in replacement that does not require buying a new machine. In some cases, the shop owners may elect to do the conversion themselves to avoid the high cost of paying for a professional company for the conversion (U.S. EPA, 2016a).

2.12.2 Number of Sites and Potentially Exposed Workers

EPA estimated the number of workers and occupational non-users potentially exposed to 1-BP at dry cleaners using Bureau of Labor Statistics' OES data (2015) and the U.S. Census' SUSB (2012). The method for estimating number of workers is detailed in Appendix A. These estimates were derived using industry- and occupation-specific employment data from the BLS and U.S. Census. EPA anticipates that dry cleaners are categorized under NAICS 812320, "Drycleaning and Laundry Services (except Coin-Operated).

According to a public comment submitted by Enviro Tech International, Inc. (Enviro Tech), a major 1-BP supplier, approximately 28 machines (nine converted Perc machines and 19 DrySolv machines) were known to be in service in 2016. The number of machines was reduced to 23 (nine converted Perc machines and 14 DrySolv machines) in 2017, after Enviro Tech ceased selling DrySolv to users of converted Perc machines (Enviro Tech International, 2017b). More recent communication with Enviro Tech indicates only eight dry cleaning establishments are using 1-BP in 2019 (Enviro Tech International, 2019). Assuming one machine per facility, EPA estimates a total of 32 workers and occupational non-users are exposed to 1-BP (Table 2-26).

Table 2-26. Estimated Number of Workers Potentially Exposed to 1-BP in Dry Cleaning Shops

Exposed Workers	Exposed Occupational non-users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational non-users per Site
24	8	32	8	3	1

Source: (U.S. BLS, 2016) (U.S. Census Bureau, 2015) (Enviro Tech International, 2017b) (Enviro Tech International, 2019)

2.12.3 Exposure Assessment

2.12.3.1 Worker Activities

Figure 2-17 provides an overview of the dry cleaning process. Worker activities at dry cleaning shops can include:

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

At dry cleaning facilities, workers are primarily exposed when 1) adding makeup solvent to the machine, typically by manually dumping it through the front hatch, 2) opening the machine door during the wash cycle, and 3) removing garments from the machines (Blando et al., 2010). Workers can also be exposed during maintenance activities, such as cleaning the machine lint trap, button trap and still, changing solvent filters, and disposing hazardous wastes. However, these maintenance activities occur on a much less frequent basis (NIOSH, 1997a).

Engineering controls such as local exhaust ventilation (LEV) located at or near the machine door can reduce worker exposure during machine loading, machine unloading, and maintenance activities (NCDOL, 2013). However, there are currently no regulatory requirements for installing such controls to reduce 1-BP emissions and associated worker exposures at dry cleaning facilities. In addition, engineering controls may not be economically feasible for dry cleaning shops.

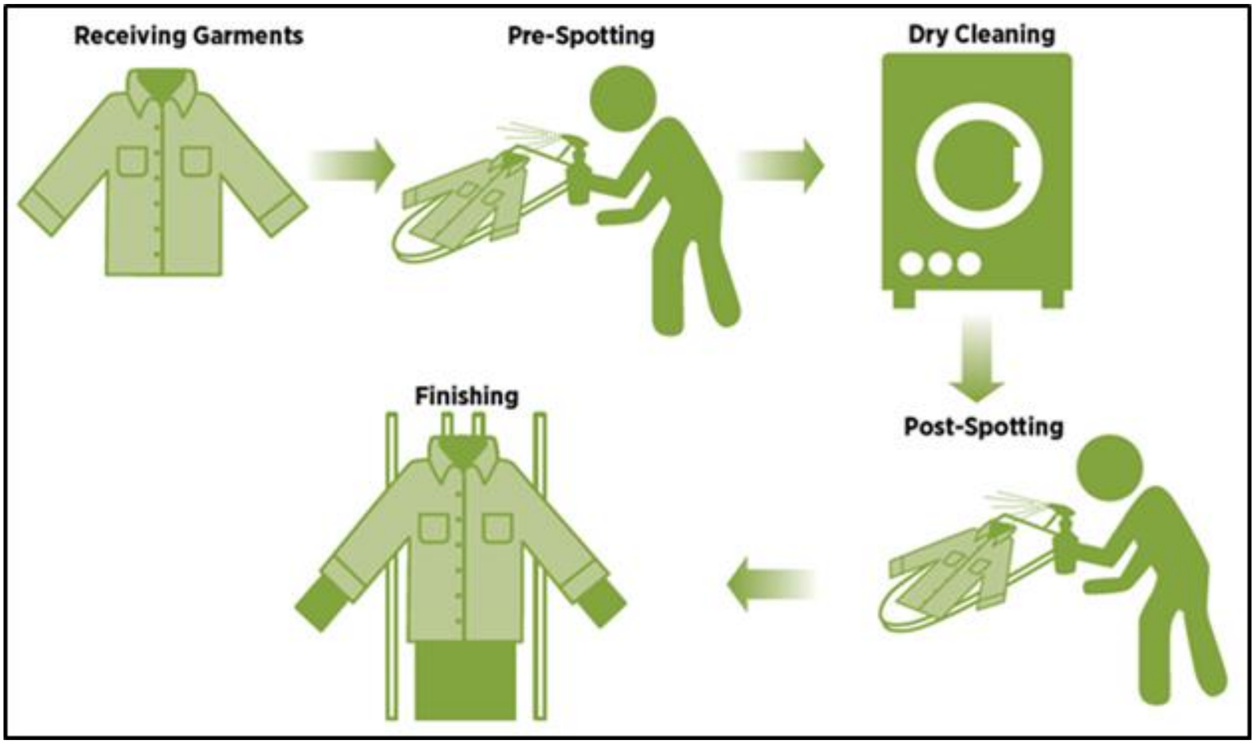

Figure 2-17. Overview of Dry Cleaning

2.12.3.2 Occupational Exposure Assessment Methodology

For dry cleaning, EPA assessed exposure using available exposure monitoring data and modeling results.

2.12.3.3 Occupational Exposure Results

Monitoring Data

Table 2-27 presents an analysis of the 8-hr TWA PBZ monitoring data from literature. The data were obtained from two literature studies covering four dry cleaning shops in New Jersey. The studies noted variability in 1-BP exposure among different dry cleaning shops, different job titles, and in some cases on different days when the exposure monitoring was conducted. The exposure data were also impacted by the willingness of individual shops to participate in exposure monitoring. The study (NIOSH, 2010) contains additional partial-shift exposure data that are not summarized here. For those data, an 8-hr TWA value was not obtained because owners of the shop requested that NIOSH remove the sampling equipment once they had finished running the dry cleaning machines (NIOSH, 2010).

All shops included in the studies used converted 3rd generation machines. Across the two studies, the shops dry cleaned one to 14 loads of garments per day. Some shops that converted the machines themselves “cooked” the solvent, a practice that had been performed widely for Perc but is no longer recommended by the manufacturers for 1-BP operation (NIOSH, 2010). Only one shop added make-up solvent during the study. This shop added make-up solvent due to leaks and evaporative losses on Sample Day 1 and Sample Day 2 by manually dumping a 5-gallon can of solvent product through the front hatch of the machine, but did not perform this activity on the remaining two sampling days (Blando et al., 2010). The facilities had general building ventilation, ceiling-mounted or wall-mounted fans, but lacked controls specifically designed to reduce exposure to the dry cleaning solvent.

EPA defined workers as employees who operate the dry cleaning machine or who perform dry cleaning activities such as spotting, pressing, and finishing. For workers, the 95th and 50th percentile exposures are 50.2 and 29.4 ppm 8-hr TWA, respectively. The exposure level is impacted by the number of loads cleaned, the number of solvent cooking cycles used, and whether any "make-up" solvent was added in that particular shop and on that particular day when the monitoring was conducted (Blando et al., 2010). These activities can result in a larger release of solvent vapors into the work environment, contributing to higher worker exposure to 1-BP. The studies also noted that work load and work practices varied greatly among the shops (NIOSH, 2010). Further, NIOSH (NIOSH, 2010) noted that the highest 1-BP concentration in air was found when a facility with a converted Perc machine cooked the solvent, a practice that "had been performed widely for Perc but is no longer recommended by the manufacturers for 1-BP operation" (NIOSH, 2010).

EPA defined occupational non-users as employees who work in the dry cleaning shops but do not perform dry cleaning activities. For occupational non-users, the 95th and 50th percentile exposures are 20.6 and 12.1 ppm 8-hr TWA, respectively. The data suggest that cashiers, clerks, and other employees at the shop are also exposed to 1-BP. In addition to occupational non-users, children may also be present at some small, family-owned dry cleaning shops, and thereby be exposed to 1-BP. The monitoring studies do not contain information on exposure to children.

Table 2-27. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Dry Cleaning Based on Monitoring Data

	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $AC_{1\text{-BP, 8-hr TWA}}$ and $ADC_{1\text{-BP, 8-hr TWA}}$		**Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 8-hr TWA}}$**		
Category	95th Percentile	50th Percentile	95th Percentile	50th Percentile	Data Points
Worker [a]	50.2	29.4	25.75	11.7	8
ONU [b]	20.6	12.1	10.58	4.8	6

Source: (Blando et al., 2010; NIOSH, 2010).

[a] Worker refers to dry cleaning machine operators.

[b] Occupational non-user refers to cashiers and clerks.

Model Data

Because there are multiple activities with potential 1-BP exposure at a dry cleaner, a multi-zone modeling approach is used to account for 1-BP vapor generation from multiple sources. This model framework was peer reviewed as part of the 2016 draft 1-BP Risk Assessment. The model has been updated to address public and peer review comments. The model also reflects additional information that became available since 2016; specifically, several model input parameters have been refined. Figure 2-18 illustrates this multi-zone approach, which considers the following worker activities:

- **Spot cleaning of stains on both dirty and clean garments:** On receiving a garment, dry cleaners inspect for stains or spots they can remove as much of as possible before cleaning the garment in a dry cleaning machine. Spot cleaning may also occur after dry cleaning if the stains or spots were not adequately removed. Spot cleaning occurs on a spotting board and can involve the use of a spotting agent containing various solvents, such as 1-BP. Workers are exposed to 1-BP when applying it via squeeze bottles, hand-held spray bottles, or even from spray guns connected to pressurized tanks. Once applied, the worker may come into further contact with the 1-BP if using a brush, spatula, pressurized air or steam, or their fingers to scrape or flush away the stain (Young, 2012; NIOSH, 1997a). For modeling, EPA assumed the near-field is a rectangular volume covering the body of a worker.

- **Unloading garments from dry cleaning machines:** At the end of each dry cleaning cycle, workers manually open the machine door to retrieve cleaned garments. During this activity, workers are exposed to 1-BP vapors remaining in the dry cleaning machine cylinder. For modeling, EPA assumed that the near-field consists of a hemispherical area surrounding the machine door, and that the entire cylinder volume of air containing 1-BP exchanges with the workplace air, resulting in a "spike" in 1-BP concentration in the near-field, C_D, during each unloading event. This concentration is directly proportional to the amount of residual 1-BP in the cylinder when the door is opened. The near-field concentration then decays with time until the next unloading event occurs.

- **Finishing and pressing:** The cleaned garments taken out of the cylinder after each dry clean cycle contain residual solvents and are not completely dried (Von Grote, 2003). The residual solvents are continuously emitted into the workplace during pressing and finishing, where workers manually place the cleaned garments on the pressing machine to be steamed and ironed. EPA assumed any residual solvent is entirely evaporated during pressing, resulting in an increase in the near-field 1-BP concentration during this activity. Workers are exposed to 1-BP vapors while standing in vicinity of the press machine. For modeling, EPA assumed the near-field is a rectangular volume covering the body of a worker.

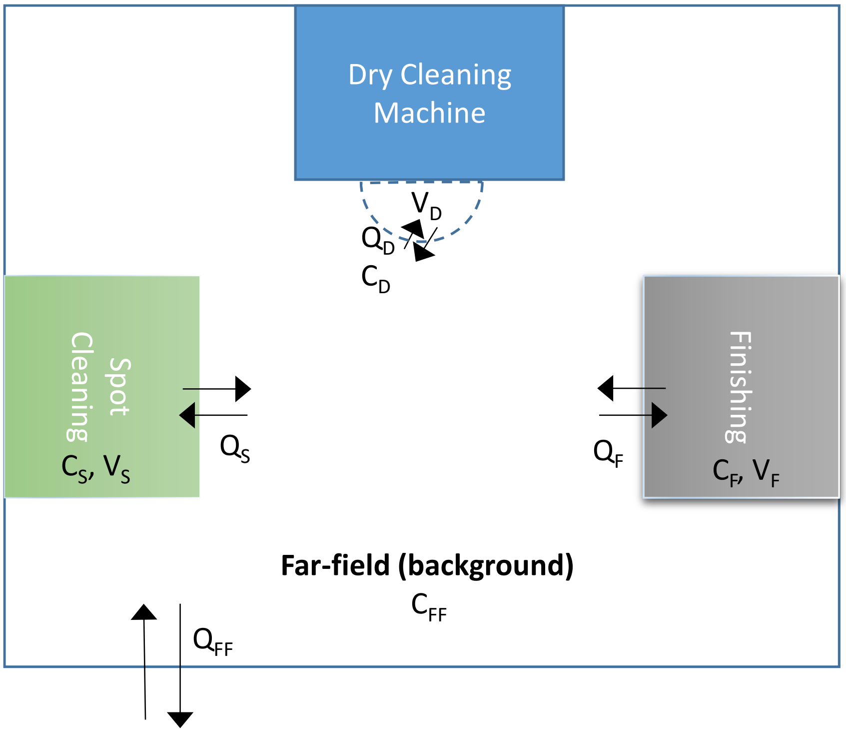

Figure 2-18. Illustration of the Multi-Zone Model

As the figure shows, 1-BP vapor is generated in each of the three near-fields, resulting in worker exposures at concentrations C_S, C_D, and C_F. The volume of each zone is denoted by V_S, V_D, and V_F. The ventilation rate for the near-field zone (Q_S, Q_D, Q_F) determines how quickly 1-BP dissipates into the far-field (i.e., the facility space surrounding the near-fields), resulting in occupational non-user exposures to 1-BP at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the 1-BP dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly 1-BP dissipates out of the surrounding space and into the outside air. Appendix H summarizes the parameters and equations for the multi-zone model. The far-field volume, air exchange rate, and near-field indoor wind speed are identical to those used in the 1-BP Spot Cleaning Model (see Section 2.13). These values were selected using engineering judgment and literature data that EPA believed to be representative of a typical dry cleaner.

Many dry cleaning shops are small, family-owned businesses. EPA assumed small dry cleaners operate up to 12 hours a day and up to 6 days a week. In addition, EPA assumed each facility has a single machine. The assumption of a single machine per facility is supported by an industry study conducted in King County, Washington, where 96 percent of 151 respondents reported having only one machine at their facility. Four reported having two machines, and two reported having three machines (Whittaker and Johanson, 2011). Based on the survey results, this assumption is presumably representative of the majority of small dry cleaning shops.

EPA modeled the baseline scenario assuming the facility operates a converted third generation machine, the machine type observed at all three New Jersey dry cleaners in the Blando et al. (2010) study. For the engineering control scenario, EPA modeled a facility with a fourth generation machine. EPA believes facilities using 1-BP are unlikely to own fifth generation machines (ERG, 2005).

EPA assessed three types of workers within the modeled dry cleaning facility: 1) a worker who performs spot cleaning; 2) a worker who unloads the dry cleaning machine and finishes and presses the garments; and 3) an occupational non-user. Each worker type is described in further detail below. EPA assumed each worker activity is performed over the full 12-hour operating day.

- EPA assumed spot cleaning occurs for a duration varying from two to five hours in the middle of the twelve-hour day. The worker is exposed at the spot cleaning near-field concentration during this time, and at the far-field concentration for the remainder of the day. Spot cleaning can be performed for both dry cleaned loads and for laundered loads.

- EPA assumed a separate worker unloads the dry cleaning machine, and finishes and presses the garments. After each load, EPA assumed this worker spends five minutes unloading the machine, during which he or she is exposed at the machine near-field concentration. After unloading, the worker spends five minutes in the finishing near-field to prepare the garments. Then, the worker spends another 20 minutes finishing and pressing the cleaned garments. During this 20-minute period of finishing and pressing, the residual 1-BP solvent is off-gassed into the finishing near-field. The amount of residual 1-BP solvent is estimated using measured data presented in (Von Grote, 2003). These unloading and finishing activities are assumed to occur at regular intervals throughout the twelve-hour day. The frequency of unloading and finishing depends on the number of loads dry cleaned each day, which varies from one to 14, where 14 was the maximum number of loads observed in the NIOSH (2010) and Blando (2010) studies. When this worker is not unloading the dry cleaning machine or finishing and pressing garments, the worker is exposed at the far-field concentration.

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

Table 2-28 presents the *Monte Carlo* results with the Latin hypercube sampling method and 10,000 iterations. Statistics of the 12-hr TWA exposures (95th and 50th percentiles) are calculated at the end of the simulation after all iterations have completed. The AC, ADC, and LADC calculations are integrated into the *Monte Carlo* simulation, such that the exposure frequency matches the model input values for each iteration. As shown in the table, the worker who performs unloading and finishing activities have the highest exposure; this exposure can be reduced if the facility switches from a third generation to fourth generation machine. However, the machine type does not significantly impact exposure level for other persons present at the facility, including the spot cleaner and the occupational non-user. The model values cover a wider distribution of exposure levels when compared to the monitoring data. This is likely due to the wide range of model input parameter values covering a higher number of possible exposure scenarios. However, the modeled occupational non-user exposures are lower than actual monitoring results. The model assumes the occupational non-user spends their time entirely in the far-field. In reality, it is possible that these employees will occasionally perform activities in the near-field, thereby having a higher level of exposure.

Table 2-29 presents the exposure for children who may be present at the dry cleaning facility. Because many dry cleaners are family owned and operated, EPA assumed children may be present for a four-hour period (3 – 7pm) afterschool, during which they may be exposed at similar levels as occupational non-users.

Table 2-28. Statistical Summary of 1-BP Dry Cleaning Exposures for Workers and Occupational Non-users based on Modeling

Machine Type	12-hr TWA Exposures (ppm) $C_{1\text{-BP, 12-hr TWA}}$		Acute, Non-Cancer Exposures (ppm) $AC_{1\text{-BP, 24-hr TWA}}$		Chronic, Non-Cancer Exposures (ppm) $ADC_{1\text{-BP, 24-hr TWA}}$		Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 24-hr TWA}}$	
	95th Percentile	50th Percentile	95th Percentile	50th Percentile	95th Percentile	50th Percentile	95th Percentile	50th Percentile
Workers: Machine Unloading and Finishing (Near-Field)								
3rd Gen.	60.53	14.13	30.27	7.06	21.70	4.98	8.57	1.89
4th Gen.	6.36	2.38	3.18	1.19	2.30	0.84	0.94	0.31
Workers: Spot Cleaning (Near-Field)								
3rd Gen.	7.93	2.93	3.97	1.47	2.83	1.03	1.14	0.39
4th Gen.	5.65	2.40	2.83	1.20	2.02	0.85	0.82	0.32
Occupational non-users (Far-Field)								
3rd Gen.	6.65	1.82	3.33	0.91	2.37	0.64	0.95	0.24
4th Gen.	4.21	1.31	2.11	0.65	1.49	0.46	0.60	0.17

Table 2-29. Statistical Summary of 1-BP Dry Cleaning Exposures for Children based on Modeling

Machine Type	12-hr TWA Exposures (ppm) $C_{1\text{-BP, 4-hr TWA}}$		Acute, Non-Cancer Exposures (ppm) $AC_{1\text{-BP, 24-hr TWA}}$		Chronic, Non-Cancer Exposures (ppm) $ADC_{1\text{-BP, 24-hr TWA}}$		Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 24-hr TWA}}$	
	95th Percentile	50th Percentile	95th Percentile	50th Percentile	95th Percentile	50th Percentile	95th Percentile	50th Percentile
Children (Far-Field)								
3rd Gen.	4.03	0.54	0.67	0.09	N/A	N/A	N/A	N/A
4th Gen.	1.02	0.09	0.17	0.01	N/A	N/A	N/A	N/A

N/A – Not applicable

2.13 Spot Cleaner, Stain Remover

2.13.1 Process Description

On receiving a garment, dry cleaners inspect for stains or spots and remove them as much of as possible before cleaning the garment in a machine. As Figure 2-19 shows, spot cleaning occurs on a spotting board and can involve the use of a spotting agent containing various solvents, such as 1-BP. 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 1-BP if using a brush, spatula, pressurized air or steam, or their fingers to scrape or flush away the stain (Young, 2012; NIOSH, 1997a).

Figure 2-19. Overview of Use of Spot Cleaning at Dry Cleaners

EPA assessed a separate spot cleaning scenario at dry cleaners. This scenario represents dry cleaners or other shops that use 1-BP-based spot cleaning formulations but do not otherwise use 1-BP in a dry cleaning machine. The extent of such uses is likely limited, as Enviro Tech claimed that while DrySolv spotting products were advertised to the dry cleaning industry, most were never commercialized (Enviro Tech International, 2017b).

2.13.2 Number of Sites and Potentially Exposed Workers

See Section 2.12.2 for the estimated number of workers and occupational non-users at dry cleaning shops.

2.13.3 Exposure Assessment

2.13.3.1 Worker Activities

As previously described, 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, 1997a).

2.13.3.2 Occupational Exposure Assessment Methodology

For spot cleaning, EPA assessed exposure using both available monitoring data and model results.

2.13.3.3 Occupational Exposure Results

Monitoring Data

Table 2-30 presents 8-hr TWA PBZ monitoring data from OSHA CEHD for three facilities where spot cleaning is performed. At one facility, workers spray-applied solvent formulation to stained portions of dresses and did not wear any personal protective equipment. It is unclear if there were any engineering controls at the facility to mitigate worker exposure.

The 95th and 50th percentile exposure level for workers were 4.73 ppm and 0.9 ppm 8-hr TWA. No exposure monitoring data are available for occupational non-users.

Table 2-30. Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Spot Cleaning Based on Monitoring Data

Category	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $AC_{1\text{-BP, 8-hr TWA}}$ and $ADC_{1\text{-BP, 8-hr TWA}}$ 95th percentile	50th percentile	Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 8-hr TWA}}$ 95th percentile	50th percentile	Data Points
Worker					
Worker	4.73	0.90	2.42	0.4	6

Source: (OSHA, 2019) (OSHA, 2013b)

Model Data

Figure 2-20 illustrates the near-field/far-field modeling approach that EPA applied to spot cleaning facilities. The model, including all input parameters, are described in more detail in 0. The model framework has been peer reviewed as part of the 2016 draft 1-BP Risk Assessment. Since 2016, the model has been updated to address public and peer review comments and to incorporate additional information that became available.

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.

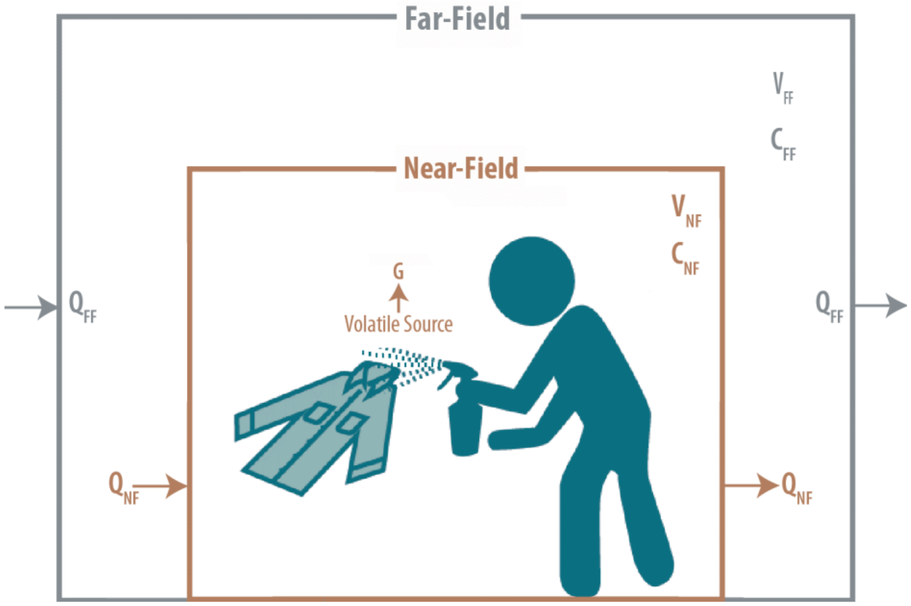

Figure 2-20. Schematic of the Near-Field/Far-Field Model for Spot Cleaning

To determine the 1-BP use rate, EPA references a comparative analysis from the Massachusetts

Department of Environmental Protection (MassDEP), which contains case studies of Perc alternatives that can be potentially used at dry cleaners. One case study estimates a dry cleaner using 1-BP spends $60 per month on spotting agents. This particular facility dry cleans 100 pieces of garments per day. MassDEP noted that the facility size can vary greatly among individual dry cleaners (MassDEP, 2013). Blando et al. (2009) estimated that 1-BP solvent products cost $45 per gallon. Based on this information, EPA calculated a spot cleaner use rate of 1.33 gallons per month, or 16 gallons per year. The Safety Data Sheet for DrySolv, a common 1-BP formulation, indicates the product contains greater than 87 percent 1-BP by weight (Enviro Tech International, 2013).

EPA performed Monte Carlo simulations, applying 100,000 iterations and the Latin hypercube sampling method. Table 2-31 presents a statistical summary of the exposure modeling results. The 95th and 50th percentile exposure for workers (near-field) are 7.03 ppm and 3.24 ppm 8-hr TWA, respectively. These results are generally comparable to the monitoring data. For occupational non-users (far-field), the 95th and 50th percentile exposure levels are 4.68 ppm and 1.63 ppm 8-hr TWA, respectively. The table also presents the AC, ADC, and LADC values, which are integrated into the Monte Carlo. EPA assumes no engineering controls (e.g., exhaust hoods) are present at spot cleaning facilities, because controls may not be financially feasible for small shops.

Table 2-31. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Use of Spot Cleaning at Dry Cleaners Based on Modeling

	Acute, Non-Cancer Exposures (8-Hour TWAs in ppm) **$AC_{1\text{-BP, 8-hr TWA}}$**		**Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm)** **$ADC_{1\text{-BP, 8-hr TWA}}$**		**Chronic, Cancer Exposures (ppm)** **$LADC_{1\text{-BP, 8-hr TWA}}$**	
Category	95th Percentile	50th Percentile	95th Percentile	50th Percentile	95th Percentile	50th Percentile
Worker	7.03	3.24	1.66	0.76	0.68	0.29
ONU	4.68	1.63	1.10	0.39	0.45	0.15

2.14 Adhesive Chemicals (Spray Adhesives)

2.14.1 Process Description

1-BP is used in spray adhesives for foam cushion manufacturing and fabrication (e.g., the furniture industry). Figure 2-21 illustrates a typical process of using spray adhesives for foam cushion manufacturing. During foam cushion manufacturing and fabrication, foam is cut into pieces and then bonded together to achieve the appropriate shape. Spray guns are used to spray-apply an adhesive onto flexible foam surfaces for bonding. Adhesive spraying typically occurs either on an open top workbench with side panels that may have some local ventilation, or in an open workspace with general room ventilation. After the adhesive is applied, workers assemble the cushions by hand-pressing together pieces of cut flexible foam (NIOSH, 2003, 2002b).

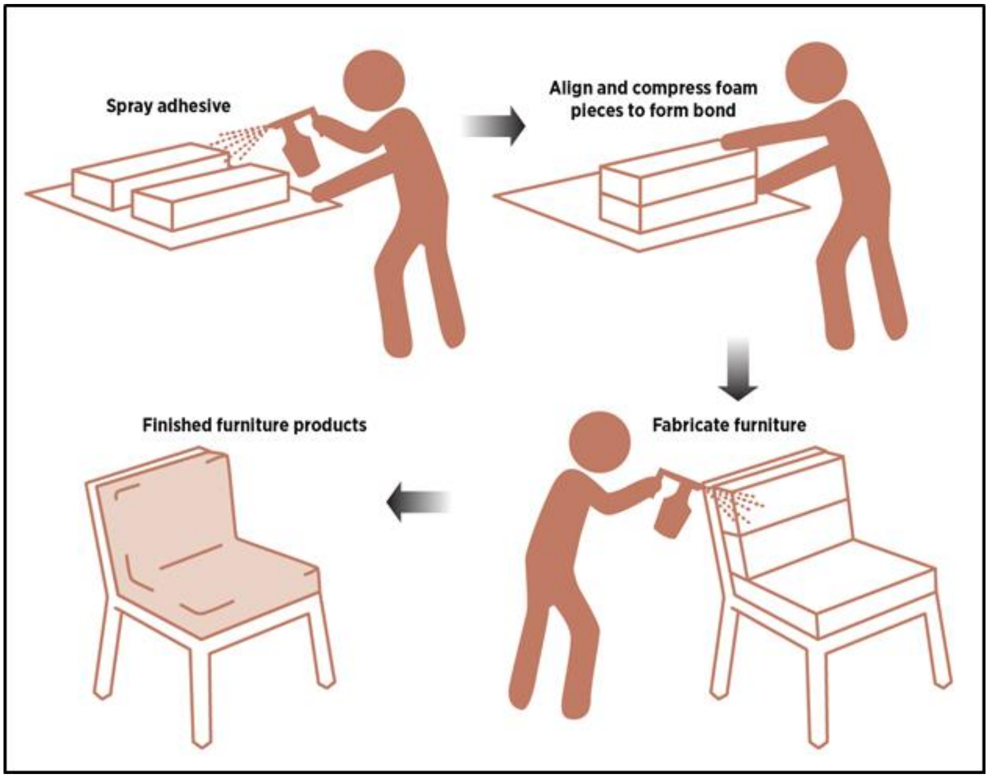

Figure 2-21. Overview of Use of Spray Adhesive in the Furniture Industry

2.14.2 Number of Sites and Potentially Exposed Workers

EPA estimated the number of workers potentially exposed to 1-BP in spray adhesives using Bureau of Labor Statistics' Occupational Employment Statistics (OES) data (2015) and U.S. Census' Statistics of US Businesses (SUSB) (2012). The method for estimating number of workers is detailed in Appendix A. The worker estimates were derived using industry- and occupation-specific employment data from these sources. The industry sectors and occupations that EPA determined to be relevant to spray adhesive use are presented in that Appendix.

The number of businesses in this use sector of 1-BP is estimated to be between 100 and 280 (CDC, 2016). Table 2-32 presents the estimated number of workers and occupational non-users using these estimates. The total number of potentially exposed workers and occupational non-users ranges from 1,503 to 4,209. Recent discussion with industry suggests the 1-BP market has since declined. In its 2017 public comment, Enviro Tech stated that it was aware of only two end users who currently use 1-BP as a carrier for an adhesive (Enviro Tech International, 2017a). It is unclear whether the Enviro Tech estimate is comprehensive of the current spray adhesive market.

Table 2-32. Estimated Number of Workers Potentially Exposed to 1-BP in Spray Adhesive Use in Foam Cushion Manufacturing

Exposed Workers	Exposed Occupational Non-Users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational Non-Users per Site
Low-end					
551	952	1,503	100	6	10
High-end					
1,543	2,666	4,209	280	6	10

Note: 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. Values are rounded to the nearest integer.

2.14.3 Exposure Assessment

2.14.3.1 Worker Activities

Worker activities include manual spraying of 1-BP containing adhesives, typically in a spray station or spray booth, and hand-pressing and assembling pieces of flexible foam after the adhesive is applied. See Section 2.14.3.3 for additional discussion of worker activity, job function, and their potential for exposure.

2.14.3.2 Occupational Exposure Assessment Methodology

For use of 1-BP in spray adhesives, EPA estimated exposure using available exposure monitoring data. 1-BP exposure monitoring data were identified in several literature studies, including journal articles, NIOSH HHE, and OSHA CEHD database. NIOSH HHEs are conducted at the request of employees, employers, or union officials and help inform on potential hazards present at the workplace. HHEs can also be conducted in response to a technical assistance request from other government agencies. OSHA CEHD are workplace monitoring data from OSHA inspections. These inspections can be random or targeted, or can be the result of a worker complaint.

Among these sources, three NIOSH studies provide the most comprehensive information on worker exposure to 1-BP from spray adhesives in foam cushion manufacturing. Two of the three HHEs also compare exposure pre- and post-engineering controls. A summary of these HHEs follows:

- From March 1998 to April 2001, NIOSH investigated a facility in Mooresville, North Carolina to assess 1-BP exposures during manufacturing of foam seat cushions (NIOSH, 2002a). The company had four departments: Saw, Assembly, Sew, and Covers. Workers in Assembly and Covers departments worked directly with the adhesive; however, workers in all four departments were exposed. The spray adhesive used at this facility contained between 60 and 80 percent 1-BP. NIOSH conducted an initial exposure assessment in 1998 and observed that the ventilation exhaust filters were clogged with adhesive. In 2001, NIOSH conducted a follow-up exposure assessment after the facility made improvements to its ventilation system.
- From November 2000 to August 2001, NIOSH investigated workplace exposures to 1-BP during manufacturing of foam seat cushions at another cushion company in North Carolina (NIOSH, 2002b). This facility used a spray adhesive containing 55 percent 1-BP. NIOSH conducted an initial exposure assessment in 2000 and recommended that the facility reduce worker exposure by enclosing the spray stations to create “spray booths.” Subsequently, in 2001, NIOSH conducted a follow-up assessment after spray station enclosures were installed.

- From April 1999 to May 2001, NIOSH investigated another cushion company in North Carolina (NIOSH, 2003). In this study, NIOSH conducted two separate exposure assessments. In the initial assessment, NIOSH measured 1-BP inhalation exposures to workers in and near the adhesive spray operation areas. In the second assessment, NIOSH measured additional 1-BP inhalation exposures at the facility. There were no changes to the facility's ventilation system (i.e., engineering controls) between the first and second assessment.

2.14.3.3 Occupational Exposure Results

Table 2-33 summarizes available 1-BP exposure data from the NIOSH and OSHA sources. The data set includes pre-EC and post-EC scenarios for each worker job category. EPA defined three job categories for 1-BP spray adhesive use:

- Sprayers: Workers who perform manual spraying of 1-BP adhesive as a regular part of his or her job;
- Non-sprayers: Workers who are not "sprayers," but either handle the 1-BP adhesive or spend the majority of their shift working in an area where spraying occurs. For example, the NIOSH (2002a) study indicated spraying occurs in the Assembly and Covers departments. EPA assumes workers in these departments who do not perform spraying still work in the vicinity of spraying operations and may be regularly exposed to 1-BP; and
- Occupational non-users: Workers who do not regularly perform work in an area of the facility where spraying occurs. For example, EPA assumes workers in the Saw and Sew departments of the 2002 NIOSH study (NIOSH, 2002a) are "occupational non-users."

For each worker job category (sprayer, non-sprayer or occupational non-user) and exposure scenario (pre-EC or post-EC), EPA calculated the 95th and 50th percentile exposure levels from the observed data set. Pre-EC exposure scenarios suggest that all workers at foam cushion manufacturing facilities that use 1-BP spray adhesives have substantial exposure to 1-BP. Sprayers have the highest levels of exposure because they work directly with the 1-BP adhesive. However, non-sprayers and occupational non-users may also be exposed at high levels. The difference in exposure between sprayers and non-sprayers may not be meaningful, as the number of data points available for non-sprayers is less than half than the data available for sprayers.

In general, exposure levels for occupational non-users vary widely depending on the worker's specific work activity pattern, individual facility configuration, and proximity to the 1-BP adhesive. For example, workers in the saw and sew departments in the NIOSH (2002a) study classified as "occupational non-users" are exposed at levels above 100 ppm 8-hr TWA. The high exposure levels are caused by their proximity to spraying operations in other departments, even though no adhesive is used in the saw and sew departments (NIOSH, 2002a). Additionally, some workers may not have a single assigned role; as such, their exposure level will vary depending on the specific tasks performed.

Post-EC exposure scenarios suggest that engineering controls, if well designed, maintained, and operated, can reduce worker exposures by an order of magnitude. However, engineering controls alone do not reduce exposures for sprayers and non-sprayers to levels below 0.1 ppm, the time-weighted average threshold limit value (TLV) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH).

Additional 1-BP worker exposure monitoring data have been identified in other literature studies such as Hanley et al. (2009; 2006), Ichihara et al. (2002), Majersik et al. (2007). However, these studies are not used in EPA's analysis because they either do not provide individual data points or lack specific information on worker job descriptions to adequately categorize the exposure results.

Table 2-33. Statistical Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Spray Adhesive on Monitoring Data

Category [a]	**Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $AC_{1\text{-BP, 8-hr TWA}}$ and $ADC_{1\text{-BP, 8-hr TWA}}$**		**Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 8-hr TWA}}$**		Data Points
	95th Percentile	50th Percentile	95th Percentile	50th Percentile	
Sprayer, Pre EC	253.6	132.8	130.04	52.8	83
Sprayer, Post EC	41.90	17.81	21.49	7.1	49
Non-Sprayer [b], Pre EC	210.9	127.2	108.1	50.6	31
Non-Sprayer [b], Post EC	28.8	18.0	14.79	7.2	9
ONU[c], Pre EC	128.7	3.00	66.0	1.2	39
ONU[c], Post EC	5.48	2.00	2.81	0.8	17

Sources: (OSHA, 2013b; NIOSH, 2003, 2002a, b) (Toraason et al., 2006)

[a] EC = Engineering Controls. Pre-EC = Initial NIOSH visit; Post EC = Follow-up NIOSH visit engineering controls implemented: Enclosing spray tables to create "spray booths" and/or improve ventilation.

[b] Non-Sprayer refers to those employees who are not sprayers, but either handle the adhesive or spend the majority of their shift working in an area where spraying occurs.

[c] Occupational non-user refers to those employees who do not regularly work in a department/area where spraying occurs (e.g., employees in saw and sew departments).

2.15 THERMAX^{TM} Installation

2.15.1 Process Description

1-BP is used in the production of a polyisocyanurate rigid board insulation produced by Dow Chemical Company that goes by the trade name THERMAX^{TM}. THERMAX^{TM} can be used for interior and exterior applications including walls, ceilings, roofs, foundations, basements, and crawl spaces in commercial and residential buildings. After THERMAX^{TM} is installed, seams are typically covered with aluminum foil tape. Additional wallboard, baseboard, or molding may then be installed over the insulation[10].

2.15.2 Number of Sites and Potentially Exposed Workers

EPA does not know the exact number of THERMAX^{TM} installation sites. EPA's 2018 Draft Generic Scenario for Application of Spray Polyurethane Foam Insulation (SPF GS) (U.S. EPA, 2018b) estimates there are eight workers per site directly involved in construction labor and six additional workers per site that are not directly involved in construction labor. The SPF GS estimates are based on data from the U.S. Bureau of Labor Statistics (U.S. BLS, 2016) for NAICS codes 236100 (residential building construction) and 236200 (nonresidential building construction). Based on these estimates, a total of 14 employees per installation site may be potentially exposed. Some of these workers may be dedicated insulation installers who only install THERMAX^{TM}, moving from site to site after each installation. Others may be general construction workers who stay at a construction site for the entire duration of construction/renovation.

2.15.3 Exposure Assessment

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[10] https://www.dupont.com/content/dam/dupont/amer/us/en/performance-building-solutions/public/documents/179-04453.pdf

THERMAX^{TM} products comprise a polyisocyanurate foam core with aluminum facers on each side. Because the aluminum facers inhibit the off-gassing of 1-BP, workers are only potentially exposed to 1-BP off-gassed from edges of the insulation.

EPA conducted a screening-level analysis using EPA's Indoor Environment Concentrations in Buildings with Conditioned and Unconditioned Zones (IECCU) model to estimate the potential 1-BP concentration from off-gassing of THERMAX^{TM} insulation. The IECCU model is a simulation program that can be used to model indoor chemical air concentrations in buildings with multiple zones and multiple sources and sinks. The IECCU model uses a general mass balance equation for a chemical of interest to calculate the time series of indoor concentrations. The equation combines all processes governing source emissions, convective transfer by bulk air, sorption, and re-emission by indoor sinks, interactions with airborne particles and settled dust and gas-phase chemical reactions. Results of the analysis show that worker and ONU exposure to 1-BP during installation in would be negligible, with 1-BP concentrations below 0.01 ppm 8-hr TWA for the initial work day inside a residential home, and less on subsequent days after install. Additional details of this screening-level analysis can be found in Appendix L.

2.16 Other Uses

2.16.1 Process Description

Based on products identified in EPA's data gathering and information received in public comments, a variety of other aerosol and non-aerosol uses may exist for 1-BP [see *Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: 1-Bromopropane*, EPA-HQ-OPPT-2016-0741-0003 (U.S. EPA, 2017b)]. Examples of these uses include, but are not limited to (AIA, 2017) (CRC Industries Inc., 2017) (Enviro Tech International, 2017a) (HESIS, 2016):

- Aerosol mold cleaning and release: 1-BP is a carrier solvent in aerosol mold cleaning and release products. These products are used to coat the molds for injection molding, compression molding, blow molding and extrusion applications. The product use rate varies depending on mold size and frequency of re-application. This use is likely limited because 1-BP is not compatible with some mold release applications.
- Asphalt extraction: 1-BP is used for asphalt extraction in centrifuge extractors, vacuum extractors, and reflux extractors. In this process, 1-BP is used to separate asphalt from the aggregate and filler material to allow for determination of asphalt content. This condition of use is expected to make up one percent of the total domestic 1-BP use volume.
- Coin and scissor cleaner: 1-BP is used in product formulations designed to clean collectible coins and scissors.
- General purpose degreaser: General purpose degreasing products containing 1-BP (both aerosol and non-aerosol) are used in industrial settings, with usage varying widely by facility. Refineries and utilities are known to be the largest volume users, with usage being cyclical as 1-BP is used to clean and maintain equipment primarily during plant shutdowns. 1-BP is also used for heavy duty transportation maintenance, e.g., maintaining buses, trains, trucks, etc.
- High voltage cable cleaner: 1-BP is contained in both aerosol and non-aerosol cleaning products, which are used to clean the semi-conductive cores of high voltage cables when splicing and terminating cables. A few ounces of product are used to clean each splice.

- Refrigerant flush: 1-BP is used to flush oxygen lines in hospitals and in the aerospace industry. 1-BP is also used to clean refrigeration lines in various industries. This condition of use is expected to make up one percent of the total domestic 1-BP use volume.
- Temperature indicator: 1-BP is used in temperature indicating fluids and coatings. These coatings can be applied to fabrics, rubber, plastics, glass, and/or polished metal. When the substrate is heated, the coating will melt at the designated temperature, leaving a mark on the surface. This condition of use is expected to make up less than 0.5 percent of the total domestic 1-BP use volume.
- Other uses: 1-BP has a number of other uses, such as adhesive accelerant, as coating component for pipes and fixtures, and as laboratory chemical for research and development.

2.16.2 Number of Sites and Potentially Exposed Workers

EPA has not identified information on the number of sites and potentially exposed workers associated with these uses. The use of 1-BP for these conditions of use is expected to be minimal. It is possible that some aerosol degreasing facilities presented in Section 2.11 also use 1-BP as a general-purpose cleaner / degreaser.

2.16.3 Exposure Assessment

EPA has not identified exposure data associated with these conditions of use. The worker activity, use pattern, and associated exposure will vary for each condition of use. For aerosol applications, EPA anticipates the worker activity and exposure route may be similar to those described for aerosol degreasing in Section 2.11. For uses as a temperature indicator, workers will likely be exposed via inhalation of vapor as 1-BP volatilizes from the applied coating.

2.17 Disposal, Recycling

2.17.1 Process Description

Each of the conditions of use of 1-BP may generate waste streams that are collected and transported to third-party sites for disposal, treatment, or recycling. Industrial sites that treat or dispose onsite wastes that they themselves generate are assessed in each condition of use assessment in Sections 2.1 through 2.16. Wastes containing 1-BP that are generated during a condition of use and sent to a third-party site for treatment, disposal, or recycling may include wastewater, solid wastes, and other wastes.

Solid wastes are defined under RCRA as any material that is discarded by being: abandoned; inherently waste-like; a discarded military munition; or recycled in certain ways (certain instances of the generation and legitimate reclamation of secondary materials are exempted as solid wastes under RCRA). Solid wastes may subsequently meet RCRA’s definition of hazardous waste by either being listed as a waste at 40 CFR §§ 261.30 to 261.35 or by meeting waste-like characteristics as defined at 40 CFR §§ 261.20 to 261.24. Solid wastes that are hazardous wastes are regulated under the more stringent requirements of Subtitle C of RCRA, whereas non-hazardous solid wastes are regulated under the less stringent requirements of Subtitle D of RCRA. Solid wastes containing 1-BP may be regulated as a hazardous waste under RCRA waste code D001 for ignitable liquids (40 CFR 261.21). 1-BP may also be co-mingled with solvent mixtures that are RCRA regulated substances. These wastes would be either incinerated in a hazardous waste incinerator or disposed to a hazardous waste landfill. Some amount of 1-BP may be improperly disposed as municipal wastes, although they are likely to be a small fraction of the overall waste stream.

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 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 (Kitto, 1992).

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 (Environmental Technology Council, 2018).[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. [11]

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

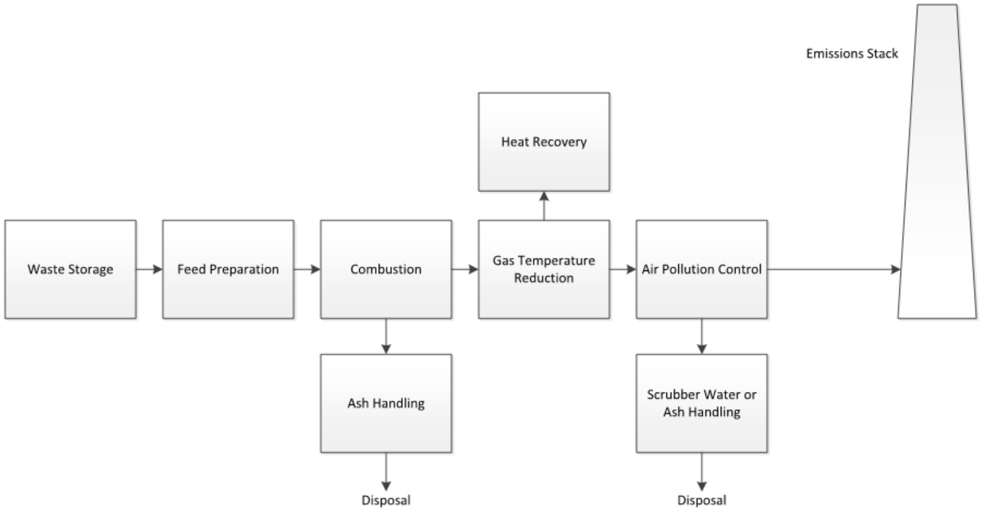

Figure 2-22. Typical Industrial Incineration Process

Municipal Waste Landfill

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

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

Hazardous Waste Landfill

Hazardous waste landfills are excavated or engineered sites specifically designed for the final disposal of non-liquid hazardous wastes. Design standards for these landfills require double liner, double leachate collection and removal systems, leak detection system, run on, runoff and wind dispersal controls, and construction quality assurance program (U.S. EPA, 2018c). There are also requirements for closure and post-closure, such as the addition of a final cover over the landfill and continued monitoring and maintenance. These standards and requirements prevent potential contamination of groundwater and nearby surface water resources. Hazardous waste landfills are regulated under Part 264/265, Subpart N.

Solvent Recovery

Waste solvents are generated when it becomes contaminated with suspended and dissolved solids, organics, water, or other substances (U.S. EPA, 1980). Waste solvents can be restored to a condition that permits reuse via solvent reclamation/recycling. The recovery process involves an initial vapor recovery (e.g., condensation, adsorption and absorption) or mechanical separation (e.g., decanting, filtering, draining, setline and centrifuging) step followed by distillation, purification and final packaging. Worker activities are expected to be unloading of waste solvents and loading of reclaimed solvents. Figure 2-23 illustrates a typical solvent recovery process flow diagram (U.S. EPA, 1980). It is not known to what extent 1-BP is collected for reclamation/recycling off-site.

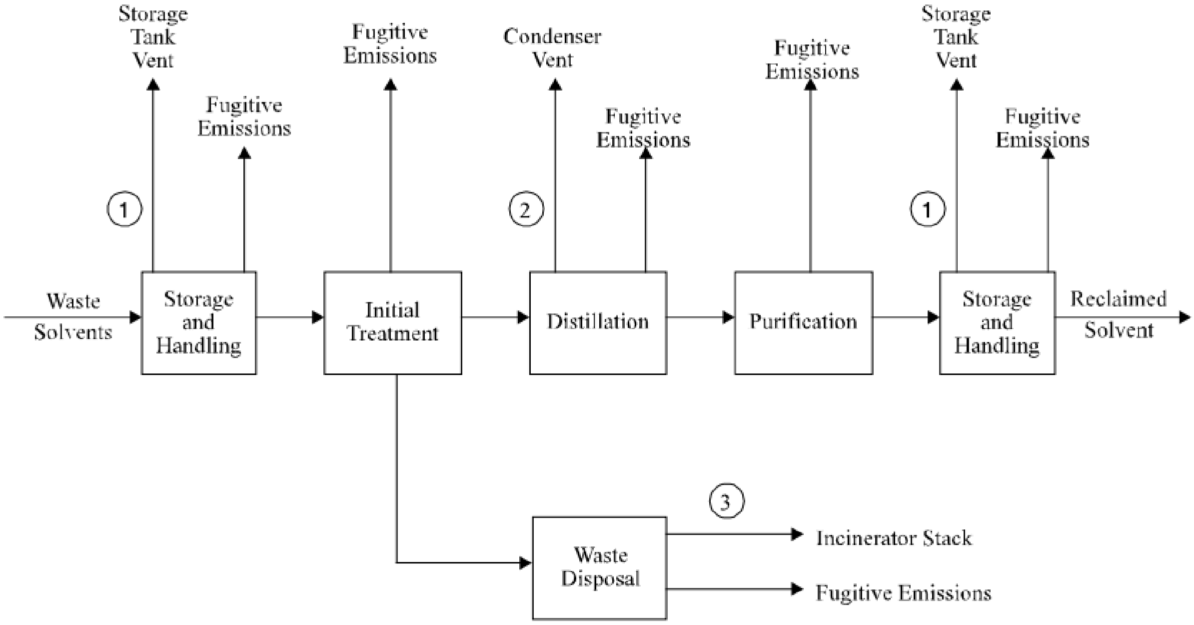

Figure 2-23. General Process Flow Diagram for Solvent Recovery Processes
Source: (U.S. EPA, 1980)

2.17.2 Number of Sites and Potentially Exposed Workers

Table 2-34 presents the industry sectors likely involved in waste treatment and disposal, and the average number of workers and ONUs per site within these sectors based on EPA's analysis of BLS data. EPA calculated the total number of workers and ONUs potentially exposed to 1-BP by multiplying these estimates by the number of waste treatment and disposal facilities that reported releases to the TRI (i.e., facilities that reported one of the NAICS codes in Table 2-34 as their primary NAICS code in TRI). For reporting year 2016, three hazardous waste treatment and disposal facilities and one cement plant reported releases of 1-BP to the TRI. It is possible that additional hazardous waste treatment facilities treat and dispose 1-BP but do not meet the TRI reporting threshold for reporting year 2016. In addition, it is possible that some consumer products containing 1-BP may be improperly disposed as municipal solid wastes, and that some amount of 1-BP is present in non-hazardous waste streams.

Table 2-34. Estimated Number of Workers Potentially Exposed to 1-BP during Waste Handling

Exposed Workers	Exposed Occupational Non-Users	Total Exposed	Estimated Number of Establishments	Workers per Site	Occupational Non-Users per Site
NAICS 562211 Hazardous Waste Treatment and Disposal					
27	15	42	3	9	5
NAICS 562212 Solid Waste Landfill					
			unknown	3	2
NAICS 562213 Solid Waste Combustors and Incinerators					
			unknown	13	8
NAICS 562219 Other Nonhazardous Waste Treatment and Disposal					
			unknown	3	2
NAICS 327310 Cement Manufacturing					
22	3	25	1	22	3

Note: 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. Values are rounded to the nearest integer.

2.17.3 Exposure Assessment

2.17.3.1 Worker Activities

At waste disposal sites, workers are potentially exposed via dermal contact with waste containing 1-BP or via inhalation of 1-BP vapor. Depending on the concentration of 1-BP in the waste stream, the route and level of exposure may be similar to that associated with container 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[12]. The potential for direct worker handling of the wastes is unknown.

2.17.3.2 Occupational Exposure Assessment Methodology

EPA did not identify exposure monitoring data related to waste treatment and disposal sites. To assess worker exposure, EPA assumes wastes containing 1-BP are transported and handled as bulk liquid shipments and models exposure using the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* (previously described in Section 2.2.3.2).

2.17.3.3 Occupational Exposure Results

Table 2-35 summarizes the model exposures from waste handling activities. The model assumes liquid wastes contain a range of concentrations of 1-BP, and estimates high-end and central tendency exposure concentrations for waste unloading scenario at industrial facilities. The model exposure may not be representative of the full distribution of possible exposure levels at waste disposal facilities.

Table 2-35. Summary of 1-BP 8-hr TWA Exposures (AC, ADC and LADC) for Disposal Based on Modeling

	Acute and Chronic, Non-Cancer Exposures (8-Hour TWAs in ppm) $AC_{1\text{-BP, 8-hr TWA}}$ and $ADC_{1\text{-BP, 8-hr TWA}}$		**Chronic, Cancer Exposures (ppm) $LADC_{1\text{-BP, 8-hr TWA}}$**	
Category	High-end	Central tendency	High-end	Central tendency
Worker	5.67E-2	3.83E-3	2.91E-2	1.52E-3

2.18 Dermal Exposure Assessment

Because 1-BP is a volatile liquid, the dermal absorption of 1-BP depends on the type and duration of exposure. Where exposure is non-occluded, only a fraction of 1-BP that comes into contact with the skin will be absorbed as the chemical readily evaporates from the skin. However, there can be dermal exposure in cases of occluded exposure, repeated contacts, or dermal immersion. For example, work activities with a high degree of splash potential may result in 1-BP liquids trapped inside the gloves, inhibiting the evaporation of 1-BP and increasing the exposure duration.

To assess exposure, EPA used the *Dermal Exposure to Volatile Liquids Model* (see following equation) to calculate the dermal retained dose for both non-occluded and occluded scenarios. The equation modifies the *EPA/OPPT 2-Hand Dermal Exposure to Liquids Model* (peer reviewed) by incorporating a "fraction absorbed (f_{abs})" parameter to account for the evaporation of volatile chemicals and a "protection factor (PF)" to account for glove use. Default PF values, which vary depending on the type of glove used and the presence of employee training program, are shown in Table 2-36:

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

Where:

D_{exp} is the dermal retained dose (mg/kg-day)
S is the surface area of contact (cm^2)
Q_u is the quantity remaining on the skin (mg/cm^2-event)

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

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 1-BP: 0.0029)
PF is the glove protection factor (Default: see Table 2-36)

The fractional absorption (f_{abs}) for 1-BP is estimated to be 0.29 percent in a non-occluded, finite dose scenario based on an *in vitro* dermal penetration study conducted by Frasch et al. (2011) and adjusting for typical wind speed encountered in the workplace. The author noted a large standard deviation in the experimental measurement, which is indicative of the difficulty in spreading a small, rapidly evaporating dose of 1-BP evenly over the skin surface. Appendix J.7 provides additional details on fractional absorption estimates; the appendix also discusses an alternative approach for estimating f_{abs} using a theoretical framework provided by Kasting and Miller (Kasting and Miller, 2006).[13]

Table 2-36. Glove Protection Factors for Different Dermal Protection Strategies

Dermal Protection Characteristics	Setting	Protection Factor, PF
a. No gloves used, or any glove / gauntlet without permeation data and without employee training	Industrial and Commercial Uses	1
b. Gloves with available permeation data indicating that the material of construction offers good protection for the substance		5
c. Chemically resistant gloves (i.e., as *b* above) with "basic" employee training		10
d. Chemically resistant gloves in combination with specific activity training (e.g., procedure for glove removal and disposal) for tasks where dermal exposure can be expected to occur	Industrial Uses Only	20

Source: (Marquart et al., 2017)

Table 2-37 presents the estimated dermal retained dose for *workers* in various exposure scenarios, including what-if scenarios for glove use. The exposure estimates assume one exposure event (applied dose) per work day and that 0.29 percent of the applied dose is absorbed through the skin. Table 2-37 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 1-BP during use in open systems (e.g., during solvent changeout in vapor degreasing and dry cleaning) and not expected in closed-type systems (e.g., during connection/disconnection of hoses used in loading of bulk containers in manufacturing). See further discussion on occlusion in Appendix J. The exposure estimates are provided for each condition of use, where the conditions of uses are "binned" based on the maximum possible exposure concentration (Y_{derm}), the likely level of exposure, and potential for occlusion. The exposure concentration is determined based EPA's review of currently available products and formulations containing 1-BP. For example, EPA found that 1-BP concentration in degreasing formulations such as Solvon PB can be as high as 97 percent:

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[13] Using the Kasting and Miller method, the steady-state fractional absorption for 1-BP is estimated to be 6 to 9 percent.

- **Bin 1:** 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:
    - 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 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 1-BP that could lead to chemical permeation under the cuff of the glove or excessive liquid contact time with chemical permeation through the glove.
- **Bin 2:** 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 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 1-BP when charging and draining degreasing equipment, performing work on the degreasing tank, drumming waste solvent, and removing waste sludge. These activities could lead to chemical permeation under the cuff of the glove or excessive liquid contact time where chemical permeates through the glove.
- **Bin 3:** Bin 3 covers the use of 1-BP in spray adhesives in foam cushion product manufacturing, which is a unique condition of use. Workers (sprayers) can be dermally exposed when mixing adhesive, charging adhesive to spray equipment, and cleaning adhesive spray equipment. Other workers (non-sprayers) may also have incidental contact with the applied adhesive during subsequent fabrication steps. 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 operations such as spray applications and fabrication steps (non-sprayers).
    - Gloves used with a protection factor of 5 and 10: Workers may wear gloves when mixing adhesive, charging adhesive to spray equipment, and cleaning adhesive spray equipment.

    EPA assumes the commercial facilities in Bin 3 do not offer activity-specific training on donning and doffing gloves.
  - Occluded Exposure: Occlusion may occur when workers are handling bulk liquid 1-BP when mixing adhesive, charging adhesive to spray equipment, and cleaning adhesive spray equipment that could lead to chemical permeation under the cuff of the glove or excessive liquid contact time with 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 be accompanied by basic employee training, but not activity-specific training.
- **Bin 4:** Bin 4 covers commercial activities of similar maximum concentration. Most of these uses are uses at dry cleaners, and/or uses expected to have direct dermal contact with bulk liquids. At dry cleaning shops, workers may be exposed to bulk liquids while charging and draining solvent to/from machines, removing and disposing sludge, and maintaining equipment. Workers can also be exposed to 1-BP used in spot cleaning products at the same shop. 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 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 1-BP 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 with 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 be accompanied by basic employee training, but not activity-specific training.
- **Bin 5:** Bin 5 covers aerosol uses, where workers are likely to have direct dermal contact with film applied to substrate and incidental deposition of aerosol to skin. This bin also covers miscellaneous non-aerosol applications that are typically niche uses of 1-BP. EPA assesses the following glove use scenarios for Bin 5 conditions of use:
  - No gloves used: Actual use of gloves in this use is uncertain. EPA assumes workers may not wear gloves 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 gloves when applying aerosol products. EPA assumes the commercial facilities in Bin 5 do not offer activity-specific training on donning and doffing gloves.
  - Scenarios not assessed: EPA does not assess glove use with protection factors of 20 as EPA assumes chemical-resistant gloves used in these industries would be accompanied by basic employee training, but not activity-specific training. EPA does not assess occlusion for aerosol applications because 1-BP formulation is 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.

As shown in the table, the calculated retained dose is low for all non-occluded scenarios as 1-BP evaporates quickly after exposure. Dermal exposure to liquid is not expected for occupational non-users, as they do not directly handle 1-BP.

Table 2-37. Estimated Dermal Retained Dose (mg/day) for Workers in All Conditions of Use

Condition of Use	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)	
Manufacture	Bin 1	1.0	2.2 (CT) 6.5 (High-end)	0.4 (CT) 1.3 (High-end)	0.2 (CT) 0.7 (High-end)	0.1 (CT) 0.3 (High-end)	N/A – occlusion not expected
Import, Repackaging							
Processing - Incorporating into formulation							
Processing as a reactant							
Processing - Incorporating into articles							
Recycling							
Disposal							
Use – Batch vapor degreaser	Bin 2	0.97	2.1 (CT) 6.3 (High-end)	0.4 (CT) 1.3 (High-end)	0.2 (CT) 0.6 (High-end)	0.1 (CT) 0.3 (High-end)	727 (CT) 2,180 (High-end)
Use – In-line vapor degreaser							
Use - Cold cleaner							
Use – Adhesive chemicals (Spray adhesives)	Bin 3	0.8	1.7 (CT) 5.2 (High-end)	0.3 (CT) 1.0 (High-end)	0.2 (CT) 0.5 (High-end)	N/A	599 (CT) 1,798 (High-end)
Use - Dry cleaning	Bin 4	0.94	2.0 (CT) 6.1 (High-end)	0.4 (CT) 1.2 (High-end)	0.2 (CT) 0.6 (High-end)	N/A	704 (CT) 2,112 (High-end)
Use - Spot cleaner, Stain remover							
Use - Other non-aerosol uses	Bin 5	1.0	2.2 (CT) 6.5 (High-end)	0.4 (CT) 1.3 (High-end)	0.2 (CT) 0.7 (High-end)	N/A	N/A – occlusion not expected
Use – Aerosol spray degreaser/cleaner, other aerosol uses							

3 Discussion of Uncertainties and Limitations

3.1 Variability

EPA addressed variability in models by identifying key model parameters to apply a statistical distribution that mathematically defines the parameter's variability. EPA defined statistical distributions for parameters using documented statistical variations where available. Where the statistical variation is not known, assumptions are made to estimate the parameter distribution using available literature data.

3.2 Uncertainties and Limitations

Uncertainty is "the lack of knowledge about specific variables, parameters, models, or other factors" and can be described qualitatively or quantitatively (U.S. EPA, 2001b). The following sections discuss uncertainties associated with the 1-BP engineering assessment.

3.2.1 Number of Workers

There are a number of uncertainties surrounding the estimated number of workers potentially exposed to 1-BP, as outlined below. Most are unlikely to result in a systematic underestimate or overestimate, but could result in an inaccurate estimate.

CDR are used to estimate the number of workers associated with the following conditions of use: Manufacturing, Import, Processing as a Reactant, and Incorporation into Formulation, Mixture, or Reaction Product. There are inherent limitations to the use of CDR data as they are reported by manufacturers and importers of 1-BP. First, manufacturers and importers are only required to report if they manufactured or imported 1-BP in excess of 25,000 pounds at a single site during any calendar from 2012 to 2015; as such, CDR may not capture all site sand workers associated with any given chemical. Second, the estimate is based on information that is known or reasonably ascertainable to the submitter. CDR submitters (chemical manufacturers and importers) do not always have accurate information on the number of potentially exposed workers at downstream processing sites.

There are also uncertainties associated with BLS data, which are used to estimate the number of workers for the remaining conditions of use. First, BLS' OES employment data for each industry/occupation combination are only available at the 3-, 4-, or 5-digit NAICS level, rather than the full 6-digit NAICS level. This lack of granularity could result in an overestimate of the number of exposed workers if some 6-digit NAICS are included in the less granular BLS estimates but are not, in reality, likely to use 1-BP for the assessed condition of use. EPA addressed this issue by refining the OES estimates using total employment data from the U.S. Census' SUSB. However, this approach assumes that the distribution of occupation types (SOC codes) in each 6-digit NAICS is equal to the distribution of occupation types at the parent 5-digit NAICS level. If the distribution of workers in occupations with 1-BP 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 1-BP is used in each industry. Designations of which industries and occupations have potential exposures is nevertheless subjective, and some industries/occupations with few exposures might erroneously be included, or some industries/occupations with exposures might erroneously be excluded. This would result in inaccuracy but would be unlikely to systematically either overestimate or underestimate the count of exposed workers.

3.2.2 Analysis of Exposure Monitoring Data

To analyze exposure monitoring data, EPA categorized individual PBZ data point as either “worker” or “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 1-BP exposure source. As such, exposure levels for the “occupational non-user” category will have high variability depending on the specific work activity performed. It is possible that some employees categorized as “occupational non-user” have exposures similar to those in the “worker” category depending on their specific work activity pattern.

Some data sources may provide exposure estimates that are higher than typical across the distribution of facilities for that condition of use. For example, NIOSH HHEs for the spray adhesive use were conducted to address concerns regarding adverse human health effects reported following 1-BP exposure with spray adhesive use in furniture manufacturing. Two HHEs were requested by the North Carolina Department of Labor; one was conducted in response to a confidential request submitted by the facility’s employees.

There are limited exposure monitoring data in literature for certain conditions of use or job categories. For the spray adhesive use example, the number of data points available for non-sprayers is less than half of the data points available for sprayers. Additionally, very few exposure monitoring data are available for cold cleaning and for spot-cleaning. Where few data points are available, assessed exposure levels are unlikely to be representative of worker exposure across the entire job category or industry. For vapor degreasing and cold cleaning, several sources do not contain detailed information describing the type of degreaser or cleaner present at the facility. The lack of such information results in uncertainty in the assessed exposure levels associated with specific subcategories of such equipment. For example, the data presented for batch open-top vapor degreasers may actually include data associated with other types of degreaser.

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

3.2.3 Near-Field / Far-Field Model Framework

The near-field / far-field approach is used as a framework to model inhalation exposure for many conditions of use. The following describe uncertainties and simplifying assumptions generally associated with this modeling approach:

- There is some degree of uncertainty associated with each model input parameter. In general, the model inputs were determined based on review of available literature. Where the distribution of the input parameter is known, a distribution is assigned to capture uncertainty in the Monte Carlo analysis. Where the distribution is unknown, a uniform distribution is often used. The use of a uniform distribution will capture the low-end and high-end values but may not accurately reflect actual distribution of the input parameters.

- The model assumes the near-field and far-field are well mixed, such that each zone can be approximated by a single, average concentration.
- All emissions from the facility are assumed to enter the near-field. 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. Conversely, assuming the occupational non-user is exposed at the far-field concentration for the entire work day may underestimate exposure as they may not remain exclusively in the far-field.
- For certain 1-BP applications (e.g., vapor degreasing and cold cleaning), 1-BP 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 1-BP condition of use. The models have not been regressed or fitted with monitoring data.
- The models represent a baseline scenario that do not have LEV. EPA does not have adequate data to construct LEV systems into the exposure models. Additionally, there is no data on the fraction of U.S. facilities that use LEV. Where available, "what-if" values on engineering control effectiveness are applied to the model baseline to provide post-EC scenarios. These values were obtained by reviewing statements made in published literature regarding potential emission or exposure reductions after implementation of engineering control or equipment substitution.

Each subsequent section below discusses uncertainties associated with the individual model.

3.2.3.1 Vapor Degreasing and Cold Cleaning Model

The 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 vapor degreasing, EPA references a 1-BP emission factor developed by CARB for the California Solvent Cleaning Emissions Inventories (CARB, 2011). The emission factor is an average emission for the "vapor degreasing" category for the California facilities surveyed by CARB. The category includes batch-loaded vapor degreaser, aerosol surface preparation process, and aerosol cleaning process. For the purpose of modeling, EPA assumes the 1-BP emission factor is entirely attributed to vapor degreasing applications. The representativeness of the emission factor for vapor degreasing emissions in other geographic locations within the U.S. is uncertain.
- The CARB emission factor covers batch degreasing units. However, CARB does not further specify whether these are open-top vapor degreasers, enclosed, or other types of batch degreasers. EPA assumes the emission factor is representative of open-top vapor degreaser, as it is the most common design for batch units using 1-BP. In addition, EPA assumes that the

surveyed facilities likely switched to using 1-BP, an alternative, non-HAP solvent, as a way of complying with Federal and State regulations for HAP halogenated solvents (i.e., chemical substitution, rather than equipment changes).

- The CARB emission factor, in the unit of pound per employee-year, was developed for the purpose of estimating annual emissions. These types of emission factor typically reflect the amount of solvent lost / emitted, some of which may not be relevant to worker exposure. For example, 1-BP emitted and captured through a stack may not result in worker exposure. Therefore, assuming all of the 1-BP is emitted into the workplace air may result in overestimating of exposure. In addition, the use of an annual emission factor does not capture time variability of emissions. The approach assumes a constant emission rate over a set number of operating hours, while actual emissions and worker exposures will vary as a function of time and worker activity.
- EPA combines the CARB emission factor with nationwide Economic Census employment data across 78 NAICS industry sector codes. It should be noted that vapor degreasing is not an industry-specific operation. Only a subset of facilities within the 78 selected industry sectors are expected to operate vapor degreasers. Therefore, the industry-average employment data may not be representative of the actual number of employees at vapor degreasing facilities.
- To estimate worker exposure during cold cleaning, EPA applied an emission reduction factor to the vapor degreasing model by comparing the AP-42 emission factors for the two applications. The AP-42 emission factors are dated. Furthermore, the cold cleaning model results have not been validated with actual monitoring data.
- 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 1-BP in air.
- The model assumes an exposure reduction of 90 percent with engineering control. In reality, engineering controls and their effectiveness are site-specific. Additionally, the 90 percent reduction is a value based on TCE, and may not be applicable to a more volatile chemical such as 1-BP.

3.2.3.2 Aerosol Degreasing 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 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 1-BP.
- The Use Dossier identifies 25 different aerosol degreasing formulations containing 1-BP (EPA-HQ-OPPT-2016-0741-0003 (U.S. EPA, 2017b)). For each Monte Carlo iteration, the model determines the 1-BP concentration in product by selecting one of 25 possible formulations, assuming equal probability of each formulation being used. In reality, some formulations are likely more prevalent than others.

3.2.3.3 Dry Cleaning Model

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

- The model assumes each facility only has one dry cleaning machine, cleaning one to fourteen loads of garments per day. While the dry cleaning facilities in Blando et al. (2010) and NIOSH (2010) appear to only have one machine, the representativeness of these two studies is not known. Larger facilities are likely to have more machines, which could result in additional 1-BP exposures.
- Many of the model input parameters were obtained from (Von Grote, 2003), which is a German study. Aspects of the U.S. dry cleaning facilities may differ from German facilities. However, it is not known whether the use of German data will under- or over-estimate exposure.
- The model does not cover all potential worker activities at dry cleaners. For example, workers could be exposed to 1-BP emitted due to equipment leaks, when re-filling 1-BP solvent into dry cleaning machines, when interrupting a dry cleaning cycle, or when performing maintenance activities (e.g., cleaning lint and button traps, raking out the still, changing solvent filter, and handling solvent waste) (OSHA, 2005). However, there is a lack of information on these activities in the literature, and the frequency of these activities is not well understood. The likelihood of equipment leaks is dependent on whether the machines are properly converted and maintained. The frequency of solvent re-filling depends on a specific dry cleaner's workload and solvent consumption rate, which is also affected by the presence of leaks. Based on observations reported by (NIOSH, 2010) and (Blando et al., 2010), solvent charging is not performed every day. EPA was unable to develop a modeling approach for these exposure activities due to the lack of available information.

3.2.3.4 Spot Cleaning Model

The spot cleaning assessment also uses a near-field/far-field approach to model worker exposure. The model estimates a use rate of 16 gallons per year spot cleaner. This value was derived using a MassDEP case study for one specific dry cleaner in Massachusetts, handling 100 pieces of garments per day. MassDEP noted that the size of each dry cleaner can vary substantially. As such, the spot cleaner use rate will also vary by the individual facility work load.

3.2.4 Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model

For Import/repackaging, Processing as a reactant, and Processing – Incorporation into articles, the *Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model* is used to estimate the airborne concentration associated with generic chemical loading scenarios at industrial facilities. Specific uncertainties associated with this model are described below:

- After each loading event, the model assumes saturated air containing 1-BP that remains in the transfer hose and/or loading arm is released to air. The model calculates the quantity of saturated air using design dimensions of loading systems published in the OPW Engineered Systems catalog and engineering judgment. These dimensions may not be representativeness of the whole range of loading equipment used at industrial facilities handling 1-BP.
- The model estimates fugitive emissions from equipment leaks using total organic compound emission factors from EPA's Protocol for Equipment Leak Emission Estimates (U.S. EPA, 1995), and engineering judgement on the likely equipment type used for transfer (e.g., number of valves, seals, lines, and connections). The applicability of these emission factors to 1-BP, and the accuracy of EPA's assumption on equipment type are not known.

- The model assumes the use of a vapor balance system to minimize fugitive emissions. Although most industrial facilities are likely to use a vapor balance system when loading/unloading volatile chemicals, EPA does not know whether these systems are used by all facilities that potentially handle 1-BP.

3.2.5 Modeling Dermal Exposures

The *Dermal Exposure to Volatile Liquids Model* assumes a single exposure event per day based on existing framework of the *EPA/OPPT 2-Hand Dermal Exposure* model. The model does not address how contact duration and frequency affects dermal exposure.

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Appendix A Approach for Estimating Number of Workers

This appendix summarizes the methods that EPA used to estimate the number of workers where CDR data are not available. This approach is used to estimate number of workers associated with the following 1-BP conditions of use:

- Processing – Incorporation into Articles;
- Batch Vapor Degreaser (Open-Top);
- Batch Vapor Degreaser (Closed-Loop);
- In-line Vapor Degreaser (Conveyorized);
- Aerosol Spray Degreaser/Cleaner;
- Dry Cleaning;
- Adhesive Chemicals (Spray Adhesives); and
- Disposal.

The method consists of the following steps: [14]

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

For the following conditions of use, the approach for estimating number of workers has been previously documented in Appendix F of EPA's 2016 draft Risk Assessment:

- Vapor Degreaser (Batch Open-Top, Batch Closed-Loop, and Conveyorized);
- Aerosol Spray Degreaser/Cleaner;
- Dry Cleaning and Spot Cleaning; and
- Adhesive Chemicals (Spray Adhesives).

Step 1: Identifying Affected NAICS Codes

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

- Querying the U.S. Census Bureau's *NAICS Search* tool using keywords associated with each condition of use to identify NAICS codes with descriptions that match the condition of use.

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[14] For conditions of use previously assessed in EPA's 2016 draft Risk Assessment, 2015 BLS data (U.S. BLS, 2015) and 2012 SUSB data (U.S. Census Bureau, 2012) are used.

- Referencing EPA/OPPT Generic Scenarios (GS’s) and Organisation for Economic Co-operation and Development (OECD) Emission Scenario Documents (ESDs) for a condition of use to identify NAICS codes cited by the GS or ESD.
- Reviewing Chemical Data Reporting (CDR) data for the chemical, identifying the industrial sector codes reported for downstream industrial uses, and matching those industrial sector codes to NAICS codes using Table D-2 provided in the CDR reporting instructions.

Table_Apx A-1 provides the applicable NAICS codes for these 1-BP conditions of use.

Table_Apx A-1. Affected NAICS Codes for Select 1-BP Conditions of Use

Condition of Use	NAICS	Industry
Processing – Incorporation into Articles	326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing
Batch Vapor Degreaser (Open-Top)	Multiple	See Appendix F of EPA’s 2016 1-BP draft Risk Assessment
Batch Vapor Degreaser (Closed-Loop)		
In-line Vapor Degreaser (Conveyorized)		
Aerosol Spray Degreaser/Cleaner	Multiple	See Appendix F of EPA’s 2016 1-BP draft Risk Assessment
Dry Cleaning	812320	Drycleaning and Laundry Services (except Coin-Operated)
Adhesive Chemicals (Spray Adhesives)	337121	Upholstered Household Furniture Manufacturing
	337125	Household Furniture (except Wood and Metal) Manufacturing
	337127	Institutional Furniture Manufacturing
	337214	Office Furniture (except Wood) Manufacturing
Disposal	562211	Hazardous Waste Treatment and Disposal
	562212	Solid Waste Landfill
	562213	Solid Waste Combustors and Incinerators
	562219	Other Nonhazardous Waste Treatment and Disposal
	327310	Cement Manufacturing

Step 2: Estimating Total Employment by Industry and Occupation

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

Among the relevant NAICS codes (identified previously), EPA reviewed the occupation description and identified those occupations (SOC codes) where workers are potentially exposed to 1-BP. Table_Apx A-2 shows the SOC codes EPA classified as occupations potentially exposed to 1-BP. These occupations are classified into workers (W) and occupational non-users (O). All other SOC codes are assumed to represent occupations where exposure is unlikely.

Table_Apx A-2. SOCs with Worker and ONU Designations for All Conditions of Use Except Dry Cleaning

SOC	Occupation	Designation
11-9020	Construction Managers	O
17-2000	Engineers	O
17-3000	Drafters, Engineering Technicians, and Mapping Technicians	O
19-2031	Chemists	O
19-4000	Life, Physical, and Social Science Technicians	O
47-1000	Supervisors of Construction and Extraction Workers	O
47-2000	Construction Trades Workers	W
49-1000	Supervisors of Installation, Maintenance, and Repair Workers	O
49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	W
49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	W
49-9010	Control and Valve Installers and Repairers	W
49-9020	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	W
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9060	Precision Instrument and Equipment Repairers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-1000	Supervisors of Production Workers	O
51-2000	Assemblers and Fabricators	W
51-4020	Forming Machine Setters, Operators, and Tenders, Metal and Plastic	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W
51-6030	Sewing Machine Operators	O
51-6040	Shoe and Leather Workers	O
51-6050	Tailors, Dressmakers, and Sewers	O
51-6090	Miscellaneous Textile, Apparel, and Furnishings Workers	O
51-8020	Stationary Engineers and Boiler Operators	W
51-8090	Miscellaneous Plant and System Operators	W
51-9000	Other Production Occupations	W

W = Worker designation
O = ONU designation

For dry cleaning facilities, due to the unique nature of work expected at these facilities and that different workers may be expected to share among activities with higher exposure potential (e.g., unloading the dry cleaning machine, pressing/finishing a dry cleaned load), EPA made different SOC code worker and ONU assignments for this condition of use. Table_Apx A-3 summarizes the SOC codes with worker and ONU designations used for dry cleaning facilities.

Table_Apx A-3. SOCs with Worker and ONU Designations for Dry Cleaning Facilities

SOC	Occupation	Designation
41-2000	Retail Sales Workers	O
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
49-9070	Maintenance and Repair Workers, General	W
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
51-6010	Laundry and Dry-Cleaning Workers	W
51-6020	Pressers, Textile, Garment, and Related Materials	W

SOC	Occupation	Designation
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 (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 1-BP exposure are included. As an example, OES data are available for the 4-digit NAICS 8123 *Drycleaning and Laundry Services*, which includes the following 6-digit NAICS:

- NAICS 812310 Coin-Operated Laundries and Drycleaners;
- NAICS 812320 Drycleaning and Laundry Services (except Coin-Operated);
- NAICS 812331 Linen Supply; and
- NAICS 812332 Industrial Launderers.

In this example, only NAICS 812320 is of interest. The Census data allow EPA to calculate employment in the specific 6-digit NAICS of interest as a percentage of employment in the BLS 4-digit NAICS.

The 6-digit NAICS 812320 comprises 46 percent of total employment under the 4-digit NAICS 8123. This percentage can be multiplied by the occupation-specific employment estimates given in the BLS OES data to further refine our estimates of the number of employees with potential exposure.

Table_Apx A-4 illustrates this granularity adjustment for NAICS 812320.

Table_Apx A-4. 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. Census Bureau, 2015) (U.S. BLS, 2016)

Step 4: Estimating the Percentage of Workers Using 1-BP 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, where available. This accounts for the fact that 1-BP may be only one of multiple chemicals used for the applications of interest. EPA only identified market penetration data for a limited number of conditions of use. In the absence of market penetration data for a given condition of use, EPA assumed 1-BP may be used at up to all sites and by up to all workers calculated in this method as a bounding estimate. This assumes a market penetration of 100%. Market penetration is discussed for each condition of use in the main body of this report.

Step 5: Estimating the Number of Workers per Site

EPA calculated the number of workers and occupational non-users in each industry/occupation combination using the formula below (granularity adjustment is only applicable where SOC data are not available at the 6-digit NAICS level):

Number of Workers or ONUs in NAICS/SOC (Step 2) × Granularity Adjustment Percentage (Step 3) = Number of Workers or ONUs in the Industry/Occupation Combination

EPA then estimated the total number of establishments by obtaining the number of establishments reported in the U.S. Census Bureau's SUSB (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 Condition of Use

EPA estimated the number of workers and occupational non-users potentially exposed to 1-BP and the number of sites that use 1-BP in a given condition of use through the following steps:

6.A. Estimating the number of establishments that use 1-BP by:
  i. Obtaining the number of establishments from SUSB (2015) at the 6-digit NAICS level (Step 5) for each NAICS code in the condition of use and summing these values, and multiplying by the market penetration factor from Step 4; or
  ii. Obtaining the number of establishments from the TRI, literature, or public comments for the condition of use.

6.B. Estimating the number of workers and occupational non-users potentially exposed to 1-BP by taking the number of establishments calculated in Step 6.A and multiplying it by the average number of workers and occupational non-users per site from Step 5.

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

This report assesses 1-BP exposures to workers and occupational non-users in occupational settings, presented as 8-hr time weighted average (TWA) exposure. The 8-hr TWA exposures are then used to calculate acute exposure concentration (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, unless otherwise noted).

Equation_Apx B-1

$$\mathrm{AC} = \frac{\mathrm{C} \times \mathrm{ED}}{\mathrm{AT}_{\mathrm{Acute}}}$$

Where:

AC = Acute exposure concentration
C = Contaminant concentration in air (8-hr TWA)
ED = Exposure duration (hr/day)
$\mathrm{AT}_{\mathrm{Acute}}$ = Averaging time for acute exposure (hr)

ADC and LADC are used to estimate workplace exposures for non-cancer and cancer risks, respectively. These exposures are estimated as follows:

Equation_Apx B-2

$$\mathrm{ADC\ or\ LADC} = \frac{\mathrm{C} \times \mathrm{ED} \times \mathrm{EF} \times \mathrm{WY}}{\mathrm{AT\ or\ AT_c}}$$

Equation_Apx B-3

$$\mathrm{EF} = \mathrm{AWD} \times \mathrm{f}$$

Equation_Apx B-4

$$\mathrm{AT} = \mathrm{LT} \times 260\,\frac{\mathrm{day}}{\mathrm{yr}} \times 8\,\frac{\mathrm{hr}}{\mathrm{day}}$$

Equation_Apx B-5

$$\mathrm{AT_C} = \mathrm{LT_C} \times 260\,\frac{\mathrm{day}}{\mathrm{yr}} \times 8\,\frac{\mathrm{hr}}{\mathrm{day}}$$

Where:

ADC = Average daily concentration (8-hr TWA) used for chronic non-cancer risk calculations
LADC = Lifetime average daily concentration (8-hr TWA) used for chronic cancer risk calculations
EF = Exposure frequency (day/yr)
WY = Working years per lifetime (yr)

AT = Averaging time (hr) for chronic, non-cancer risk[15]
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 non-cancer risk
LT_C = Lifetime years (yr) for cancer risk

The parameter values in Table_Apx B-1 and Table_Apx B-2 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. In this case, the lifetime working years (LT) is defined as a triangular distribution with a minimum of 10.4 years, a mode of 36 years, and a maximum of 44 years (U.S. BLS, 2014) (U.S. Census Bureau, 2019a) (U.S. Census Bureau, 2019b). The corresponding 95th and 50th percentile values for this distribution is 40 years and 31 years, respectively.

Table_Apx B-1. Parameter Values for Calculating Acute Concentration

Parameter Name	Symbol	Value	Unit
Exposure Duration	ED	8	hr/day
Averaging Time (acute)	AT_{Acute}	8	hr/day

Table_Apx B-2. Parameter Values for Calculating ADC and LADC

Parameter Name	Symbol	95th Percentile Value	50th Percentile Value	Unit
Exposure Duration	ED	8	8	hr/day
Annual Working Days	AWD	260	260	day/yr
Fractional Working Days with Exposure	f	1	1	unitless
Working Years per Lifetime	WY	40	31	yr
Lifetime (chronic, non-cancer)	LT	40	31	yr
Lifetime (chronic, cancer)	LT_C	78	78	yr
Averaging Time (chronic, non-cancer)	AT	83,200	64,480	hr
Averaging Time (chronic, cancer)	AT_C	162,240	162,240	hr

Table_Apx B-3 presents parameters specific to the *dry cleaning* condition of use. The 95th and 50th percentile exposure frequencies are determined through a 100,000-iteration Monte Carlo simulation, where the fractional working days with exposure is defined as a uniform distribution with values ranging from 0.8 to 1, and the annual working day is defined as a triangular distribution with minimum of 250 days, maximum of 312 days, and mode of 300 days per year.

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[15] For the developmental endpoint only, averaging time (AT) for chronic non-cancer risk is based on 365 days per year instead of 260 days per year.

Table_Apx B-3. Parameter Values for Calculating ADC and LADC for Dry Cleaning

Parameter Name	Symbol	95th Percentile Value	50th Percentile Value	Unit
Exposure Duration	ED	8	8	hr/day
Exposure Frequency	EF	293	258	day/yr
Averaging Time (chronic, non-cancer)	AT	93,760	63,984	hr
Averaging Time (chronic, cancer)	AT_C	182,832	160,992	hr

Table_Apx B-4 presents the parameters for calculating AC, ADC, and LADC *where the exposure concentration, C, is presented as 12-hr TWA* (instead of 8-hr TWA). In this case, the averaging time in the denominator of the ADC and LADC equation is calculated using Equation_Apx B-6.

Equation_Apx B-6

$$\mathrm{AT\ or\ AT_c} = \mathrm{LT\ or\ LT_c} \times 365\,\frac{\mathrm{day}}{\mathrm{yr}} \times 24\,\frac{\mathrm{hr}}{\mathrm{day}}$$

Table_Apx B-4. Parameter Values for Calculating AC, ADC and LADC using 12-hr TWA Exposure Concentration

Parameter Name	Symbol	95th Percentile Value	50th Percentile Value	Unit
Exposure Duration	ED	12	12	hr/day
Averaging Time (acute)	AT_{Acute}	12	12	hr/day
Averaging Time (chronic, non-cancer)	AT	350,400	271,560	hr
Averaging Time (chronic, cancer)	AT_C	683,280	683,280	hr

Appendix C Summary of Department of Defense Data

Table_Apx C-1 summarizes available 1-BP exposure monitoring data at six DOD facilities from 2014 to 2017. The monitoring data comprise of short-term samples where the sampling time ranges from six to 180 minutes (0.1 to 3 hours). Short-term exposure level ranges from 0.3 to 22.5 ppm.

Based on available process descriptions, all work activities monitored involved some type of degreasing, including vapor degreasing, aerosol degreasing, cold cleaning, spray or wipe cleaning. The process equipment may be automatic or manually operated. Some degreasing processes occur on an as-needed basis, while others are conducted throughout the entire work shift. In each case, it is not clear whether the worker performs additional activities with potential for 1-BP exposure outside of the sampling duration, as such, it is not possible to calculate the full-shift TWA exposure from the short-term measurements.

Table_Apx C-1. Summary of DOD Exposure Monitoring Data

Workplace	Process Name	Process Frequency	Process Duration	Sample Date	Work Shift Duration	Sampling Time (min)	Measured Result (ppm)
Advanced Composites	198E Phosphoric Acid Line	Daily	6-8 hours	12 Dec 17	8 Hours	24	2.7
Generators Workplace	356A Parts Cleaning	Daily	0-15 mins	04 Sep 14	9 Hours	66	4.8
		Daily	0-15 mins	19 Nov 14	9 Hours	82	0.6
Electrical/ Environmental / Battery Shop	Electrical Components Maintenance/Repair/Replace	Daily	0.5-1 hour	07 Jul 17	10 Hours	180	22.5
		Daily	0.5-1 hour	07 Jul 17	10 Hours	140	0.3
56-N10	56: BLDG: Validate pre-cleaning with contact cleaner (spray/wipe cleaning) in Pre-Cleaning Area	Special Occasions	-	21 Jul 16	8 Hours	96	5.2
		Special Occasions	-	21 Jul 16	8 Hours	101	8.0
Code 32	3221-1018 Vapor Degreasing Code 3221	Daily	-	02 Jun 14	8 Hours	151	1.4
		Daily	-	02 Jun 14	8 Hours	151	1.4
		Daily	-	02 Jun 14	8 Hours	142	2.9
		Daily	-	02 Jun 14	8 Hours	101	1.4
FRCNW-500-530-NDI	IND00208-Aerosol Can Degreasing	Special Occasions	0-15 mins	31 Aug 17	8 Hours	6	5.2

- Data not available/provided

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

Appendix D Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model Approach and Parameter

This appendix presents the modeling approach and model equations used in the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model. The model was developed through review of relevant literature and consideration of existing EPA/OPPT exposure models. The model approach is a generic inhalation exposure assessment at industrial facilities that is applicable for any volatile chemical with the following conditions of use:

- Manufacture (loading of chemicals into containers);
- Processing as a reactant/intermediate (unloading of chemicals);
- Processing into formulation, mixture, or reaction products;
- Import (repackaging); and
- Other similar conditions of use at industrial facilities (e.g., industrial processing aid).

As an example, imported 1-BP material may be packaged and loaded into a container before distributing to another industrial processing or use site (e.g., formulation sites). At the industrial processing or use site, 1-BP is then unloaded from the container into a process vessel before being incorporated into a mixture, used as a chemical intermediate, or otherwise processed/used. For the model, EPA assumes 1-BP is unloaded into tank trucks and railcars and transported and distributed in bulk. EPA also assumes the chemical is handled as a pure substance (100 percent concentration).

Because 1-BP is volatile (vapor pressure above 0.01 torr at room temperature), fugitive emissions may occur when 1-BP is loaded into or unloaded from a tank truck or railcar. Sources of these emissions include:

- Displacement of saturated air containing 1-BP as the container/truck is filled with liquid;
- Emissions of saturated air containing 1-BP that remains in the loading arm, transfer hose, and related equipment; and
- Emissions from equipment leaks from processing units such as pumps, seals and valves.

These emissions result in subsequent exposure to workers involved in the transfer activity. The following subsections address these emission sources.

D.1 Displacement of Saturated Air Inside Tank Trucks and Railcars

For screening-level assessments, EPA typically uses the *EPA/OAQPS AP-42 Loading Model* to conservatively assess exposure during container unloading activities (U.S. EPA, 2013a). The model estimates release to air from the displacement of air containing chemical vapor as a container/vessel is filled with liquid. The model assumes the unloading activity displaces an air volume equal to the size of the container, and that displaced air is either 50 percent or 100 percent saturated with chemical vapor (U.S. EPA, 2013a).

EPA expects the majority of industrial facilities to use a vapor balance system to minimize fugitive emissions when loading and unloading tank trucks and railcars. As such, vapor losses from displacement of air is likely mitigated by the use of such systems. Actual fugitive emissions are likely limited to any saturated vapor that remain in the hose, loading arm, or related equipment after being disconnected from the truck or railcar. This emission source is addressed in the next subsection.

D.2 Emissions of Saturated Air that Remain in Transfer Hoses/Loading Arm

After loading is complete, transfer hoses and/or loading arms are disconnected from tank trucks and railcars. Saturated air containing the chemical of interest that remains in transfer equipment may be released to air, presenting a source of fugitive emissions. The quantity of 1-BP released will depend on concentration in the vapor and the volume of vapor in the loading arm/hose/piping.

Table_Apx D-1 presents the dimensions for several types of loading systems according to an OPW Engineered Systems catalog. OPW Engineered Systems (2014) specializes in the engineering, designing, and manufacturing of systems for loading and unloading a wide range of materials including petroleum products, liquefied gases, asphalt, solvents, and hazardous and corrosive chemicals. These systems include loading systems, swivel joints, instrumentation, quick and dry-disconnect systems, and safety breakaways. Based on the design dimensions, the table presents the calculated total volume of loading arm/system and assumes the volume of vapor containing 1-BP equals the volume of the loading arm/system.

Chemical-specific transport container information was not available; therefore, EPA assumed a default approach with the “central tendency” as tank truck loading/unloading and the “high-end” as railcar loading/unloading. Central tendency and high-end approaches are based on the expected transfer arm volume (and therefore, potential exposure concentration). To estimate the high-end transfer arm volume, EPA calculated the 95th percentile of the OPW Engineered Systems loading arms volumetric data resulting in a high-end value of 17.7 gallons. For the central tendency tank truck scenario, EPA assumed a 2-inch diameter, 12-ft long transfer hose. This hose has a volume of 2.0 gallons.

Once the volume is known, the emission rate, E_T (g/s), can be calculated as follows:

Equation_Apx D-1

$$\boldsymbol{E_T = \frac{f \times MW \times 3,786.4 \times V_h \times X \times VP}{t_{disconnect} \times T \times R \times 3,600 \times 760}}$$

Default values for Equation_Apx D-1 can be found in Table_Apx D-2.

Table_Apx D-1. Example Dimension and Volume of Loading Arm/Transfer System

	Length of Loading Arm/Connection (in) [a]				Volume, V_h (gal) [b]			
OPW Engineered Systems Transfer Arm	**2-inch**	**3-inch**	**4-inch**	**6-inch**	**2-inch**	**3-inch**	**4-inch**	**6-inch**
Unsupported Boom-Type Bottom Loader	149.875	158.5	165.25	191.75	2.0	4.9	9.0	23.5
"A" Frame Loader M-32-F	153.75	159.75	164.5	NA	2.1	4.9	8.9	NA
"A" Frame Hose Loader AFH-32-F	180.75	192.75	197.5	NA	2.5	5.9	10.7	NA
CWH Series Counterweighted Hose Loader	NA	NA	309	NA	NA	NA	16.8	NA
Spring Balanced Hose Loader SRH-32-F	204.75	216.75	221.5	NA	2.8	6.6	12.0	NA
Spring Balanced Hose Loader LRH-32-F	NA	270	277.625	NA	NA	8.3	15.1	NA
Top Loading Single Arm Fixed Reach	201.75	207.75	212.5	NA	2.7	6.4	11.6	NA
Top Loading Scissor Type Arm	197.875	206.5	213.25	NA	2.7	6.3	11.6	NA
Supported Boom Arm B-32-F	327.375	335	341.5	NA	4.5	10.3	18.6	NA
Unsupported Boom Arm GT-32-F	215.875	224.5	231.25	NA	2.9	6.9	12.6	NA
Slide Sleeve Arm A-32F	279	292.5	305.125	NA	3.8	9.0	16.6	NA
Hose without Transfer Arm								
Hose (EPA judgment)	120	--	--	--	1.6	--	--	--

Source: (OPW Engineered Systems, 2014)

a – Total length includes length of piping, connections, and fittings.

b – Calculated based on dimension of the transfer hose/connection, $V_h = \pi r^2 L$ (converted from cubic inch to gallons).

Table_Apx D-2. Default Values for Calculating Emission Rate of 1-BP from Transfer/Loading Arm

Parameter	Parameter Description	Default Value	Unit
E_T	Emission rate of chemical from transfer/loading system	Calculated from model equation	g/s
f	Saturation factor [a]	1	dimensionless
MW	Molecular weight of the chemical	122.99	g/mol
V_h	Volume of transfer hose	See Table_Apx D-1	gallons
r	Fill rate [a]	2 (tank truck) 1 (railcar)	containers/hr
$t_{disconnect}$	Time to disconnect hose/couplers (escape of saturated vapor from disconnected hose or transfer arm into air)	0.25	hr
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of the pure chemical	146.26	torr
T	Temperature	298	K
R	Universal gas constant	82.05	atm-cm^3/gmol-K

a – Saturation factor and fill rate values are based on established EPA release and inhalation exposure assessment methodologies (U.S. EPA, 2013a).

D.3 Emission from Leaks

During loading/unloading activities, emissions may also occur from equipment leaks from valves, pumps, and seals. Per EPA's *Chapter 5: Petroleum Industry* of AP-42 (U.S. EPA, 2015) and EPA's

Protocol for Equipment Leak Emission Estimates (1995), the following equation can be used to estimate emission rate E_L, calculated as the sum of average emissions from each process unit:

Equation_Apx D-2

$$E_L = \sum (F_A \times WF_{TOC} \times N) \times \frac{1{,}000}{3{,}600}$$

Parameters for calculating equipment leaks using Equation_Apx D-3 can be found in Table_Apx D-3.

Table_Apx D-3. Parameters for Calculating Emission Rate of 1-BP from Equipment Leaks

Parameter	Parameter Description	Default Value	Unit
E_L	Emission rate of chemical from equipment leaks	Calculated from model equation	g/s
F_A	Applicable average emission factor for the equipment type	See Table_Apx D-4	kg/hr-source
WF_{TOC}	Average weight fraction of chemical in the stream	1	dimensionless
N	Number of pieces of equipment of the applicable equipment type in the stream	See Table_Apx D-4	Source

To estimate emission leaks using this modeling approach, EPA modeled a central tendency loading rack scenario using tank truck loading/unloading and a high-end loading rack scenario using railcar loading/unloading as discussed in Appendix D.2. EPA used engineering judgment to estimate the type and number of equipment associated with the loading rack in the immediate vicinity of the loading operation. EPA assumes at least one worker will be near the loading rack during the entire duration of the loading operation.

Table_Apx D-4 presents the average emission factor for each equipment type, based on the synthetic organic chemical manufacturing industry (SOCMI) emission factors as provided by EPA's 1995 Protocol (U.S. EPA, 1995), and the likely number of pieces of each equipment used for each chemical loading/unloading activity, based on EPA's judgment. Note these emission factors are for emission rates of total organic compound emission and are assumed to be applicable to 1-BP. In addition, these factors are most valid for estimating emissions from a population of equipment and are not intended to be used to estimate emissions for an individual piece of equipment over a short period of time.

Table_Apx D-4. Default Values for F_A and N

Equipment Type	Service	SOCMI Emission Factor, F_A (kg/hr-source) [a]	Number of Equipment, N (central tendency)	Number of Equipment, N (high-end)
Valves	Gas Light liquid Heavy liquid	0.00597 0.00403 0.00023	3 (gas) 5 (light liquid) --	3 (gas) 10 (light liquid) --
Pump seals [b]	Light liquid Heavy liquid	0.0199 0.00862	--	--
Compressor seals	Gas	0.228	--	--
Pressure relief valves	Gas	0.104	1	1
Connectors	All	0.00183	2	3
Open-ended lines	All	0.0017	--	--
Sampling connections	All	0.015	2	3

Source: (U.S. EPA, 1995)

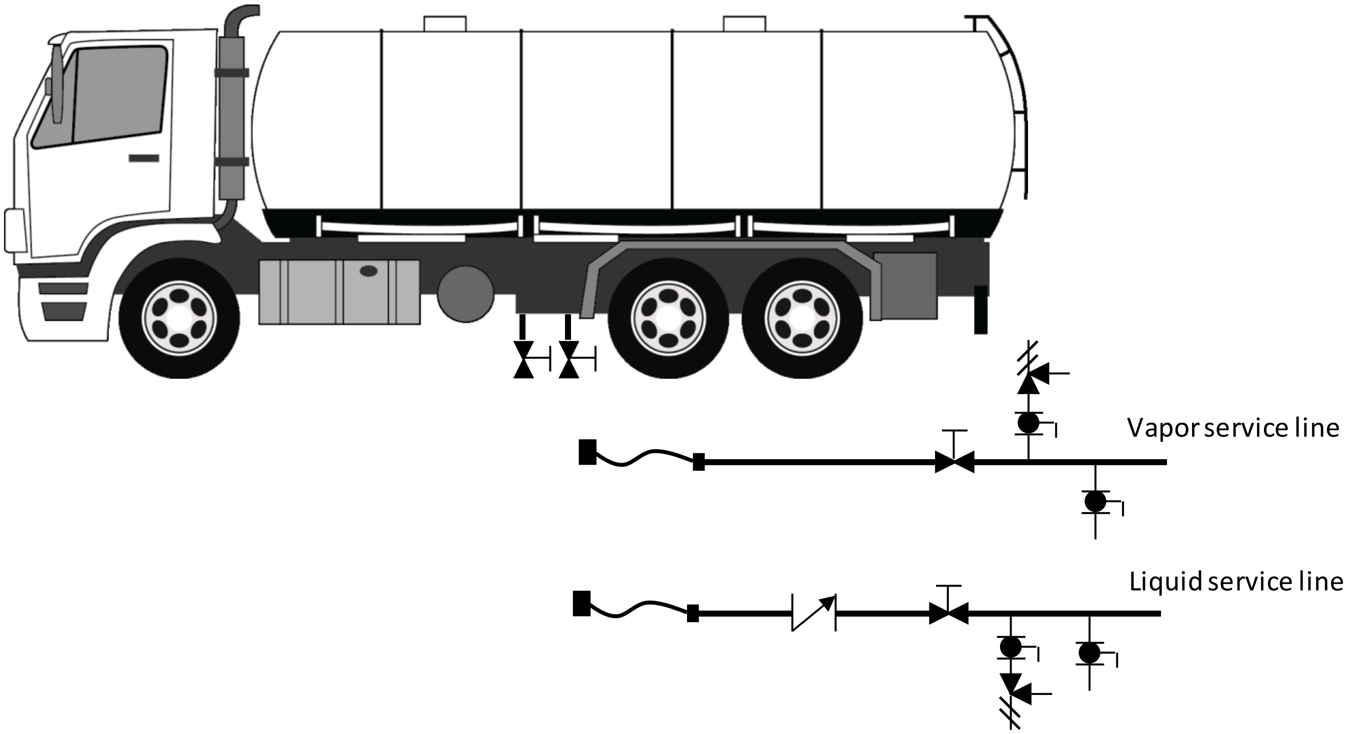
a – SOCMI average emission factors for total organic compounds from EPA's 1995 Protocol (U.S. EPA, 1995). "Light liquid" is defined as "material in a liquid state in which the sum of the concentration of individual constituents with a vapor pressure over 0.3 kilopascals (kPa) at 20 °C is greater than or equal to 20 weight percent." "Heavy liquid" is defined as "not in gas/vapor service or light liquid service." Since 1-BP has a vapor pressure of 146 mmHg (19.5 kPa) at 25 °C, EPA modeled 1-BP liquid as a light liquid.

b – The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

EPA assumed the following equipment are used in loading racks for the loading/unloading of tank trucks and railcars. Figure_Apx D-1 illustrates an example tank truck and unloading rack equipment.

- Tank Truck Loading/Unloading:
  - Liquid Service:
    - Four valves (modeled as valves in light liquid service)
    - One safety relief valve (modeled as valve in light liquid service)
    - One bleed valve or sampling connection
    - One hose connector
  - Vapor Service:
    - Three valves (modeled as valves in gas service)
    - One pressure relief valve
    - One bleed valve (modeled as a sampling connection)
    - One hose connector
- Railcar Loading/Unloading
  - Liquid Service: EPA assumed, for the high-end scenario, two parallel liquid service lines, each using the same equipment as assumed for tank trucks. Therefore, a total of:
    - Eight valves (modeled as valves in light liquid service)
    - Two safety relief valves (modeled as valve in light liquid service)
    - Two bleed valves or sampling connections
    - Two transfer arm connectors
  - Vapor Service: EPA assumed a single line in vapor service with the same equipment as assumed for tank trucks.
    - Three valves (modeled as valves in gas service)
    - One pressure relief valve

- One bleed valve (modeled as a sampling connection)
- One transfer arm connector



Figure_Apx D-1. Illustration of Transfer Lines Used During Tank Truck Unloading and Associated Equipment Assumed by EPA

D.4 Exposure Estimates

The vapor generation rate, *G*, or the total emission rate over time, can be calculated by aggregating emissions from all sources:

- During the transfer period, emissions are only due to leaks, with emission rate $G = E_L$.
- After transfer, during the disconnection of the hose(s), emissions are due to both leaks and escape of saturated vapor from the hose/transfer arm with emission rate $G = E_T + E_L$.

The vapor generation rate can then be used with the *EPA/OPPT Mass Balance Inhalation Model* to estimate worker exposure during loading/unloading activities (U.S. EPA, 2013a). The *EPA/OPPT Mass Balance Inhalation Model* estimates the exposure concentration using Equation_Apx D-3 and the default parameters found in Table_Apx D-5 (U.S. EPA, 2013a). Table_Apx D-6 presents exposure estimates for 1-BP using this approach. These estimates assume one unloading/loading event per day and 1-BP is loaded/unloaded at 100% concentration. The loading operation occurs in an outdoor area with minimal structure, with wind speeds of 9 mph (central tendency) or 5 mph (high-end).

Equation_Apx D-3

$$C_m = \frac{C_v}{V_m}$$

Table_Apx D-5. Parameters for Calculating Exposure Concentration Using the EPA/OPPT Mass Balance Model

Parameter	Parameter Description	Default Value	Unit
C_m	Mass concentration of chemical in air	Calculated from model equation	mg/m^3
C_v	Volumetric concentration of chemical in air	Calculated as the lesser of: $\frac{170{,}000 \times T \times G}{MW \times Q \times k}$ or $\frac{1{,}000{,}000 \times X \times VP}{760}$	ppm
T	Temperature of air	298	K
G	Vapor generation rate	E_L during transfer period E_T+E_L after transfer/during disconnection of hose/transfer arm	g/s
MW	Molecular weight of the chemical	122.99	g/mol
Q	Outdoor ventilation rate	237,600 (central tendency) $26{,}400 \times \left(60 \times \frac{vz}{5280}\right)$ (high-end)	ft^3/min
vz	Air speed	440	ft/min
k	Mixing factor	0.5	dimensionless
X	Vapor pressure correction factor	1	dimensionless
VP	Vapor pressure of the pure chemical	146.26	torr
V_m	Molar volume	24.45 @ 25ºC, 1 atm	L/mol

EPA also calculated acute and 8-hr TWA exposures as shown in Equation_Apx D-4 and Equation_Apx D-5, respectively. The acute TWA exposure is the weighted average exposure during the entire exposure duration per shift, accounting for the number of loading/unloading events per shift. The 8-hr TWA exposure is the weighted average exposure during an entire 8-hr shift, assuming zero exposures during the remainder of the shift. EPA assumed one container is loaded/unloaded per shift: one tank truck per shift for the central tendency scenario and one railcar per shift for the high-end scenario.

Equation_Apx D-4

$$Acute\ TWA = \frac{\left(C_{m(leak\ only)} \times (h_{event} - t_{disconnect}) + \left(C_{m(leak\ and\ hose)} \times t_{disconnect}\right)\right) \times N_{cont}}{h_{shift}}$$

Equation_Apx D-5

$$8 - hr\ TWA = \frac{\left(C_{m(leak\ only)} \times (h_{event} - t_{disconnect}) + \left(C_{m(leak\ and\ hose)} \times t_{disconnect}\right)\right) \times N_{cont}}{8}$$

Where:

$C_{m(leak\ only)}$ = Airborne concentration (mass-based) due to leaks during unloading while hose connected (mg/m^3)

$C_{m(leak\ and\ hose)}$ = Airborne concentration (mass-based) due to leaks and displaced air during hose disconnection (mg/m^3)

h_{event} = Exposure duration of each loading/unloading event (hr/event); calculated as the inverse of the fill rate, r: 0.5 hr/event for tank trucks and 1 hr/event for railcars

h_{shift} = Exposure duration during the shift (hr/shift); calculated as $h_{event} \times N_{cont}$: 0.5 hr/shift for tank trucks and 1 hr/shift for railcars

$t_{disconnect}$ = Time duration to disconnect hoses/couplers (during which saturated vapor escapes from hose into air) (hr/event)

N_{cont} = Number of containers loaded/unloaded per shift (event/shift); assumed one tank truck per shift for central tendency scenario and one railcar per shift for high-end scenario

Table_Apx D-6. Calculated 1-BP Emission Rates and Resulting Exposures from the Tank Truck and Railcar Loading and Unloading Release and Inhalation Exposure Model

Scenario	E_L (g/s)	E_T (g/s)	$E_L + E_T$ (g/s)	C_m (leaks only) (mg/m^3)	C_m (leaks and hose vapor) (mg/m^3)	Acute TWA [a] (mg/m^3)	8-hr TWA (mg/m^3)	8-hr TWA (ppm)
Central Tendency	0.015	6.04E-3	0.021	0.26	0.36	0.31	0.019	3.83E-3
High-End	0.059	5.46E-2	0.1114	1.85	3.57	2.28	0.29	5.67E-2

a – Acute TWA exposure is a 0.5-hr TWA exposure for the central tendency scenario and a 1-hr TWA exposure for the high-end scenario.

Appendix E Open-Top Vapor Degreasing Near-Field/Far-Field Inhalation Exposure Model Approach and Parameter

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; and
- Cold 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 (Keil, 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 1-BP 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:

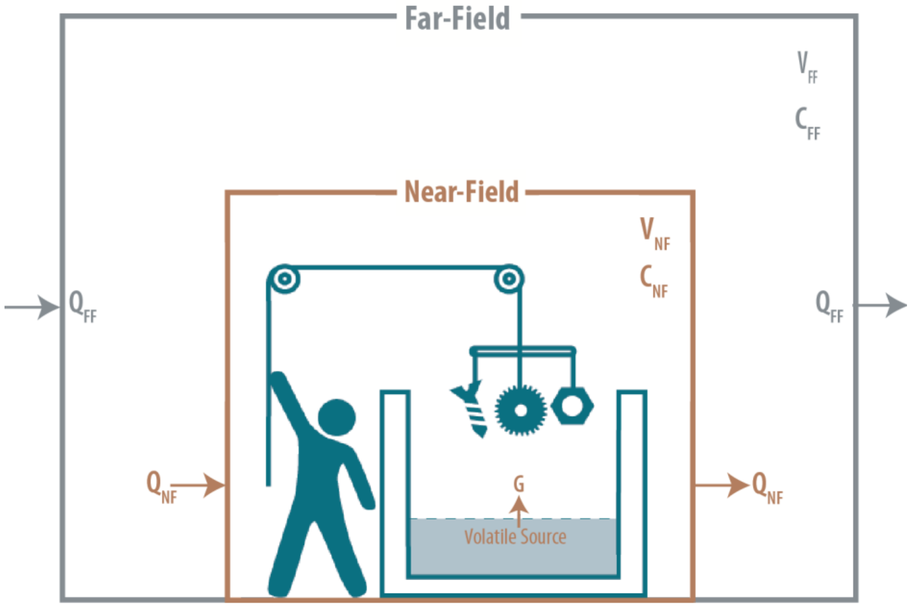
- Far-field size;
- Near-field size;
- Air exchange rate;
- Indoor air speed;
- Emission factor;
- Number of employees per site; and
- Operating hours per day.

An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 100,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence).

Model results from the Monte Carlo simulation are presented as 50th and 95th percentile values. The statistics were calculated directly in @Risk. The 50th percentile value was selected to represent a central tendency exposure level, whereas the 95th percentile value was selected to represent a high-end exposure. The following subsections detail the model design equations and parameters for the vapor degreasing model.

E.1 Model Design Equations

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



Figure_Apx 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

The model design equations are presented below in Equation_Apx E-1 through Equation_Apx E-16.

Near-Field Mass Balance

Equation_Apx E-1

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

Far-Field Mass Balance

Equation_Apx E-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 (Keil, 2009):

Equation_Apx E-3

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

Equation_Apx E-4

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

Where:

Equation_Apx E-5

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

Equation_Apx E-6

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

Equation_Apx E-7

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

Equation_Apx E-8

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

Equation_Apx E-9

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

Equation_Apx E-10

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

Equation_Apx E-11

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

EPA calculated the hourly TWA concentrations in the near-field and far-field using the following equations. Note that the numerator and denominator of Equation_Apx E-12 and Equation_Apx E-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 is interested in calculating 8-hr TWA exposures). Mathematically, the numerator and denominator must reflect the same amount of time. This is indeed the case since the numerator assumes exposures are zero for any hours not within the operating time. Therefore, mathematically speaking, both the numerator and the denominator reflect eight hours regardless of the values selected for t_1 and t_2.

Equation_Apx E-12

$$C_{NF,TWA} = \frac{\int_{t_1}^{t_2} C_{NF} dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(k_1 + k_2 e^{\lambda_1 t} - k_3 e^{\lambda_2 t}\right) dt}{t_{avg}} =$$

$$\frac{G\left(k_1 t_2 + \frac{k_2 e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_3 e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(k_1 t_1 + \frac{k_2 e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_3 e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

Equation_Apx E-13

$$C_{FF,TWA} = \frac{\int_{t_1}^{t_2} C_{FF} dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(\frac{1}{Q_{FF}} + k_4 e^{\lambda_1 t} - k_5 e^{\lambda_2 t}\right) dt}{t_{avg}} =$$

$$\frac{G\left(\frac{t_2}{Q_{FF}} + \frac{k_4 e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_5 e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(\frac{t_1}{Q_{FF}} + \frac{k_4 e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_5 e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

To calculate the mass transfer to and from the near-field, the Free Surface Area, FSA, is defined to be the surface area through which mass transfer can occur. Note that the FSA is not equal to the surface area of the entire near-field. EPA defined the near-field zone to be a rectangular box resting on the floor; therefore, no mass transfer can occur through the near-field box's floor. FSA is calculated in Equation_Apx E-14, below:

Equation_Apx E-14

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

Where: L_{NF}, W_{NF}, and H_{NF} are the length, width, and height of the near-field, respectively. The near-field ventilation rate, Q_{NF}, is calculated in Equation_Apx E-15 from the near-field indoor wind speed, v_{NF}, and FSA, assuming half of FSA is available for mass transfer into the near-field and half of FSA is available for mass transfer out of the near-field:

Equation_Apx E-15

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

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx E-16:

Equation_Apx E-16

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

Using the model inputs in Table_Apx E-1, EPA estimated 1-BP 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.

E.2 Model Parameters

Table_Apx I-1 summarizes the model parameters and their values for the Open-Top Vapor Degreasing Near-Field/Far-Field Exposure Model.

Table_Apx 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	Model Parameter Values		Uncertainty Analysis Assumptions			Distribution Type	Comments
			Value	Basis	Lower Bound	Upper Bound	Mode		
Near-field indoor wind speed	v_{NF}	cm/s (ft/s)	—	—	0	202.2	—	Lognormal, μ= 22.41 cm/s σ= 19.96 cm/s	See Section E.2.3
Near-field volume	V_{NF}	ft^3	600	—	—	—	—	—	See Section E.2.4
Far-field volume	V_{FF}	ft^3	10,594	Minimum	10,594	70,629	17,657	Triangular	See Section E.2.1
Air exchange rate	AER	hr^{-1}	2	Minimum	2	20	3.5	Triangular	See Section E.2.2
Operating days per year	OD	day/yr	260	—	—	—	—	—	The 2001 EPA Generic Scenario on the Use of Vapor Degreasers estimates that degreasers of all sizes operate 260 days per year (ERG, 2001).
Starting time	t_1	hr	0	—	—	—	—	—	Constant value.
Exposure Duration	t_2	hr	—	—	—	—	—	—	Equal to operating hours per day. See Section E.2.5
Averaging time	t_{avg}	hr	8	—	—	—	—	—	See Section E.2.6
Emission factor	EF	lb/employee-yr	—	—	0	77.7	—	Lognormal, μ= 10.4 σ= 17.2	See Section E.2.7
Number of employees per site	EMP	employee/site	—	—	1	1,800	—	LogLogistic Υ =1 β = 51.1 α = 2.13	See Section E.2.8

Input Parameter	Symbol	Unit	Model Parameter Values		Uncertainty Analysis Assumptions			Distribution Type	Comments
			Value	Basis	Lower Bound	Upper Bound	Mode		
Units per site	U	unit/site	—	—	1	1.2	—	Discrete	The EPA TCE RA (2014b) estimated 1 unit/site for small vapor degreasing facilities, and 1.2 unit/site for large facilities based on analysis of the National Emissions Inventory (NEI). Because NEI data are not available for 1-BP, EPA assumed equal probability of small versus large facilities.
Vapor generation rate	G	kg/unit-hr	—	—	—	—	—	N/A	Calculated as the following: G = EF x EMP / (2.2 x OH x OD x U)
Operating hours per day	OH	hr/day	2	—	2	24	—	Discrete	See Section E.2.9
Engineering controls effectiveness	EC	%	90	—	—	—	—	—	Value supported by Wadden et al. (1989). The study indicates local exhaust ventilation can reduce workplace emissions by 90 percent. The estimate is based on an LEV system for an open-top vapor degreaser (lateral exhaust hoods installed on two sides of the tank).

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 (2003) that indicated volumes at German metal degreasing facilities can vary from 300 to several thousand cubic meters. They noted that smaller volumes are more typical and assumed 400 and 600 m^3 (14,126 and 21,189 ft^3) in their exposure models (Von Grote, 2003). These are the highest and lowest values EPA identified in the literature; therefore, EPA assumes a triangular distribution bound from 300 m^3 (10,594 ft^3) to 2,000 m^3 (70,629 ft^3) with a mode of 500 m^3 (the midpoint of 400 and 600 m^3) (17,657 ft^3).

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 22.41 cm/s and standard deviation of 19.96 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 would have 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 Section E.2.9 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 Emission Factor

EPA referenced 1-BP emission factor from a CARB study to estimate vapor generation rate.

To develop the California Solvent Cleaning Emissions Inventories, CARB surveyed solvent cleaning facilities and gathered site-specific information for 213 facilities. CARB estimated a 1-BP emission factor of 10.43 lb/employee-yr with a standard deviation of 17.24 lb/employee-yr (CARB, 2011). CARB estimated that more than 98 percent of 1-BP emissions were attributed to vapor degreasing for the solvent cleaning facilities surveyed. EPA applied a lognormal distribution to account for uncertainty in the CARB emission factor. The distribution is truncated at the 99th percentile value of the dataset to prevent the model from sampling values that approach infinity or are otherwise unrealistically large.

E.2.8 Number of Employees

To estimate the number of employees, EPA used data from the 2007 Economic Census for the vapor degreasing NAICS codes identified in the TCE RA (U.S. EPA, 2014b). EPA fitted a LogLogistics distribution to the Census data set. The distribution is truncated at the highest observed NAICS-specific average employee per site from Census (1,800 employees), and has a lower bound of 1 employee per site.

E.2.9 Operating Hours

For the operating hours, EPA used a discrete distribution based on the daily operating hours reported in the 2014 NEI for TCE (U.S. EPA, 2018a). 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. The lowest observed value is 2 hr/day, and the highest value is 24 hr/day.

Appendix F Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model Approach and Parameter

The Cold Cleaning Near-Field/Far-Field Inhalation Exposure Model uses the same model design equations as described in E.1, but incorporates the several parameters specific to cold cleaning operation. Table_Apx F-1 presents the parameters for the cold cleaning model.

Table_Apx F-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	Model Parameter Values		Uncertainty Analysis Assumptions			Distribution Type	Comments
			Value	Basis	Lower Bound	Upper Bound	Mode		
Near-field indoor wind speed	v_{NF}	cm/s (ft/s)	—	—	0	202.2	—	Lognormal, μ= 22.41 cm/s σ= 19.96 cm/s	Baldwin and Maynard (1998) surveyed the wind speeds in 55 work areas covering a wide range of workplaces. The study states that the pooled distribution of all surveys and the distributions of each survey, in general, could be approximated by a lognormal distribution. For industrial facilities, the parameter is a lognormal distribution with a mean of 22.41 cm/s, and standard deviation of 19.96 cm/s. The maximum value is determined to be 202.2 cm/s, the largest observed value in the study.
Near-field volume	V_{NF}	ft^3	600	—	—	—	—	—	EPA applied the same dimensions used in the final TCE risk assessment (i.e., 10 ft for L_{NF} and W_{NF} and 6 ft for H_{NF}) (U.S. EPA, 2014b). Value supported by Demou et al. (2009).
Far-field volume	V_{FF}	ft^3	10,594	Minimum	10,594	70,629	17,657	Triangular	Per von Grote (2003), volumes at European metal degreasing facilities can vary from 300 to several thousand cubic meters. They noted smaller volumes are more typical, and assumed 400 and 600 m^3 in their models. EPA assumed 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, or 17,657 ft^3)

Input Parameter	Symbol	Unit	Model Parameter Values		Uncertainty Analysis Assumptions			Distribution Type	Comments
			Value	Basis	Lower Bound	Upper Bound	Mode		
Air exchange rate	AER	hr^{-1}	2	Minimum	2	20	3.5	Triangular	Hellweg et al. (2009) identifies average AER for occupational settings utilizing mechanical ventilation systems to be between 3 and 20 hr^{-1}. The EPA TCE RA peer review comments indicate values around 2 to 5 hr^{-1} may be more likely (SCG, 2013). A triangular distribution is used with the mode equal to the midpoint of the range provided by the RA peer reviewers (3.5 is the midpoint of the range 2 to 5 hr^{-1}).
Operating days per year	OD	day/yr	260	—	—	—	—	—	The 2001 EPA Generic Scenario on the Use of Vapor Degreasers estimates that degreasers of all sizes operate 260 days per year (ERG, 2001).
Starting time	t_1	hr	0	—	—	—	—	—	Constant value.
Exposure Duration	t_2	hr	—	—	—	—	—	—	Equal to operating hours per day.
Averaging time	t_{avg}	hr	8	—	—	—	—	—	Constant value.
Emission factor	EF	lb/employee-yr	—	—	0	77.7	—	Lognormal, μ= 10.4 σ= 17.2	To develop the California Solvent Cleaning Emissions Inventories, CARB surveyed solvent cleaning facilities and gathered site-specific information for 213 facilities. CARB estimated a 1-BP emission factor of 10.43 lb/employee-yr with a standard deviation of 17.24 lb/employee-yr (CARB, 2011). CARB estimated that more than 98 percent of 1-BP emissions were attributed to vapor degreasing for the solvent cleaning facilities surveyed. EPA applied a lognormal distribution to account for uncertainty in the CARB emission factor. The distribution is truncated at the 99th percentile value of the dataset.
Number of employees per site	EMP	employee/ site	—	—	1	1,800	—	LogLogistic Υ =1	Data based on 2007 Economic Census for the vapor degreasing NAICS codes identified in the TCE RA (U.S. EPA, 2014b). EPA fitted a

Input Parameter	Symbol	Unit	Model Parameter Values		Uncertainty Analysis Assumptions			Distribution Type	Comments
			Value	Basis	Lower Bound	Upper Bound	Mode		
								β = 51.1 α = 2.13	LogLogistics distribution to the Census data set. The distribution is truncated at the highest observed NAICS-specific average employee per site from Census (1,800 employees) and has a lower bound of 1 employee per site.
Units per site	U	unit/site	—	—	1	1.2	—	Discrete	The EPA TCE RA (2014b) estimated 1 unit/site for small vapor degreasing facilities, and 1.2 unit/site for large facilities based on analysis of the National Emissions Inventory (NEI). Because NEI data are not available for 1-BP, EPA assumed equal probability of small versus large facilities.
Vapor generation rate	G	kg/unit-hr	—	—	—	—	—	N/A	Calculated as the following: G = EF x EMP / (2.2 x OH x OD x U)
Reduction Factor	RF	—	—	—	0.032	0.57	—	Uniform	EPA AP-42 suggests that cold cleaning emissions range from 3.2 to 57.1 percent of emissions from a traditional open-top vapor degreaser (U.S. EPA, 1981).
Operating hours per day	OH	hr/day	—	—	3	24	—	Discrete	Distribution is based on NEI data for cold cleaner operating hours per day for TCE. The lowest observed value is 3 hr/day, and the highest value is 24 hr/day.

Appendix G Brake Servicing Near-Field/Far-Field Inhalation Exposure Model Approach and Parameter

This appendix presents the modeling approach and model equations used in the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. The model was developed through review of the literature and consideration of existing EPA/OPPT exposure models. This model uses a near-field/far-field approach (Keil, 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 1-BP 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 1-BP in the aerosol formulation;
- Amount of degreaser used per brake job;
- Number of degreaser applications per brake job;
- Time duration of brake job;
- Operating hours per week; and
- Number of jobs per work shift.

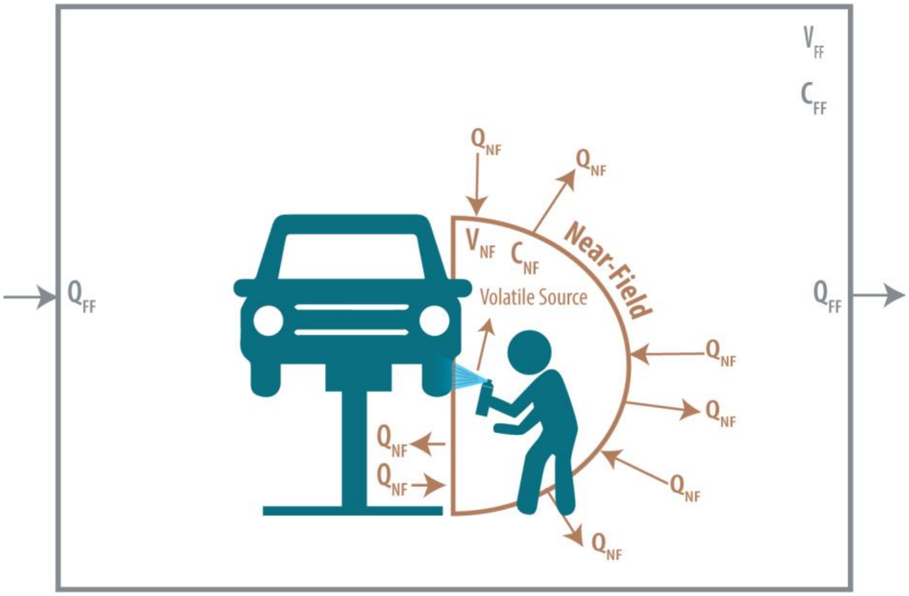
An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 100,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence).

Model results from the Monte Carlo simulation are presented as 95th and 50th percentile values. The statistics were calculated directly in @Risk. The 95th percentile value was selected to represent high-end exposure level, whereas the 50th percentile value was selected to represent central tendency exposure level. The following subsections detail the model design equations and parameters for the brake servicing model.

G.1 Model Design Equations

In brake servicing, the vehicle is raised on an automobile lift to a comfortable working height to allow the worker (mechanic) to remove the wheel and access the brake system. Brake servicing can include inspections, adjustments, brake pad replacements, and rotor resurfacing. These service types often involve disassembly, replacement or repair, and reassembly of the brake system. Automotive brake cleaners are used to remove oil, grease, brake fluid, brake pad dust, or dirt. Mechanics may occasionally use brake cleaners, engine degreasers, carburetor cleaners, and general purpose degreasers interchangeably (CARB, 2000). Automotive brake cleaners can come in aerosol or liquid form (CARB, 2000): this model estimates exposures from aerosol brake cleaners (degreasers).

Figure_Apx I-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 1-BP 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 1-BP dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational bystander exposures to 1-BP at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the 1-BP dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly 1-BP dissipates out of the surrounding space and into the outside air.



Figure_Apx G-1. The Near-Field/Far-Field Model as Applied to the 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 (2000) for brake cleaning activities and as explained in Sections G.2.5 and G.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 (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 1-BP using the weight fraction of 1-BP in the aerosol product. EPA uses a discrete distribution of weight fractions for 1-BP based on aerosol products identified in EPA's Use Dossier (U.S. EPA, 2017b).

The model design equations are presented below in Equation_Apx G-1 through Equation_Apx G-21.

Near-Field Mass Balance

Equation_Apx G-1

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

Far-Field Mass Balance

Equation_Apx G-2

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

Where:

V_{NF} = near-field volume;
V_{FF} = far-field volume;
Q_{NF} = near-field ventilation rate;
Q_{FF} = far-field ventilation rate;
C_{NF} = average near-field concentration;
C_{FF} = average far-field concentration; and
t = elapsed time.

Solving Equation_Apx G-1 and Equation_Apx G-2 in terms of the time-varying concentrations in the near-field and far-field yields Equation_Apx G-3 and Equation_Apx G-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 1-BP 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 1-BP from a previous application). The initial far-field concentration is equal to the residual far-field concentration remaining after the previous five-minute increment. EPA then calculated the decayed concentration in the near-field and far-field at the end of the five-minute period, just before the degreaser application at the top of the next period ($t_{m,n+1}$). EPA then calculated a 5-minute TWA exposure for the near-field and far-field, representative of the worker's and ONUs' exposures to the airborne concentrations during each five-minute increment using Equation_Apx G-13 and Equation_Apx G-14. The *k* coefficients (Equation_Apx G-5 through Equation_Apx G-8) are a function of the initial near-field and far-field concentrations, and therefore are re-calculated at the top of each five-minute period. In the equations below, where the subscript "m, n-1" is used, if the value of n-1 is less than zero, the value at "m-1, 11" is used and where the subscript "m, n+1" is used, if the value of n+1 is greater than 11, the value at "m+1, 0" is used.

Equation_Apx G-3

$$C_{NF,t_{m,n+1}} = \left(k_{1,t_{m,n}} e^{\lambda_1 t} + k_{2,t_{m,n}} e^{\lambda_2 t}\right)$$

Equation_Apx G-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_Apx G-5

$$k_{1,t_{m,n}} = \frac{Q_{NF}\left(C_{FF,0}(t_{m,n}) - C_{NF,0}(t_{m,n})\right) - \lambda_2 V_{NF} C_{NF,0}(t_{m,n})}{V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx G-6

$$k_{2,t_{m,n}} = \frac{Q_{NF}\left(C_{NF,0}(t_{m,n}) - C_{FF,0}\,(t_{m,n})\right) + \lambda_1 V_{NF} C_{NF,0}(t_{m,n})}{V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx G-7

$$k_{3,t_{m,n}} = \frac{(Q_{NF} + \lambda_1 V_{NF})(Q_{NF}\left(C_{FF,0}(t_{m,n}) - C_{NF,0}(t_{m,n})\right) - \lambda_2 V_{NF} C_{NF,0}(t_{m,n}))}{Q_{NF} V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx G-8

$$k_{4,t_{m,n}} = \frac{(Q_{NF} + \lambda_2 V_{NF})(Q_{NF}\left(C_{NF,0}(t_{m,n}) - C_{FF,0}(t_{m,n})\right) + \lambda_1 V_{NF} C_{NF,0}(t_{m,n}))}{Q_{NF} V_{NF}(\lambda_1 - \lambda_2)}$$

Equation_Apx G-9

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

Equation_Apx G-10

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

Equation_Apx G-11

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

Equation_Apx G-12

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

Equation_Apx G-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_Apx G-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_Apx G-15

$$C_{NF,\text{ 8-hr } TWA} = \frac{\sum_{m=0}^{7}\sum_{n=0}^{11}\left[C_{NF,\text{5-min } TWA,t_{m,n}} \times 0.0833\ hr\right]}{8\ hr}$$

Equation_Apx G-16

$$C_{NF,\text{ 8-hr } TWA} = \frac{\sum_{m=0}^{7}\sum_{n=0}^{11}\left[C_{FF,\text{5-min } TWA,t_{m,n}} \times 0.0833\ hr\right]}{8\ hr}$$

Equation_Apx G-17

$$C_{NF,\text{1-hr}\,TWA} = \frac{\sum_{n=0}^{11}\left[C_{NF,\text{5-min}\,TWA,t_{m,n}} \times 0.0833\ hr\right]}{1\ hr}$$

Equation_Apx G-18

$$C_{FF,\text{1-hr}\,TWA} = \frac{\sum_{n=0}^{11}\left[C_{FF,\text{5-min}\,TWA,t_{m,n}} \times 0.0833\ hr\right]}{1\ hr}$$

EPA calculated rolling 1-hour TWA's throughout the workday and the model reports the maximum calculated 1-hour TWA.

To calculate the mass transfer to and from the near-field, the free surface area (FSA) is defined to be the surface area through which mass transfer can occur. The FSA is not equal to the surface area of the entire near-field. EPA defined the near-field zone to be a hemisphere with its major axis oriented vertically, against the vehicle, and aligned through the center of the wheel (see Figure_Apx G-1). The top half of the circular cross-section rests against, and is blocked by, the vehicle and is not available for mass transfer. The FSA is calculated as the entire surface area of the hemisphere's curved surface and half of the hemisphere's circular surface per Equation_Apx G-19, below:

Equation_Apx G-19

$$FSA = \left(\frac{1}{2} \times 4\pi R_{NF}^2\right) + \left(\frac{1}{2} \times \pi R_{NF}^2\right)$$

Where: R_{NF} is the radius of the near-field

The near-field ventilation rate, Q_{NF}, is calculated in Equation_Apx G-20 from the indoor wind speed, v_{NF}, and FSA, assuming half of the FSA is available for mass transfer into the near-field and half of the FSA is available for mass transfer out of the near-field:

Equation_Apx G-20

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

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx G-21:

Equation_Apx G-21

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

Using the model inputs described in Appendix G.2, EPA estimated 1-BP 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.

G.2 Model Parameters

Figure_Apx G-1 summarizes the model parameters and their values for the Brake Servicing Near-Field/Far-Field Inhalation Exposure Model. Each parameter is discussed in detail in the following subsections.

Table_Apx G-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 (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 with and without 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.
1-BP weight fraction	wtfrac	wt frac	—	—	0.01	1	—	Discrete	Discrete distribution of 1-BP-based aerosol product formulations based on products identified in EPA's Use Dossier (2017b).
Degreaser Used per Brake Job	W_d	oz/ job	14.4	—	—	—	—	Constant Value	Based on data from 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 1-BP/ application	—	—	0.4	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 (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 operating weeks per year and 8 hours per work shift.

G.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.

G.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 with and without 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).

G.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 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.

G.2.4 Near-Field Volume

EPA defined the near-field zone to be a hemisphere with its major axis oriented vertically, against the vehicle, and aligned through the center of the wheel (see Figure_Apx G-1). The near-field volume is calculated per Equation_Apx G-22. EPA defined a near-field radius (R_{NF}) of 1.5 meters, approximately 4.9 feet, as an estimate of the working height of the wheel, as measured from the floor to the center of the wheel.

Equation_Apx G-22

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

G.2.5 Application Time

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

G.2.6 Averaging Time

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

G.2.7 1-BP Weight Fraction

EPA reviewed the *Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: 1-Bromopropane* report (U.S. EPA, 2017b) for aerosol degreasers and cleaners that contain 1-BP. EPA (2017b) identifies 25 aerosol degreasers and cleaners that overall range in 1-BP content from one to 100 weight percent. The identified aerosol degreasers and cleaners include a brake and engine cleaner and also electronic/electrical parts cleaners, a resin remover, machine cleaners, and general purpose degreasers. EPA includes all of these aerosol cleaners in the estimation of 1-BP 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 1-BP weight fraction based on the number of occurrences of each product type. For all but two products, the concentration of 1-BP was reported as a range. EPA used a uniform distribution to model the 1-BP weight fraction within the product type. **Table_Apx G-2** provides a summary of the reported 1-BP content reported in the safety data sheets identified in EPA

(2017b), the number of occurrences of each product type, and the fractional probability of each product type.

Table_Apx G-2. Summary of 1-Bromopropane-Based Aerosol Degreaser Formulations

Name of Aerosol Degreaser Product Identified in EPA (2017b)	1-Bromopropane Weight Percent	Number of Occurrences	Fractional Probability
Aerosol buffing solution (Perc-based)	1-3%	1	0.040
Aerosol cleaner (NMP-based)	25-30%	1	0.040
Super degreaser	40-50%	1	0.040
LPS Instant Super Degreaser (SDS indicates aerosol form)	90-100%	1	0.040
5020 Quick Solv Solvent Degreaser (SDS indicates aerosol form)	60-100%	1	0.040
United C174 Contact Cleaner - aerosol contact cleaner	10-30%	1	0.040
PENSOLV PB 2000 - aerosol solvent degreaser (>95% 1-BP)	95-100%	1	0.040
NU TRI CLEAN Aerosol (>90% 1-BP)	90-100%	1	0.040
POWER SOLV 5000	90-100%	1	0.040
Solv 2427	60-100%	1	0.040
Type TRTM Cleaner/ Degreaser – Aerosol	95-100%	1	0.040
CRC Cable Clean Degreaser 02064	90-100%	1	0.040
CRC Cable Clean RD	1-3%	1	0.040
CBC II contact Cleaner	44%	1	0.040
Electro-Wash NR	65-75%	1	0.040
Kontact Restorer	65-75%	1	0.040
Pow-R-Wash NR Contact Cleaner	65-75%	1	0.040
LPS NoFlash Nu	60-70%	1	0.040
525 Contact Cleaner	47-84%	1	0.040
Enviro Tac	60-100%	1	0.040
Mega Safe	60-100%	1	0.040
76334 High Tech Electronic Cleaner	40-50%	1	0.040
PCA II	60-100%	1	0.040
Sprayon® ELTM 2846 Non-chlorinated Flash Free Electronic Solvent Aerosol or EL2846 Non-chlorinated Electrical Degreaser – Aerosol	92.64%	1	0.040
N-Propyl Bromide Safety Solvent	90-100%	1	0.040
	Total	**25**	**1.000**

G.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).

G.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.

G.2.10 Amount of 1-BP Used per Application

EPA calculated the amount of 1-BP used per application using Equation_Apx G-23. The calculated mass of 1-BP used per application ranges from 0.4 to 37.1 grams.

Equation_Apx G-23

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

Where:

Amt = Amount of 1-BP used per application (g/application);
W_d = Weight of degreaser used per brake job (oz/job);
Wtfrac = Weight fraction of 1-BP in aerosol degreaser (unitless); and
N_A = Number of degreaser applications per brake job (applications/job).

G.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).

G.2.12 Number of Brake Jobs per Work Shift

CARB (2000) visited 137 automotive maintenance and repair shops and collected data on the number of brake jobs performed annually at each facility. CARB calculated an average of 936 brake jobs performed per facility per year. EPA calculated the number of brake jobs per work shift using the average number of jobs per site per year, the operating hours per week, and assuming 52 weeks of operation per year and eight hours per work shift using Equation_Apx G-24 and rounding to the nearest integer. The calculated number of brake jobs per work shift ranges from one to four.

Equation_Apx G-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 H Dry Cleaning Multi-Zone Inhalation Exposure Model Approach and Parameter

This appendix presents the modeling approach and model equations used in the Dry Cleaning Multi-Zone Inhalation Exposure Model. The model was developed through review of relevant literature and consideration of existing EPA exposure models. This model uses a near-field/far-field approach (Keil, 2009), where a vapor generation source located inside the near-field diffuses into the surrounding environment. Workers are assumed to be exposed to 1-BP vapor concentrations in the near-field, while occupational non-users are exposed at concentrations in the far-field. Because there are multiple activities with potential 1-BP exposure at a dry cleaner, a multi-zone modeling approach is used to account for 1-BP vapor generation from multiple sources.

The model uses the following parameters to estimate exposure concentrations in the near-field and far-field:

- Far-field size;
- Near-field size;
- Air exchange rate;
- Indoor air speed;
- Exposure duration;
- Concentration of solvent in the drum after the dry cleaning cycle;
- Residual solvent adhered to garments after dry cleaning;
- Spot cleaning use rate; and
- Operating hours per day.

An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Professional Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 10,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence). Note: this is fewer iterations than used for the near-field/far-field models described in other appendices as the multi-zone model takes significantly longer to run and 10,000 iterations allowed the simulation to be complete in a reasonable amount of time while still capturing the variability of each parameter.

Model results from the Monte Carlo simulation are presented as 95th and 50th percentile values. The statistics were calculated directly in @Risk[16]. The 95th percentile value was selected to represent high-end exposure level, whereas the 50th percentile value was selected to represent central tendency exposure level. The following subsections detail the model design equations and parameters for the dry cleaning model.

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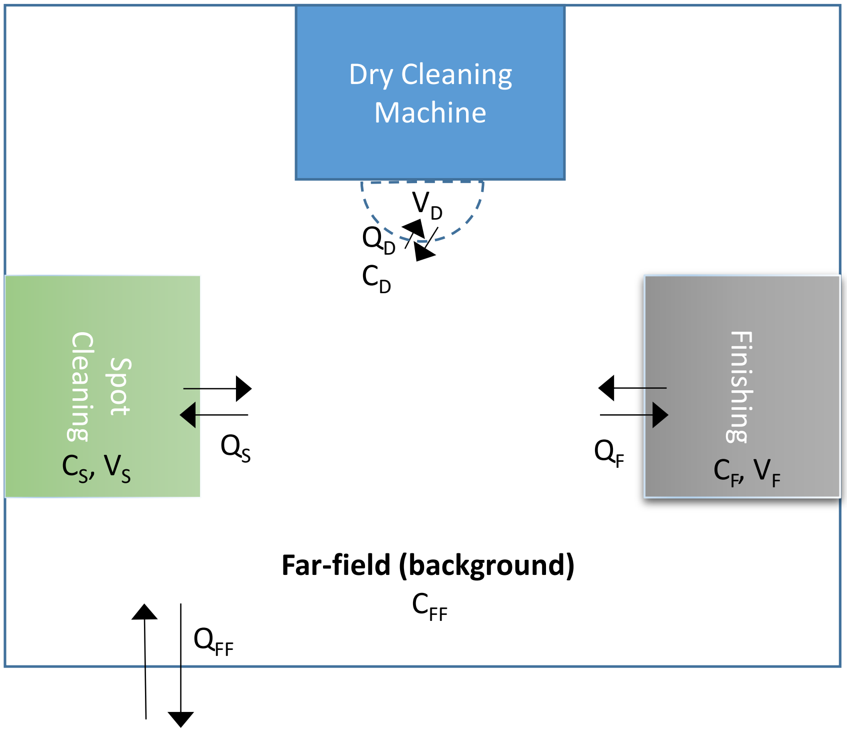
[16] *@Risk*; Palisade; https://www.palisade.com/risk/

H.1 Model Design Equations

Figure_Apx H-1 illustrates the near-field/far-field modeling approach as it was applied by EPA to the Dry Cleaning Multi-Zone Inhalation Exposure Model. As the figure shows, 1-BP vapor is generated in each of the three near-fields, resulting in worker exposures at concentrations C_S, C_D, and C_F. The volume of each zone is denoted by V_S, V_D, and V_F. The ventilation rate for the near-field zone (Q_S, Q_D, Q_F) determines how quickly 1-BP dissipates into the far-field (i.e., the facility space surrounding the near-fields), resulting in occupational non-user exposures to 1-BP at a concentration C_{FF}. V_{FF} denotes the volume of the far-field space into which the 1-BP dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly 1-BP dissipates out of the surrounding space and into the outside air.



Figure_Apx H-1. Illustration of the Dry Cleaning Multi-Zone Inhalation Exposure Model

The model design equations are presented below in Equation_Apx H-1 through Equation_Apx H-15.

Near-Field Mass Balance for Spot Cleaning (Multi-Zone)

Equation_Apx H-1

$$V_S \frac{dC_S}{dt} = C_{FF}Q_S - C_SQ_S + G_S$$

Near-Field Mass Balance for Finishing (Multi-Zone)

Equation_Apx H-2

$$V_F \frac{dC_F}{dt} = C_{FF}Q_F - C_FQ_F + G_F$$

Near-Field Mass Balance for Dry Cleaning Machine (Multi-Zone)

Equation_Apx H-3

$$V_D \frac{dC_D}{dt} = C_{FF} Q_D - C_D Q_D$$

Far-Field Mass Balance

Equation_Apx H-4

$$V_{FF} \frac{dC_{FF}}{dt} = C_S Q_S + C_F Q_F + C_D Q_D - C_{FF} Q_S - C_{FF} Q_F - C_{FF} Q_D - C_{FF} Q_{FF}$$

Where:

V_S = near-field volume for spot cleaning;
V_F = near-field volume for finishing;
V_D = near-field volume for unloading dry cleaning machine;
V_{FF} = far-field volume;
Q_S = near-field ventilation rate for spot cleaning;
Q_F = near-field ventilation rate for finishing;
Q_D = near-field ventilation rate for dry cleaning machine;
Q_{FF} = far-field ventilation rate;
C_S = average near-field concentration for spot cleaning;
C_F = average near-field concentration for finishing;
C_D = average near-field concentration for dry cleaning machine;
C_{FF} = average far-field concentration;
G_S = average vapor generation rate for spot cleaning;
G_F = average vapor generation rate for finishing; and
t = elapsed time.

To calculate the mass transfer to and from the near-field, the free surface area, FSA, is defined to be the surface area through which mass transfer can occur. Note that the FSA may not be equal to the surface area of the entire near-field.

For spot-cleaning, EPA defined the near-field zone to be a rectangular box resting on the floor; therefore, no mass transfer can occur through the near-field box's floor. FSA is calculated using Equation_Apx H-5:

Equation_Apx H-5

$$FSA_S = 2(L_S H_S) + 2(W_S H_S) + (L_S W_S)$$

For finishing, EPA defined the near-field zone to be a rectangular box resting on the floor; therefore, no mass transfer can occur through the near-field box's floor. FSA is calculated using Equation_Apx H-6:

Equation_Apx H-6

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

For dry cleaning, EPA defined the near-field zone to be a hemispheric area projecting from the door of the dry cleaning machine, calculated as Equation_Apx H-7:

Equation_Apx H-7

$$FSA_D = 2\pi r_D^2$$

Where:

FSA_S = free surface area for spot cleaning;
FSA_F = free surface area for finishing;
FSA_D = free surface area for dry cleaning machine;
L_S = near-field length for spot cleaning;
H_S = near-field height for spot cleaning;
W_S = near-field width for spot cleaning;
L_F = near-field length for finishing;
H_F = near-field height for finishing;
W_F = near-field width for finishing; and
r_D = radius of the dry cleaning machine door opening.

The near-field ventilation rates, Q_S, Q_D, and Q_F are calculated from the near-field indoor wind speed, ν_{NF}, and FSA, using Equation_Apx H-8 through Equation_Apx H-10, assuming half of FSA is available for mass transfer into the near-field and half of FSA is available for mass transfer out of the near-field. The near-field indoor wind speed is assumed to be the same across all three near fields:

Equation_Apx H-8

$$Q_S = \frac{1}{2} v_{NF} FSA_S$$

Equation_Apx H-9

$$Q_F = \frac{1}{2} v_{NF} FSA_F$$

Equation_Apx H-10

$$Q_D = \frac{1}{2} V_{NF} FSA_D$$

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx H-11:

Equation_Apx H-11

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

The model results in the following four, coupled ordinary differential equations (ODEs) given in Equation_Apx H-12 through Equation_Apx H-15:

Equation_Apx H-12

$$\frac{dC_S}{dt} = -\frac{Q_S}{V_S} C_S + \frac{Q_S}{V_S} C_{FF} + \frac{G_S}{V_S}$$

Equation_Apx H-13

$$\frac{dC_F}{dt} = -\frac{Q_F}{V_F} C_F + \frac{Q_F}{V_F} C_{FF} + \frac{G_F}{V_F}$$

Equation_Apx H-14

$$\frac{dC_D}{dt} = -\frac{Q_D}{V_D}C_D + \frac{Q_D}{V_D}C_{FF}$$

Equation_Apx H-15

$$\frac{dC_{FF}}{dt} = \frac{Q_S}{V_{FF}}C_S + \frac{Q_F}{V_{FF}}C_F + \frac{Q_D}{V_{FF}}C_D - \frac{Q_S + Q_F + Q_D + Q_{FF}}{V_{FF}}C_{FF}$$

When solving coupled ODEs, it is common to transform the equations into a standard mathematical format. This standard mathematical format allows one to more easily identify appropriate solution methodologies from standard mathematical references. EPA transformed these four ODEs into the following format in Equation_Apx H-16 through Equation_Apx H-19:

Equation_Apx H-16

$$y_1' = a_{11}y_1 + a_{14}y_4 + g_1$$

Equation_Apx H-17

$$y_2' = a_{22}y_2 + a_{24}y_4 + g_2$$

Equation_Apx H-18

$$y_3' = a_{33}y_3 + a_{34}y_4$$

Equation_Apx H-19

$$y_4' = a_{41}y_1 + a_{42}y_2 + a_{43}y_3 + a_{44}y_4$$

Where:

$$\frac{dC_s}{dt} = y_1'$$

$$\frac{dC_F}{dt} = y_2'$$

$$\frac{dC_D}{dt} = y_3'$$

$$\frac{dC_{FF}}{dt} = y_4'$$

And:

$$C_s = y_1 \qquad C_F = y_2 \qquad C_D = y_3 \qquad C_{FF} = y_4$$

$$-\frac{Q_S}{V_S} = a_{11} \qquad -\frac{Q_F}{V_F} = a_{22} \qquad -\frac{Q_D}{V_D} = a_{33}$$

$$\frac{Q_S}{V_S} = a_{14} \qquad \frac{Q_F}{V_F} = a_{24} \qquad \frac{Q_D}{V_D} = a_{34}$$

$$\frac{Q_S}{V_{FF}} = a_{41} \qquad \frac{Q_F}{V_{FF}} = a_{42} \qquad \frac{Q_D}{V_{FF}} = a_{43} \qquad -\frac{Q_S+Q_F+Q_D+Q_{FF}}{V_{FF}} = a_{44}$$

$$\frac{G_S}{V_S} = g_1 \qquad \frac{G_F}{V_F} = g_2$$

These ordinary differential equations can be solved using a numerical integration method. EPA used the fourth-order Runge-Kutta method (RK4). RK4 numerically integrates a system of coupled ordinary differential equations from time step *n* to *n+1* with a constant time step size of *h* using the following equations (shown for generic variables y_1, y_2, y_3, and y_4 as a function of *t*).

Equation_Apx H-20

$$\frac{dy_1}{dt} = f_1(t, y_1, y_2, y_3, y_4)$$

Equation_Apx H-21

$$\frac{dy_2}{dt} = f_2(t, y_1, y_2, y_3, y_4)$$

Equation_Apx H-22

$$\frac{dy_3}{dt} = f_3(t, y_1, y_2, y_3, y_4)$$

Equation_Apx H-23

$$\frac{dy_4}{dt} = f_4(t, y_1, y_2, y_3, y_4)$$

Where, for each ODE *j* = 1, 2, 3, 4 (where 1 = spot cleaning, 2 = finishing, 3 = dry cleaning machine, and 4 = far field):

Equation_Apx H-24

$$k_1^j = f_j(t, y_1, y_2, y_3, y_4)$$

Equation_Apx H-25

$$k_2^j = f_j(t + \frac{1}{2}h, y_1 + \frac{1}{2}k_1^1 h, y_2 + \frac{1}{2}k_1^2 h, y_3 + \frac{1}{2}k_1^3 h, y_4 + \frac{1}{2}k_1^4 h)$$

Equation_Apx H-26

$$k_3^j = f_j(t + \frac{1}{2}h, y_1 + \frac{1}{2}k_2^1 h, y_2 + \frac{1}{2}k_2^2 h, y_3 + \frac{1}{2}k_2^3 h, y_4 + \frac{1}{2}k_2^4 h)$$

Equation_Apx H-27

$$k_4^j = f_j(t + h, y_1 + k_3^1 h, y_2 + k_3^2 h, y_3 + k_3^3 h, y_4 + k_3^4 h)$$

Equation_Apx H-28

$$y_j^{n+1} = y_j^n + \frac{1}{6} h(k_1^j + 2k_2^j + 2k_3^j + k_4^j)$$

RK4 is an *explicit* integration method, meaning it solves for the dependent variables at step *n+1* explicitly using the dependent variables at step *n*. RK4 is a fourth-order method, which means the local truncation error at a single integration step is on the order of h^5, while the total global error is on the order of h^4.

The choice of step size *h* is such to allow a successful integration of the system of differential equations. If parameter values are chosen such that the differential equation coefficients (the *a* terms in Equation_Apx H-16 through Equation_Apx H-19) are sufficiently large, the differential equations may become *stiff*. Stiff differential equations would require sufficiently small time step sizes to allow their integration. Stiffness can be difficult to predict. If stiffness is encountered, meaning if the solution diverges to unrealistic values, such as infinity, the step size should be reduced to see if that allows for successful integration.

Exposure Estimate Equations

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

EPA modeled the baseline scenario assuming the facility operates a converted third generation machine, the machine type observed at all three New Jersey dry cleaners evaluated in the Blando et al. (2010) study. For the engineering control scenario, EPA modeled a facility with a fourth-generation machine. EPA believes facilities using 1-BP are unlikely to own fifth generation machines (ERG, 2005).

EPA assessed three types of workers within the modeled dry cleaning facility: 1) a worker who performs spot cleaning; 2) a worker who unloads the dry cleaning machine and finishes and presses the garments; and 3) an occupational non-user. Each worker type is described in further detail below. EPA assumed each worker activity is performed over the full 12-hour operating day.

- EPA assumed spot cleaning occurs for a duration varying from two to five hours in the middle of the 12-hour day. The worker is exposed at the spot cleaning near-field concentration during this time, and at the far-field concentration for the remainder of the day. Spot cleaning can be performed for both dry cleaned loads and for laundered loads.
- EPA assumed a separate worker unloads the dry cleaning machine and finishes and presses the garments. After each load, EPA assumed this worker spends five minutes unloading the machine, during which he or she is exposed at the machine near-field concentration. After unloading, the

worker spends five minutes in the finishing near-field to prepare the garments. Then, the worker spends another 20 minutes finishing and pressing the cleaned garments. During this 20-minute period of finishing and pressing, the residual 1-BP solvent is off-gassed into the finishing near-field. The amount of residual 1-BP solvent is estimated using measured data presented in von Grote (2003). These unloading and finishing activities are assumed to occur at regular intervals throughout the twelve-hour day. The frequency of unloading and finishing depends on the number of loads dry cleaned each day, which varies from 1 to 14, where 14 was the maximum number of loads observed in the NIOSH (2010) and Blando et al. (2010) studies. When this worker is not unloading the dry cleaning machine or finishing and pressing garments, the worker is exposed at the far-field concentration.

- EPA assumed one occupational non-user is exposed at the far-field concentration for 12 hours a day. The occupational non-user could be the cashier, tailor, or launderer, who works at the facility but does not perform dry cleaning activities.

Using the model inputs described in Appendix H.2, EPA estimated 1-BP inhalation exposures for workers performing spot cleaning, workers unloading the dry cleaning machine and performing finishing and pressing activities, and for occupational non-users in the far-field. EPA then conducted the Monte Carlo simulations using @Risk (Version 7.0.0). The simulations applied 10,000 iterations and the Latin Hypercube sampling method for each model.

H.2 Model Parameters

Table_Apx H-1 summarizes the model parameters and their values for the Dry Cleaning Multi-Zone Inhalation Exposure Model. Each parameter is discussed in detail in the following subsections.

Table_Apx H-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	Constant Model Parameter Values		Variable Model Parameter Values				Notes/Comments
			Value	**Basis**	**Lower Bound**	**Upper Bound**	**Mode**	**Distribution Type**	
Facility Parameters									
Facility Height	F_H	ft	12	Median	—	—	—	—	See Section H.2.1.1
Facility Floor Area	F_{area}	ft^2	—	—	500	20,000	—	Beta	See Section H.2.1.1
Far-field volume	V_{FF}	ft^3	—	—	6,000	240,000	—	—	See Section H.2.1.1
Air exchange rate	AER	hr^{-1}	—	—	1	19	3.5	Triangular	See Section H.2.1.2
Near-field indoor wind speed	v_{NF}	ft/hr	—	—	—	202.2	—	Lognormal	See Section H.2.1.3
		cm/s	—	—	—	23,882	—	Lognormal	
Dry Cleaning Machine Parameters									
Machine Door Diameter	D	ft	2.083	—	—	—	—	—	See Section H.2.2.1
Number of Loads per Day	LD	loads/day	—	—	1	14	—	Uniform	See Section H.2.2.2
Load Time	LT	hr/load	0.5	—	—	—	—	—	See Section H.2.2.3
3rd Generation Machine Cylinder 1-BP Concentration	C_{c_3RD}	ppm	—	—	2,000	8,600	—	Uniform	See Section H.2.2.4
4th Generation Machine Cylinder 1-BP Concentration	C_{C_4TH}	ppm	—	—	240	360	—	Uniform	See Section H.2.2.4
Cylinder Volume	V_C	m^3	—	—	0.24	0.64	—	Uniform	See Section H.2.2.5
Starting time	t_1	hr	0	—	—	—	—	—	Constant value.
Exposure Duration	t_2	hr	0.083	—	—	—	—	—	See Section H.2.2.6
Finishing and Pressing Parameters									
Near-field length	L_{NF}	ft	10	—	—	—	—	—	See Section H.2.3.1
Near-field width	W_{NF}	ft	10	—	—	—	—	—	
Near-field height	H_{NF}	ft	6	—	—	—	—	—	
3rd Generation Machine Residual Solvent	$R_{solvent\_3RD}$	g/kg	—	—	0.26	3.75	—	Discrete	See Section H.2.3.2
4th Generation Machine Residual Solvent	$R_{solvent\_4TH}$	g/kg	—	—	0.12	1.26	—	Discrete	See Section H.2.3.2
Load Size	LS	lb/load	30	—	—	—	—	—	See Section H.2.3.3
Exposure Duration	t_3	hr	0.33	—	—	—	—	—	See Section H.2.3.4
Spot Cleaning Parameters									
Near-field length	L_{NF}	ft	10	—	—	—	—	—	See Section H.2.4.1

Input Parameter	Symbol	Unit	Constant Model Parameter Values		Variable Model Parameter Values				Notes/Comments
			Value	Basis	Lower Bound	Upper Bound	Mode	Distribution Type	
Near-field width	W_{NF}	ft	10	—	—	—	—	—	
Near-field height	H_{NF}	ft	6	—	—	—	—	—	
Use Rate	UR	gal/yr	—	—	13.92	16	—	Uniform	See Section H.2.4.2
Exposure Duration	t_4	hr	—	—	2	5	—	Uniform	See Section H.2.4.3
Other Parameters									
Operating hours per day	OH	hr	12	—	—	—	—	—	See Section H.2.5.1
Operating days	OD	days/yr	—	—	249	313	300	Triangular	See Section H.2.5.2
Fractional days of exposure	f	unitless	—	—	0.8	1.0	—	Uniform	See Section H.2.5.3

H.2.1 Facility Parameters

H.2.1.1 Far-Field Volume

EPA calculated the far-field volume by setting a distribution for the facility floor area and multiplying the floor area by a facility height of 12 ft (median value per CARB 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 composed the following distribution of floor area. To calculate facility volume, EPA 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_Apx H-2. Composite Distribution of Dry Cleaning Facility Floor Areas

Floor Area Value (ft^2)	Percentile (as fraction)	Source
20,000	1	(Whittaker and Johanson, 2011)
3,000	0.96	(Whittaker and Johanson, 2011)
2,000	0.84	(Whittaker and Johanson, 2011)
1,600	0.5	(CARB, 2006)
1,100	0.1	(CARB, 2006)
500	0	(CARB, 2006)

EPA fit a beta function to this distribution with parameters: $\alpha_1 = 6.655$, $\alpha_2 = 108.22$, min = 500 ft^2, max = 20,000 ft^2.

H.2.1.2 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'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. A triangular distribution is used with the mode equal to the midpoint of the range provided by the peer reviewer (3.5 is the midpoint of the range 2 to 5 hr^{-1}). The minimum and maximum of the distribution are 1 and 19 hr^{-1}, respectively.

H.2.1.3 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 categorizing the air speed surveys into settings representative of industrial facilities and representative of commercial facilities. EPA fit separate distributions for these industrial and commercial settings and used the commercial distribution for dry cleaners.

EPA fit a lognormal distribution for both data sets as consistent with the authors observations that the air speed measurements within a surveyed location were lognormally distributed and the population of the mean air speeds among all surveys were lognormally distributed. Since lognormal distributions are bound by zero and positive infinity, EPA truncated the distribution at the largest observed value among all of the survey mean air speeds from Baldwin 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.

H.2.2 Dry Cleaning Machine Parameters

H.2.2.1 Machine Door Diameter

EPA determined an approximate door diameter of 25 inches by reviewing images of several 4th generation PCE machine models manufactured by Bowe and Firbimatic.

H.2.2.2 Number of Loads per Day

EPA used a uniform distribution for the number of loads per day ranging from 1 to 14 based on observations from NIOSH (2010) and Blando et al. (2010).

H.2.2.3 Load Time

EPA estimates that dry cleaning loads using Perc have an average cycle duration of 30 minutes (0.5 hours). This estimate is consistent with von Grote (2003), which estimated total cleaning and finishing batch times of between 45 to 65 minutes for machines equivalent to U.S. 3rd generation machines and between 50 to 70 minutes for machines equivalent to U.S. 4th generation machines. von Grote (2003) further estimated that between one-fourth and one-third of the total cleaning and finishing batch time is spent finishing/pressing (see Section H.2.3.4). EPA assumed a total cleaning and finishing batch time of 60 minutes with the following breakdown:

- The finish/pressing duration is 20 minutes (see Section H.2.3.4);
- The time to unload the garments from the machine is 5 minutes based on engineering judgment;
- The time to prepare the garments for finishing/pressing is 5 minutes based on engineering judgment; and

The machine cycle duration is 30 minutes based on the total cleaning and finishing batch time of 60 minutes minus the above task durations.

H.2.2.4 Machine Cylinder Concentration

EPA used two different distributions for machine cylinder concentration depending on the machine type being modeled (third or fourth generation). For third generation machines, EPA used a uniform distribution from 2,000 to 8,600 ppm to estimate the machine cylinder concentration after a dry cleaning cycle. ERG (2005) indicated that the use of refrigerated condensers (the vapor control system used in third generation machines) can reduce PCE concentrations in the drum to between 2,000 and 8,600 ppm. EPA assumed the concentration in the drum after a cycle is not affected by the type of dry cleaning solvent used, and that these values are representative of residual concentrations of 1-BP.

For fourth generation machines, EPA used a uniform distribution from 240 to 360 ppm to estimate the machine cylinder concentration after a dry cleaning cycle. CDC (1997b) indicated that the use of refrigerated condensers and carbon adsorbers in fourth generation machines can reduce the PCE concentration in the drum below 300 ppm after the cycle is complete. EPA used a uniform distribution of 300 ppm +/- 20% to account for variability and uncertainty in the residual concentration. EPA assumed the concentration in the drum after a cycle is not affected by the type of dry cleaning solvent used.

H.2.2.5 Cylinder Volume

EPA assessed the cylinder volume using a uniform distribution of 0.24 to 0.64 m^3 based on data from von Grote (2003). von Grote (2003) presented the five most common machine sizes used in Germany based on a 2002 survey with sizes ranging from 0.24 to 0.64 m^3. EPA did not have data on the machine sizes or distributions used in the U.S. Therefore, EPA modeled the cylinder volume using the range provided by von Grote (2003) and assuming a uniform distribution of machine sizes.

H.2.2.6 Exposure Duration

EPA assumes it takes the worker five minutes to unload the dry cleaning machine.

H.2.3 Finishing and Pressing Parameters

H.2.3.1 Near-Field Volume

EPA assumed a near-field of constant dimensions of 10 ft x 10 ft x 6 ft resulting in a total volume of 600 ft^3.

H.2.3.2 Residual Solvent

EPA used two different distributions for the amount of residual solvent that adheres to garments after the dry cleaning cycle depending on the machine type being modeled (third or fourth generation). The distributions for both machine types are based on data from von Grote (2003) who estimated residual solvent for both normal loads and “off-the-peg” loads. von Grote (2003) defines “off-the-peg” loads as loads with suits and jackets with shoulder pads and estimates that approximately 20% of all loads cleaned are off-the-peg with the remaining 80% being normal loads. For third generation machines, von Grote (2003) presents data estimating 0.26 g residual solvent/kg clothes for normal loads and 3.75 g residual solvent/kg clothes for off-the peg loads. It should be noted that von Grote (2003) uses different definitions of machines generations than used in the U.S. The fourth-generation machines in von Grote (2003) are defined as non-vented dry-to-dry machines with refrigerated condensers which corresponds to third-generation machines in the U.S. Therefore, EPA used data for fourth-generation machines in von Grote (2003) to model U.S. third-generation machines.

von Grote (2003) does not have a machine generation corresponding to fourth-generation machines in the U.S. von Grote (2003) fourth-generation machines correspond to U.S. third-generation machines and von Grote (2003) fifth-generation machines correspond to U.S. fifth-generation machines (machines with refrigerated condensers, carbon adsorbers, and interlocks on the door). However, the only difference between U.S. fourth- and fifth-generation machines is the presences of interlocks on the door to prevent workers from opening prior to the solvent concentration dropping below 300 ppm. As discussed in Appendix H.2.2.4, fourth-generation machines are also expected to reduce cylinder concentrations after a cycle to 300 ppm. Therefore, EPA expects residual solvent for fourth-generation machines to be similar to fifth-generation machines and uses residual solvent data from von Grote (2003) for fifth-generation machines in the estimates for fourth-generation machines. von Grote (2003) presents data estimating 0.12 g residual solvent/kg clothes for normal loads and 1.26 g residual solvent/kg clothes for off-the peg loads for fifth-generation machines. EPA assumes a discrete distribution for both third- and fourth-generation estimates assuming 80% of loads are normal loads and 20% are off-the-peg (von Grote, 2003).

H.2.3.3 Load Size

The CARB (2006) and King County (Whittaker and Johanson, 2011) studies provide machine capacities, and the King County study also provides data on actual size of loads used by dry cleaners. EPA used the King County study data on actual load sizes to build a distribution.

Table_Apx H-3 summarizes the survey results for respondents' primary (if facility has more than one machine) or only machine. The study reports a maximum reported load of 150 lb, a minimum reported load of 7 lb, and a median reported load of 30 lb for the primary machine (Whittaker and Johanson, 2011).

Table_Apx H-3. Survey Responses of Actual Pounds Washed per Load for Primary Machine (if more than one machine) from 2010 King County Survey

Actual Pounds of Clothes Washed	Results for Primary Machine	
	Number of Respondents	Percent of Respondents
1 – 10	4	3
11 – 20	36	25
21 – 30	76	53
31 – 40	16	11
41 – 50	6	4
51+	6	4
Total	**144**	**100**

Source: (Whittaker and Johanson, 2011)

EPA used these survey results to build a distribution to describe the actual wash loads per machine, as summarized in Table_Apx H-4. To build this distribution, EPA set the following:

- The maximum, median, and minimum were set as 150 lb, 30 lb, and 7 lb, respectively, as stated in the King County survey report (Whittaker and Johanson, 2011).
- The 96th percentile was set at 50 lb as the high-end of the bin "41 to 50 lb." Per Table_Apx H-3, 4% of respondents reported greater than 50 lb; therefore, 96% of facilities reported 50 lb or less.
- The 28th percentile was set at 20 lb as the high-end of the bin "11 to 20 lb." Per Table_Apx H-3, 28% of respondents reported 20 lb or less.

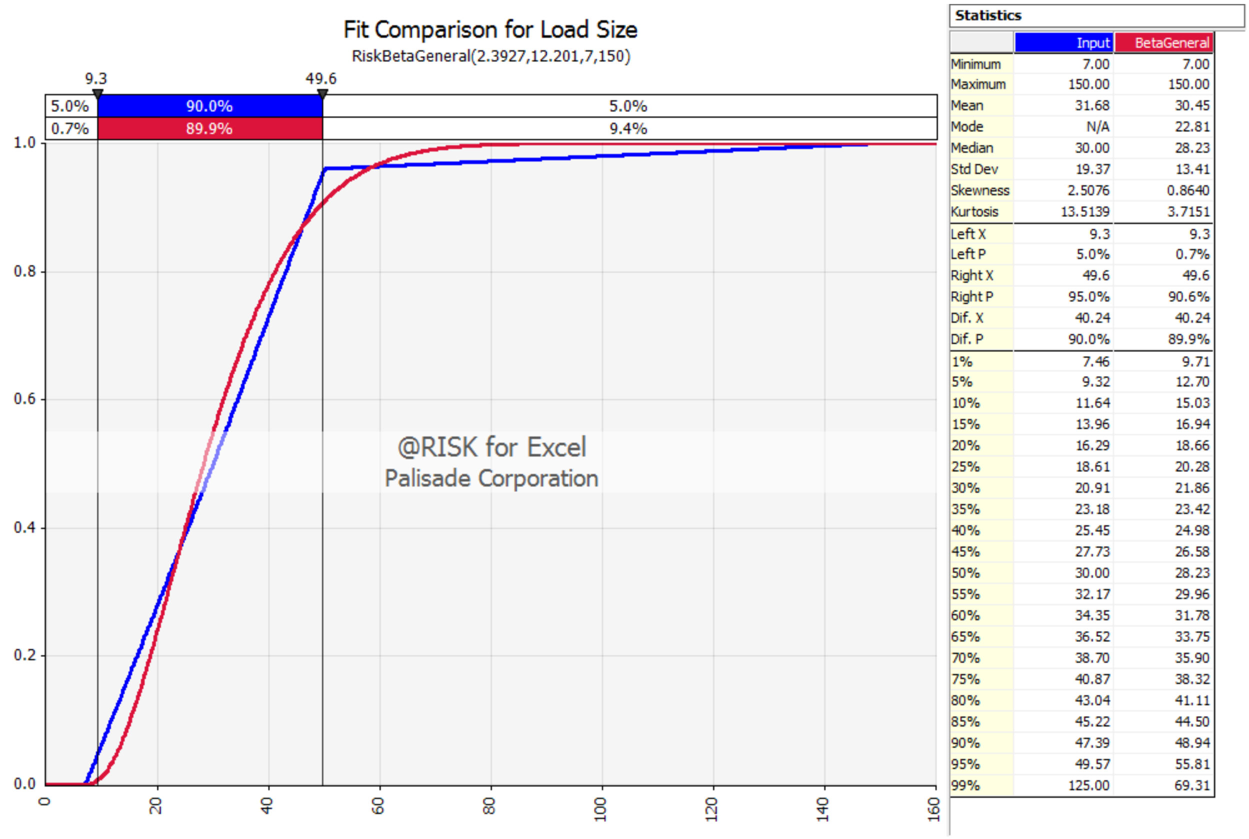
EPA then determined the best-fit distribution using the software @Risk.

Table_Apx H-4. Distribution of Actual Load Sizes from 2010 King County Survey

Actual Load Washed (lb)	Percentile (as fraction)
150	1
50	0.96
30	0.5
20	0.28
7	0

Source: (Whittaker and Johanson, 2011)

EPA fit a beta distribution to this distribution with parameters: $\alpha_1 = 2.3927$, $\alpha_2 = 12.201$, min = 7 lb, max = 150 lb. The root-mean squared (RMS) error is 0.0365, Figure_Apx H-2 illustrates this fit.



	Input	BetaGeneral
Minimum	7.00	7.00
Maximum	150.00	150.00
Mean	31.68	30.45
Mode	N/A	22.81
Median	30.00	28.23
Std Dev	19.37	13.41
Skewness	2.5076	0.8640
Kurtosis	13.5139	3.7151
Left X	9.3	9.3
Left P	5.0%	0.7%
Right X	49.6	49.6
Right P	95.0%	90.6%
Dif. X	40.24	40.24
Dif. P	90.0%	89.9%
1%	7.46	9.71
5%	9.32	12.70
10%	11.64	15.03
15%	13.96	16.94
20%	16.29	18.66
25%	18.61	20.28
30%	20.91	21.86
35%	23.18	23.42
40%	25.45	24.98
45%	27.73	26.58
50%	30.00	28.23
55%	32.17	29.96
60%	34.35	31.78
65%	36.52	33.75
70%	38.70	35.90
75%	40.87	38.32
80%	43.04	41.11
85%	45.22	44.50
90%	47.39	48.94
95%	49.57	55.81
99%	125.00	69.31

Figure_Apx H-2. Fit Comparison of Beta Cumulative Distribution Function to Load Size Survey Results

H.2.3.4 Exposure Duration

EPA assumed workers take 20 minutes to press and finish each load. This estimate is consistent with von Grote (2003), which estimated that residual solvent will evaporate continuously over a period of approximately between one-fourth and one-third of the total time to clean and finish a single load of garments. von Grote (2003) estimated total cleaning and finishing batch times of between 45 to 65 minutes for machines equivalent to U.S. 3rd generation machines and between 50 to 70 minutes for machines equivalent to U.S. 4th generation machines. This yields an overall range of finishing/pressing times of approximately 11 to 23 minutes.

H.2.4 Spot Cleaning Parameters

H.2.4.1 Near-Field Volume

EPA assumed a near-field of constant dimensions of 10 ft x 10 ft x 6 ft resulting in a total volume of 600 ft^3.

H.2.4.2 Spot Cleaning Use Rate

A MassDEP comparative analysis worksheet provides an example case study for a facility, which spends $60 per month on spot cleaner (MassDEP, 2013). The cost of 1-BP-based spot cleaner is estimated at $45 per gallon (Blando et al., 2009). These estimates result in a 1-BP-based spot cleaner use rate of 16 gallons per year. EPA assumes the 1-BP concentration could vary uniformly from 87 to 100 percent (Enviro Tech International, 2013). Applying this concentration to the 16 gallon per year use rate results in a range of 13.92 to 16 gal/yr of 1-BP. EPA modeled this range using a uniform distribution.

H.2.4.3 Exposure Duration

Morris and Wolf (2005) used data collected from dry cleaners to develop two model Perc-based dry cleaners: a small and large dry cleaner. The authors estimated the small dry cleaner spends 2.46 hr/day spotting and the large dry cleaner spends 5 hr/day spotting. EPA models the spot cleaning duration as a uniform distribution varying from 2 to 5 hr/day.

H.2.5 Other Parameters

H.2.5.1 Operating Hours

EPA assumed a typical dry cleaner operates 12 hours per day based on engineering judgment.

H.2.5.2 Operating Days per Year

EPA modeled the operating days per year using a triangular distribution from 250 to 312 days per year with a mode of 300 days per year[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.

H.2.5.3 Fractional Number of Operating Days that a Worker Works

To account for lower exposure frequencies and part-time workers, EPA defines a fractional days of exposure as a uniform distribution ranging from 0.8 to 1.0. EPA expects a worker's annual working days may be less than the operating days based on BLS/Census data that showed the weighted average worked hours per year and per worker in the dry cleaning sector is approximately 1,600 (i.e., 200 day/yr 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).

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[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 I Spot Cleaning Near-Field/Far-Field Inhalation Exposure Model Approach and Parameter

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 (Keil, 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 1-BP 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; and
- Operating hours per day.

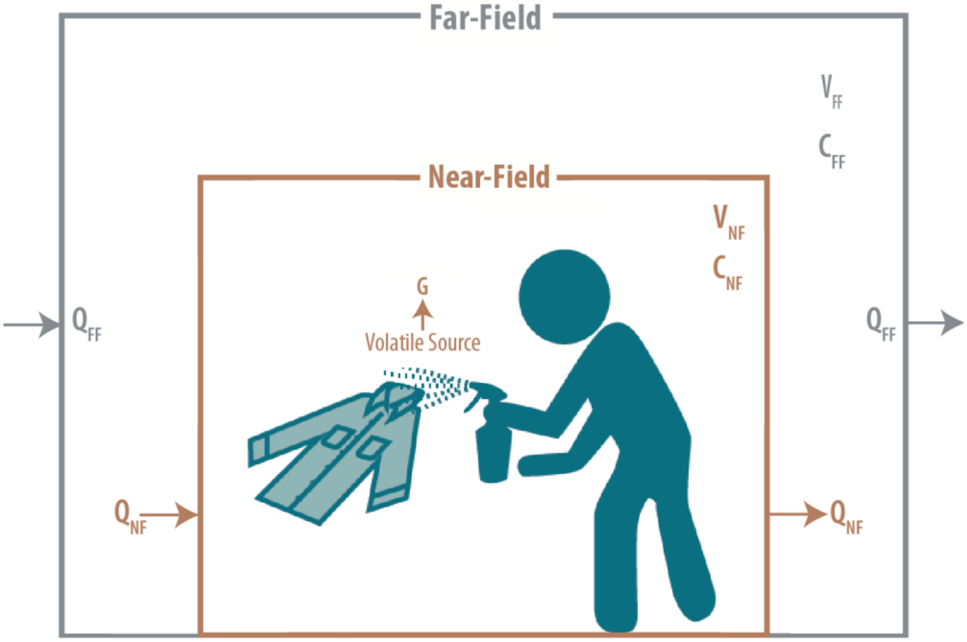
An individual model input parameter could either have a discrete value or a distribution of values. EPA assigned statistical distributions based on available literature data. A Monte Carlo simulation (a type of stochastic simulation) was conducted to capture variability in the model input parameters. The simulation was conducted using the Latin hypercube sampling method in @Risk Industrial Edition, Version 7.0.0. The Latin hypercube sampling method is a statistical method for generating a sample of possible values from a multi-dimensional distribution. Latin hypercube sampling is a stratified method, meaning it guarantees that its generated samples are representative of the probability density function (variability) defined in the model. EPA performed the model at 100,000 iterations to capture the range of possible input values (i.e., including values with low probability of occurrence).

Model results from the Monte Carlo simulation are presented as 95th and 50th percentile values. The statistics were calculated directly in @Risk. The 95th percentile value was selected to represent 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.

I.1 Model Design Equations

Figure_Apx I-1 illustrates the near-field/far-field modeling approach as it was applied by EPA to spot cleaning facilities. As the figure shows, 1-BP 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 1-BP dissipates into the far-field (i.e., the facility space surrounding the near-field), resulting in occupational non-user exposures to 1-BP at a concentration C_{FF}.

V_{FF} denotes the volume of the far-field space into which the 1-BP dissipates out of the near-field. The ventilation rate for the surroundings, denoted by Q_{FF}, determines how quickly 1-BP dissipates out of the surrounding space and into the outdoor air.



Figure_Apx I-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_Apx I-1 through Equation_Apx I-16.

Near-Field Mass Balance

Equation_Apx I-1

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

Far-Field Mass Balance

Equation_Apx I-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 (Keil, 2009):

Equation_Apx I-3

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

Equation_Apx I-4

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

Where:

Equation_Apx I-5

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

Equation_Apx I-6

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

Equation_Apx I-7

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

Equation_Apx I-8

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

Equation_Apx I-9

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

Equation_Apx I-10

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

Equation_Apx I-11

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

EPA calculated the hourly TWA concentrations in the near-field and far-field using the following equations. Note that the numerator and denominator of Equation_Apx I-12 and Equation_Apx I-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 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 I.2.8), EPA 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_Apx I-12

$$C_{NF,TWA} = \frac{\int_{t_1}^{t_2} C_{NF} dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(k_1 + k_2 e^{\lambda_1 t} - k_3 e^{\lambda_2 t}\right) dt}{t_{avg}} =$$

$$\frac{G\left(k_1 t_2 + \frac{k_2 e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_3 e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(k_1 t_1 + \frac{k_2 e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_3 e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

Equation_Apx I-13

$$C_{FF,TWA} = \frac{\int_{t_1}^{t_2} C_{FF} dt}{\int_0^{t_{avg}} dt} = \frac{\int_{t_1}^{t_2} G\left(\frac{1}{Q_{FF}} + k_4 e^{\lambda_1 t} - k_5 e^{\lambda_2 t}\right) dt}{t_{avg}} =$$

$$\frac{G\left(\frac{t_2}{Q_{FF}} + \frac{k_4 e^{\lambda_1 t_2}}{\lambda_1} - \frac{k_5 e^{\lambda_2 t_2}}{\lambda_2}\right) - G\left(\frac{t_1}{Q_{FF}} + \frac{k_4 e^{\lambda_1 t_1}}{\lambda_1} - \frac{k_5 e^{\lambda_2 t_1}}{\lambda_2}\right)}{t_{avg}}$$

To calculate the mass transfer to and from the near-field, the Free Surface Area, FSA, is defined to be the surface area through which mass transfer can occur. Note that the FSA is not equal to the surface area of the entire near-field. EPA defined the near-field zone to be a rectangular box resting on the floor; therefore, no mass transfer can occur through the near-field box's floor. FSA is calculated in Equation_Apx I-14, below:

Equation_Apx I-14

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

Where: L_{NF}, W_{NF}, and H_{NF} are the length, width, and height of the near-field, respectively. The near-field ventilation rate, Q_{NF}, is calculated in Equation_Apx I-15 from the near-field indoor wind speed, v_{NF}, and FSA, assuming half of FSA is available for mass transfer into the near-field and half of FSA is available for mass transfer out of the near-field:

Equation_Apx I-15

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

The far-field volume, V_{FF}, and the air exchange rate, AER, is used to calculate the far-field ventilation rate, Q_{FF}, as given by Equation_Apx I-16:

Equation_Apx I-16

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

Using the model inputs in Table_Apx I-1, EPA estimated 1-BP inhalation exposures for workers in the near-field and for occupational bystanders 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.

I.2 Model Parameters

Table_Apx I-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_Apx I-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. EPA fit a beta function to this distribution with parameters: $\alpha_1 = 6.655$, $\alpha_2 = 108.22$, min = 500 ft^2, max = 20,000 ft^2.
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 study).
Near-field length	L_{NF}	ft	10	—	—	—	—	—	EPA 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), Klein and Kurz (1994), and EPA TCE RA peer review comments (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). For commercial facilities, distribution has a mean wind speed of 10.85 cm/s and standard deviation of 7.88 cm/s.
		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	—	—	13.92	16	—	Uniform	MassDEP case study estimates a 1-BP dry cleaner spends $60/month on spot cleaning agent. At an estimated cost of $45/gal (Blando et al., 2009), this translates to 1.3 gal/month or 16 gal/yr. EPA assumed the formulation contains 87 to 100% 1-BP.
Vapor generation rate	G	mg/hr	—	—	2.97E+03	9.32E+04	—	Calculated	G is calculated based on UR and assumes 100% volatilization.
		g/min	—	—	0.05	1.55	—	Calculated	
Operating hours per day	OH	hr/day	—	—	2	5	—	Uniform	Determined from a California survey performed by Wolf and Morris (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.
Fractional days with exposure	f	unitless	—	—	0.8	1	—	Uniform	EPA assumed 0.8 to 1 to account for part-time employees at dry cleaners. The low-end of range corresponds to approximately 200 days/yr (i.e., the weighted average hours for dry cleaning employees based on BLS/Census data).

I.2.1 Far-Field Volume

EPA calculated the far-field volume by setting a distribution for the facility floor area and multiplying the floor area by a facility height of 12 ft (median value per CARB 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 composed the following distribution of floor area. To calculate facility volume, EPA 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_Apx I-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 fit a beta function to this distribution with parameters: $\alpha_1 = 6.655$, $\alpha_2 = 108.22$, min = 500 ft^2, max = 20,000 ft^2.

I.2.2 Near-Field Volume

EPA 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.

I.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'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. 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}).

I.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 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 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 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).

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.

I.2.5 Averaging Time

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

I.2.6 Use Rate

The Massachusetts Department of Environmental Protection (MassDEP) provided a comparative analysis of several dry cleaner case studies using various Perc alternatives. The document estimates a 1-BP dry cleaner spends $60 per month on spot cleaning agent (MassDEP, 2013). At an estimated cost of $45 per gallon (Blando et al., 2009), this use rate translates to 1.3 gallon per month or 16 gallons per year.

According to the Safety Data Sheet, DrySolv contains more than 87 percent 1-BP by weight (Enviro Tech International, 2013). EPA assumed the spot cleaning formulation contains 87 to 100 percent 1-BP.

I.2.7 Vapor Generation Rate

EPA set the vapor generation rate for spot cleaning (G) equal to the use rate of 1-BP with appropriate unit conversions. EPA assumed all 1-BP applied to the garment evaporates. EPA used a density of 1.33 g/cm^3. To calculate an hourly vapor generation rate, EPA 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.

I.2.8 Operating Hours

Wolf and Morris (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 models a uniform distribution of spotting labor varying from 2 to 5 hr/day.

Appendix J Dermal Exposure Assessment Method

This method was developed through review of relevant literature and consideration of existing exposure models, such as EPA models and the European Centre for Ecotoxicology and Toxicology of Chemicals Targeted Risk Assessment (ECETOC TRA).

J.1 Incorporating the Effects of Evaporation

J.1.1 Modification of EPA/OPPT Models

Current EPA/OPPT dermal models do not incorporate the evaporation of material from the dermis. The dermal retained dose, D_{exp} (mg/day), is calculated as (U.S. EPA, 2013a):

Equation_Apx J-1

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

Where:

S is the surface area of contact (cm^2)
Q_u is the quantity remaining on the skin after an exposure event (mg/cm^2-event)
Y_{derm} is the weight fraction of the chemical of interest in the liquid ($0 \leq Y_{derm} \leq 1$)
FT is the frequency of events (integer number per day).

Here Q_u does not represent the quantity remaining after evaporation, but represents the quantity remaining after the bulk liquid has fallen from the hand that cannot be removed by wiping the skin (e.g., the film that remains on the skin).

One way to account for evaporation of a volatile solvent would be to add a multiplicative factor to the EPA/OPPT model to represent the proportion of chemical that remains on the skin after evaporation, f_{abs} ($0 \leq f_{abs} \leq 1$):

Equation_Apx J-2

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

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.

J.2 Theoretical Estimation 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 evaporative flux to the steady-state dermal absorption flux, χ (dimensionless), which can be estimated using the following equation:

Equation_Apx J-3

$$\boldsymbol{\chi = 3.4 \times 10^{-3} u^{0.78} \frac{P_{vp} MW^{3.4}}{K_{oct}^{0.76} S_W}}$$

Where:

u is the air velocity (m/s)
K_{oct} is the octanol:water partition coefficient
MW is the molecular weight
S_W is the water solubility (μg/cm^3)
P_{vp} is the vapor pressure (torr)

Chemicals for which $\chi >> 1$ will largely evaporate from the skin surface, while chemicals for which $\chi << 1$ will be largely absorbed; $\chi = 1$ represents a balance between evaporation and absorption. Equation_Apx J-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.

J.2.1 Small Doses (Case 1: $M_0 \leq M_{sat}$)

In the small dose scenario, the initial dose (M_0) is less than that required to saturate the upper layers of the stratum corneum ($M_0 \leq M_{sat}$), and the chemical is assumed to evaporate from the skin surface at a rate proportional to its local concentration.

For this scenario, Frasch (2012) calculated the fraction of applied mass that is absorbed, based on the infinite limit of time (i.e., infinite amount of time available for absorption after exposure):

Equation_Apx J-4

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

Where:

m_{abs} is the mass absorbed
M_0 is the initial mass applied
f is the relative depth of penetration in the *stratum corneum* ($f = 0.1$ can be assumed)
χ is as previously defined

Note the simple algebraic solution in Equation_Apx J-4 provides a theoretical framework for the total mass that is systemically absorbed after exposure to a small finite dose (mass/area) of chemical, which depends on the relative rates of evaporation, permeation, and the initial load. At "infinite time," the applied dose is either absorbed or evaporated (Frasch, 2012). The finite dose is a good model for *splash-type exposure in the workplace* (Frasch and Bunge, 2015).

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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 $K_{ow} \leq 3$.

The fraction of the applied mass that evaporates is simply the complement of that absorbed:

Equation_Apx J-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_Apx J-6:

Equation_Apx J-6

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

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

Equation_Apx J-7

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

Equation_Apx J-6 and Equation_Apx J-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.

J.2.2 Large Doses (Case 2: $M_0 > M_{sat}$)

For large doses ($M_0 > M_{sat}$), the chemical saturates the upper layers of the stratum corneum, and any remaining amount forms a residual layer (or pool) on top of the skin. The pool acts as a reservoir to replenish the top layers of the membrane as the chemical permeates into the lower layer. In this case, absorption and evaporation approach steady-state values as the dose is increased, similar to an infinite dose scenario.

The steady-state fraction absorbed can be approximated by Equation_Apx J-8:

Equation_Apx J-8

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

Table_Apx J-1 presents the estimated absorbed fraction calculated using the steady-state approximation for large doses (Equation_Apx J-8) for 1-BP.

Table_Apx J-1. Estimated Fraction Evaporated and Absorbed (fabs) using Steady-State Approximation for Large Doses

Chemical Name	**1-Bromopropane**
CASRN	**106-94-5**
Molecular Formula	**C_3H_7Br**
Molecular Weight (g/mol)	122.99
P_{VP} (torr)	110.8
Universal gas constant, R (L*atm/K*mol)	0.0821
Temperature, T (K)	303
Log K_{ow}	2.1
K_{oct}	125.9
S_w (g/L)	2.45
S_w ($\mu g/cm^3$)	2450
Industrial Setting	
u (m/s)[a]	0.1674
Ratio of Evaporative Flux to Dermal Flux, χ	12.33
Fraction Evaporated	0.92
Fraction Absorbed	**0.08**
Commercial Setting	
u (m/s)[a]	0.0878
Evaporative Flux, χ	7.45
Fraction Evaporated	0.88
Fraction Absorbed	**0.12**

[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.

J.3 Potential for Occlusion

Gloves can prevent the evaporation of volatile chemicals from the skin, resulting in occlusion. Chemicals trapped in the glove may be broadly distributed over the skin (increasing S in Equation_Apx J-2), or if not distributed within the glove, the chemical mass concentration on the skin at the site of contamination may be maintained for prolonged periods of time (increasing Q_u in Equation_Apx J-2). Conceptually, occlusion is similar to the "infinite dose" study design used in *in vitro* and *ex vivo* dermal penetration studies, in which the dermis is exposed to a large, continuous reservoir of chemical.

The impact of occlusion on dermal uptake is complex: continuous contact with the chemical may degrade skin tissues, increasing the rate of uptake, but continuous contact may also saturate the skin, slowing uptake (Dancik et al., 2015). These phenomena are dependent upon the chemical, the vehicle and environmental conditions. It is probably not feasible to incorporate these sources of variability in a screening-level population model of dermal exposure without chemical-specific studies.

Existing EPA/OPPT dermal models (Equation_Apx J-1) could theoretically be modified to account for the increased surface area and/or increased chemical mass in the glove. This could be achieved through a multiplicative variable (such as used in Equation_Apx J-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 × Q_u (cm^2 × mg/cm^2-event) could be replaced by a single variable representing the mass of chemical that deposits inside the glove per event, M (mg/event):

Equation_Apx J-9

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

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 for M in Equation_Apx J-9, EPA notes the significant difference between the 50th and 95th percentile deposition, with the 95th percentile value being two times more conservative than the defaults for the *EPA/OPPT 2-Hand Dermal Exposure Model* (where the product S × Q_u is 2,247 mg/event). Given the variability in inner glove exposure and lack of information on the specific mechanism in which the inner glove contamination occurs, EPA presents occluded exposure estimates using 2,247 mg/event for parameter M in Equation_Apx J-9.

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 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.

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.

J.4 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_Apx J-1) by modification of Q_u with a protection factor, PF (unitless, PF ≥ 1):

Equation_Apx J-10

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

Given the limited state of knowledge about the protection afforded by gloves in the workplace, it is reasonable to utilize the PF values of the ECETOC TRA model (Marquart et al., 2017), rather than attempt to derive new values. Table_Apx J-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_Apx J-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

Source: (Marquart et al., 2017)

J.5 Proposed Dermal Dose Equation

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

Equation_Apx J-11

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

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

- Dermal exposure without the use of protective gloves (Equation_Apx J-11, PF = 1)
- Dermal exposure with the use of protective gloves (Equation_Apx J-11, PF = 5)
- Dermal exposure with the use of protective gloves and employee training (Equation_Apx J-11, PF = 20 for industrial users and PF = 10 for professional users)
- Dermal exposure with occlusion (Equation_Apx J-9)

EPA assumes the following parameter values for Equation_Apx J-11 in addition to the parameter values presented in Table_Apx J-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 (U.S. EPA, 2013a).
- Y_{derm}, the weight fraction of the chemical of interest in the liquid: EPA will assess a unique value of this parameter for each occupational scenario or group of similar occupational scenarios.
- FT, the frequency of events: 1 event per day. Equation_Apx J-11 shows a linear relationship between FT and D_{exp}; however, this does not account for time between contact events. Since the chemical simultaneously evaporates from and absorbs into the skin, the dermal exposure is a function of both the number of contact events per day and the time between contact events. EPA did not identify information on how many contact events may occur and the time between contact events. Therefore, EPA assumes a single contact event per day for estimating dermal exposures.

For Equation_Apx J-9, EPA assumes the quantity of liquid occluded underneath the glove (M) is equal to the product of the entire surface area of contact (S = 1,070 cm^2) and the assumed quantity of liquid remaining on the skin (Q_u = 2.1 mg/cm^2-event), which is equal to 2,247 mg/event. See discussion in Section J.3.

J.6 Equations for Calculating Acute and Chronic (Non-Cancer and Cancer Dermal Doses)

Equation_Apx J-11 estimates dermal potential dose rates (mg/day) to workers in occupational settings. The potential dose rates are then used to calculate acute retained doses (ARD), and chronic retained doses (CRD) for non-cancer and cancer risks.

Acute retained doses are calculated using the equation below.

Equation_Apx J-12

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

Where:

ARD = acute retained dose (mg/kg-day)
D_{exp} = dermal potential dose rate (mg/day)
BW = body weight (kg)

CRD is used to estimate exposures for non-cancer and cancer risks. CRD is calculated as follows:

Equation_Apx J-13

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

Equation_Apx J-14

$$AT = WY \times 260\frac{day}{yr}$$

Equation_Apx J-15

$$\boldsymbol{AT_c = LT \times 260\frac{day}{yr}}$$

Where:

CRD = Chronic dose used for chronic non-cancer or cancer risk calculations
EF = Exposure frequency (day/yr)
WY = Working years per lifetime (yr)
AT = Averaging time (day) for chronic, non-cancer risk
AT_C = Averaging time (day) for cancer risk
LT = Lifetime years (yr) for cancer risk

Table_Apx J-3 summarizes the default parameter values used to calculate each of the above acute or chronic exposure estimates.

Table_Apx J-3. Default Values for Acute and Chronic Dermal Exposure Estimates

Parameter Name	Symbol	Value	Unit
Exposure Frequency	EF	260	days/yr
Working years	WY	31 (50th percentile) 40 (95th percentile)	years
Lifetime Years, cancer	LT	78	years
Body Weight	BW	80	kg
Averaging Time, non-cancer	AT	8,060 (central tendency)[a] 10,400 (high-end)[b]	day
Averaging Time, cancer	AT_c	20,280	day

[a] Calculated using the 50th percentile value for working years (WY)

[b] Calculated using the 95th percentile value for working years (WY)

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 (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' (2019a) Survey of Income and Program Participation (SIPP) provides information on *lifetime tenure with all employers*. SIPP is a household survey that collects data on income, labor force participation, social program participation and eligibility, and general demographic characteristics through a continuous series of national panel surveys of between 14,000 and 52,000 households (U.S. Census Bureau, 2019b). EPA analyzed the 2008 SIPP Panel Wave 1, a panel that began in 2008 and covers the interview months of September 2008 through December 2008 (U.S. Census Bureau, 2019a, 2019b). 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 J-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 J-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: U.S. Census Bureau, 2019a

Note: Industries where sample size is less than five are excluded from this analysis.

BLS CPS data provides the median years of tenure that wage and salary workers had been with their current employer. Table_Apx J-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.

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[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_Apx J-5. Median Years of Tenure with Current Employer by Age Group

Age	January 2008	January 2010	January 2012	January 2014
16 years and over	4.1	4.4	4.6	4.6
16 to 17 years	0.7	0.7	0.7	0.7
18 to 19 years	0.8	1.0	0.8	0.8
20 to 24 years	1.3	1.5	1.3	1.3
25 years and over	5.1	5.2	5.4	5.5
25 to 34 years	2.7	3.1	3.2	3.0
35 to 44 years	4.9	5.1	5.3	5.2
45 to 54 years	7.6	7.8	7.8	7.9
55 to 64 years	9.9	10.0	10.3	10.4
65 years and over	10.2	9.9	10.3	10.3

Source: U.S. BLS, 2014.

Lifetime Years (LT)

EPA assumes a lifetime of 78 years for all worker demographics.

Body Weight (BW)

EPA assumes a body weight of 80 kg for all worker demographics.

J.7 Experimental Values of f_{abs} for 1-BP

Sections J.2 presents a theoretical framework for estimating the fraction of volatile chemical absorbed in finite dose and infinite dose scenarios. Where 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 a fractional absorption of 0.16 percent of applied 1-BP. The measurement was performed in an open fume hood with an average air speed of 0.3 m/s (30 cm/s) – a value likely higher than typical air velocity that workers would experience indoors. Because higher air velocity increases the rate of chemical evaporation, the experimental value likely underestimates fractional absorption. As such, this measured value should be adjusted to account for typical environmental conditions relevant to worker exposures.

J.7.1 f_{abs}

Fraction absorbed ($0 \leq f_{abs} \leq 1$) refers to the fraction of chemical that is absorbed through the stratum corneum (upper layer) of the skin. It is a function of the dimensionless χ, which is defined as the ratio of evaporative flux to absorption flux (Frasch et al., 2018):

Equation_Apx J-16

$$\chi = \frac{J_{evap}}{J_{max,SS}} = \frac{k_{evap} \times \rho}{J_{max,SS}}$$

Where:

J_{evap} is the evaporative flux (mg/cm^2-h)
$J_{max,SS}$ is the maximum steady-state absorption flux (mg/cm^2-h)
k_{evap} is the liquid-phase evaporation mass transfer coefficient (cm/h)
ρ is density (mg/cm^3)

The liquid-phase evaporation mass transfer coefficient (k_{evap}) is a function of the gas-phase mass transfer coefficient, which is dependent on the wind speed, u (Frasch et al., 2018):

Equation_Apx J-17

$$k_{evap} = k_g \frac{P_{vap}\, MW}{RT}$$

Equation_Apx J-18

$$k_g = \frac{6320 \cdot u^{0.78}}{MW^{1/3}}$$

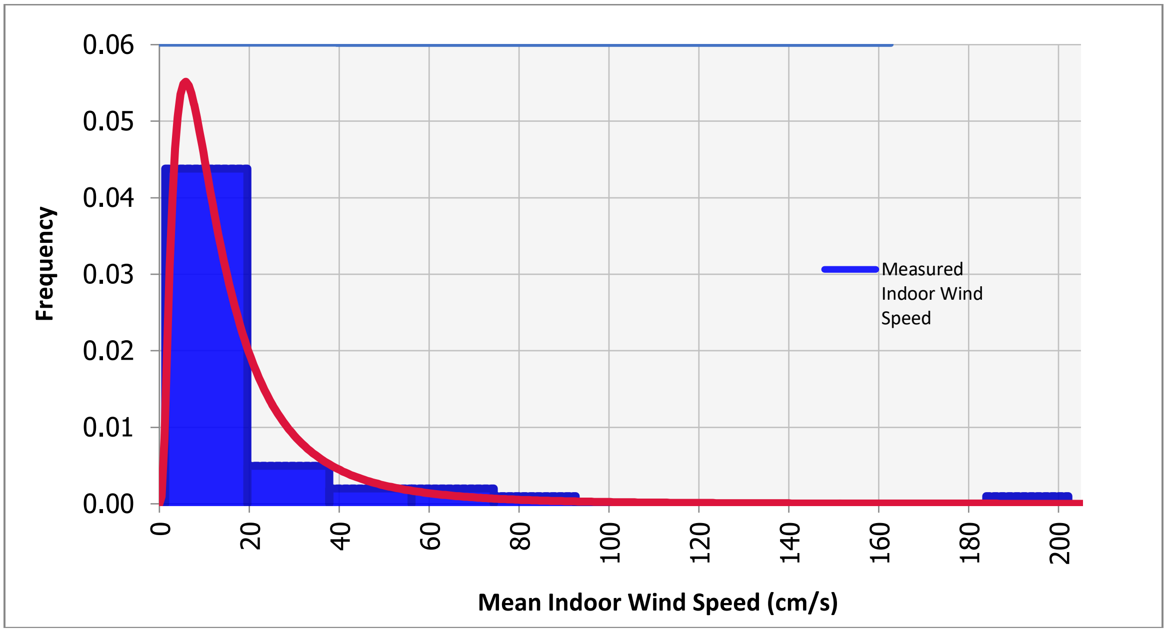
Where:

k_g is the gas-phase mass transfer coefficient
P_{vap} is the vapor pressure at the temperature of the liquid
R is the gas constant
T is temperature
u is wind speed
MW is molecular weight

Equation_Apx J-16 through Equation_Apx J-18 demonstrate that the evaporative flux J_{evap} is a function of wind speed (u) to the 0.78 power.

J.7.2 Experimental Wind Speed Measurements

Baldwin and Maynard (1998) measured indoor air speeds across 55 workplaces in the United Kingdom. These workplaces cover both industrial and commercial facilities. The authors suggest indoor wind speed data could be approximated by a lognormal distribution. Figure_Apx J-1 fits the wind speed measurements to a lognormal distribution. The fitted distribution has a mean of 17.6 cm/s and a standard deviation of 18.4 cm/s. The lower bound of the distribution is set to zero. The 50th percentile wind speed within this distribution is 12.2 cm/s. Note approximately 85 percent of the distribution are below 30 cm/s (0.3 m/s), the wind speed noted by Frasch et al. (2011) during the 1-BP evaporative flux measurement.



Figure_Apx J-1. Distribution of Mean Indoor Wind Speed as Measured by Baldwin and Maynard (1998)

J.7.3 Adjusting χ and f_{abs} for Wind Speed

From the same 1-BP *in vitro* dermal penetration study described in Section J.7, Frasch et al. (2011) measured an evaporative flux (J_{evap}) of 470 mg/cm^2-h. The experimentally measured steady-state absorption flux ($J_{max,SS}$) ranges from 625 to 960 µg/cm^2-h (infinite-dose, neat 1-BP). The evaporative flux was measured at 23°C, whereas the absorption flux was measured near the typical skin surface temperature of 32°C.

From the relationship given in Equation_Apx J-16 through Equation_Apx J-18, the adjusted evaporative flux (J'_{evap}) can be calculated as:

Equation_Apx J-19

$$J'_{evap} = J_{evap}\left(\frac{u'}{u}\right)^{0.78}\left(\frac{P_{vap}'}{P_{vap}}\cdot\frac{T}{T'}\right)$$

1-BP has a vapor pressure of 110.8 mmHg at 20°C (293K). At the skin surface temperature of 32°C (T' = 305K), the adjusted vapor pressure can be calculated using the Clausius-Clapeyron equation:

Equation_Apx J-20

$$ln\left(\frac{P_{vap}'}{P_{vap}}\right) = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T}-\frac{1}{T'}\right)$$

$$ln\left(\frac{P_{vap}'}{110.8\text{ mmHg}}\right) = \frac{32{,}130\text{ J/mol}}{8.314\text{ J/mol-K}}\left(\frac{1}{20+273}-\frac{1}{T'+273}\right)$$

If T’ = 23^{o}C (296K), P_{vap}’ = 126.6 mmHg
If T’ = 32^{o}C (305K), P_{vap}’ = 186.2 mmHg

At the 50th percentile wind speed measured by Baldwin and Maynard (1998) (u’ = 12.2 cm/s), the adjusted evaporative flux is:

$$J'_{evap} = 470\,\frac{\text{mg}}{\text{cm}^2\text{-h}} \cdot \left(\frac{12.2\ \text{cm/s}}{30\ \text{cm/s}}\right)^{0.78} \left(\frac{186.2\ \text{mmHg}}{126.6\ \text{mmHg}} \cdot \frac{296\text{K}}{305\text{K}}\right) = 332\,\frac{\text{mg}}{\text{cm}^2\text{-h}}$$

From Equation_Apx J-16 and Equation_Apx J-8:

$$\chi = \frac{J_{evap}}{J_{max,SS}} = \frac{332}{0.96} = 346$$

$$f_{abs} \sim \frac{1}{346 + 1} \sim 0.0029\ (0.29\%)$$

As such, the adjusted fraction absorbed is 0.29%, approximately an 80 percent increase from the measured 0.16% value.

Appendix K Data Integration Strategy for Occupational Exposure Data/Information

K.1 General Approach

Data integration is the stage following the data extraction and evaluation step discussed in the Application of Systematic Review in TSCA Risk Evaluations (U.S. EPA, 2018d). Data integration is where the analysis, synthesis and integration of data/ information takes place. For integration of occupational exposure data/information, EPA will normally use the highest rated quality data among the higher level of the hierarchy of preferences as described below. Tables 1 below presents the hierarchy of preferences among the primary types of data/ information to be analyzed, synthesized and integrated for the occupational exposure assessments in the TSCA risk evaluations. EPA will provide rationale when deviations from the hierarchy occur.

Selection of Data and Approaches

EPA will select data for use from the data extraction and evaluation phase of systematic review. EPA will only use data/information rated as High, Medium, or Low in the occupational exposure assessments; data/ information rated as unacceptable will not be used. If need be, data of lower rated quality or approaches in lower levels of the hierarchy may be used to supplement the analysis. For example, data/ information of high quality could be determined to be sufficient such that lower quality data may not be included or integrated with the higher quality data. Also, data/ information of high quality could be determined to be sufficient such that approaches assigned lower preference levels in the hierarchy may not be pursued even if they are available and possible. In many cases EPA does not have robust and or representative monitoring data and will augment such data with modeled estimates of exposure.

Assessment Data and Results

EPA will provide occupational exposure data and results representative of *central tendency* conditions and *high-end* conditions. A central tendency is assumed to be representative of occupational exposures in the center of the distribution for a given condition of use. For risk evaluation, EPA may use 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 plans to provide high-end results at the 95th percentile. If the 95th percentile is not available, EPA may use 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 may estimate a maximum or bounding estimate in lieu of the high-end.

EPA has defined occupational exposure scenarios (OES) as the most granular level that EPA will generate results within each condition of use. For some conditions of use, EPA may define only a single OES (e.g., a manufacturing condition of use for multiple manufacturing sites may be defined by a single manufacturing OES). Other conditions of use have multiple OES (e.g., the use of chemical X in vapor degreasing has OES for open-top batch vapor degreasing, conveyorized degreasing, web degreasing, and closed-system degreasing). EPA will attempt to provide a single set of results (central tendency and high-end) for each exposure assessed for an OES.

Integration of Data Sets

To provide the occupational results at the central tendency and high-end descriptors, EPA may integrate data sets representative of different sites, job descriptions, or process conditions to develop a distribution representative of the entire population of workers and sites involved in the given OES in the United States. Ideally, the distribution would account for inter-site variability (variability in operations among different sites) and intra-site variability (variability in operations within a single site).

To integrate data sets together, EPA will review the available metadata for each data set to ensure the data sets are representative of the same OES. EPA will document any uncertainties in the metadata or if EPA used a data set of a similar scenario as surrogate for the OES being assessed.

Integration of Data for Modeling and Calculations

For occupational exposures, EPA may use measured or estimated air concentrations to calculate exposure concentration metrics required for risk assessment, such as average daily concentration and lifetime average daily concentration. These calculations require additional parameter inputs, such as years of exposure, exposure duration and frequency, and lifetime years. EPA may estimate exposure concentrations from monitoring data, modeling, or occupational exposure limits, as identified in Table 1 and use each of these in its evidence integration to assess the strength of the evidence.

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 50th percentile or 95th percentile) or a *full distribution*. EPA will consider three general approaches for estimating the final exposure result metrics:

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

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

- Combination of deterministic and probabilistic calculations: EPA may have full distributions for some parameters but point estimates of the remaining parameters. For example, EPA may pursue Monte Carlo modeling to estimate exposure concentrations, but only have point estimates of working years of exposure, exposure duration and frequency, and lifetime years. In this case, EPA will document the approach and rationale for combining point estimates with distribution results for estimating central tendency and high-end results.
    - Probabilistic approaches can also supplement and complement monitoring estimates by providing sensitivity analysis of parameters for certain conditions and thus provide greater certainty about the strength of the evidence.

K.2 Confidence Statements

For each use, EPA considered the assessment approach, the quality of the data and models, and uncertainties in assessment results to determine a level of confidence for the 8-hr TWA data and modeled estimates and for dermal potential dose estimates.

For the inhalation air concentration monitoring data, strength of confidence is improved by the following factors:

- higher approaches in the inhalation approach hierarchy
- larger numbers of data points
- larger number of sites monitored
- larger broadness of worker population groups included in monitoring
- higher systematic review data quality ratings.

Strength of confidence in monitoring data is reduced by:

- uncertainty of the representativeness of these data toward the true distribution of inhalation concentrations for the industries and sites covered by the use.

For modeled air concentrations, strength of confidence is improved by the following factors:

- higher approaches in the inhalation approach hierarchy
- model validation
- full distributions of input parameters

Strength of confidence in modeled air concentration estimates is reduced by:

- uncertainty of the representativeness of the model or parameter inputs toward the true distribution of inhalation concentrations for the industries and sites covered by the use.

For dermal dose rate estimates, strength of confidence is improved by the following factors:

- use of actual data rather than assumptions for input parameters

Strength of confidence in dermal potential dose rates is reduced by:

- uncertainty of the representativeness of the of the model or parameter inputs toward the true distribution of dermal doses for the industries and sites covered by the use.

Table_Apx K-1. Hierarchy guiding integration of occupational exposure data/information

For occupational exposures, the generic hierarchy of preferences, listed from highest to lowest levels, is as follows (and may be modified based on the assessment):

Highest Preferred	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: Modeling exposure for chemical “X” and condition of use “A” based on observed monitoring data for chemical “Y” and condition of use “A,” assuming a known relationship (e.g., a linear relationship) between observed exposure and physical property (e.g., vapor pressure). b. Fundamental modeling approaches: Modeling exposure for chemical “X” for condition of use “A” based on fundamental mass transfer, thermodynamic, and kinetic phenomena for chemical “X” and data for condition of use “A” c. Fundamental modeling approaches (with surrogacy): A modeling approach following item 2.b, but using surrogate data in the model, such as data for condition of use “B” judged to be similar to condition of use “A” d. Statistical regression modeling approaches: Modeling exposure for chemical “X” in condition of use “A” using a statistical regression model developed based on: i. Observed monitoring data for chemical “X” statistically correlated with observed data specific for condition of use “B” judged to be similar to condition of use “A” such that replacement of input values in the model can extrapolate exposure results to condition of use “A” ii. Observed monitoring data for chemical “Y” statistically correlated with physical properties and/or molecular structure such that an exposure prediction for chemical “X” can be made (e.g., QSAR techniques)
Lowest Preferred	3. Occupational exposure limits (OELs): 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, OARS WEEL [formerly by AIHA])

Appendix L Screening-Level Analysis of 1-BP Emissions from Insulation

This appendix presents modeling results for 1-BP emissions from THERMAX insulation boards, a non-structural, rigid board insulation consisting of a glass-fiber-infused polyisocyanurate foam core laminated between 1.0-mil smooth, reflective aluminum facers on both sides. The polyisocyanurate foam contains 0.5% of 1-BP by weight. When installed, there is a ¼ inch gap between adjacent panels. For the purpose of modeling, EPA assumed there are no 1-BP emissions from the laminated surfaces and that 1-BP can be emitted only from the four edges of each panel.

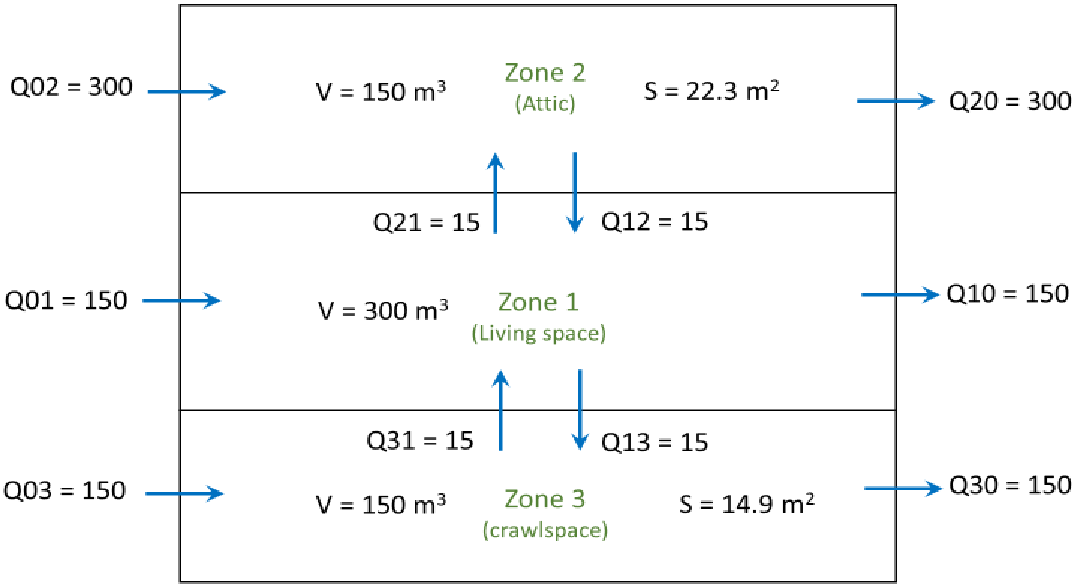
The 1-BP concentrations in the living space, attic, crawlspace and basement after installation of insulation panels were roughly estimated with two building configurations: attic/living space/crawlspace and attic/living space/basement. The temperature was set at 20ºC for all air zones. To evaluate the effect of temperature, an additional simulation was conducted by setting the temperature in the attic and basement at 30ºC.

All these screening-level simulations were performed with IECCU, an indoor environmental quality modeling platform that allows the users to create and implement a wide range of mass-balance based, deterministic models (https://www.epa.gov/tsca-screening-tools/users-guide-and-download-ieccu-indoor-environmental-concentrations-buildings). IECCU allows both conditioned zones, where the temperature is constant, and unconditioned zones, where the temperature is subject to diurnal or seasonal fluctuations.

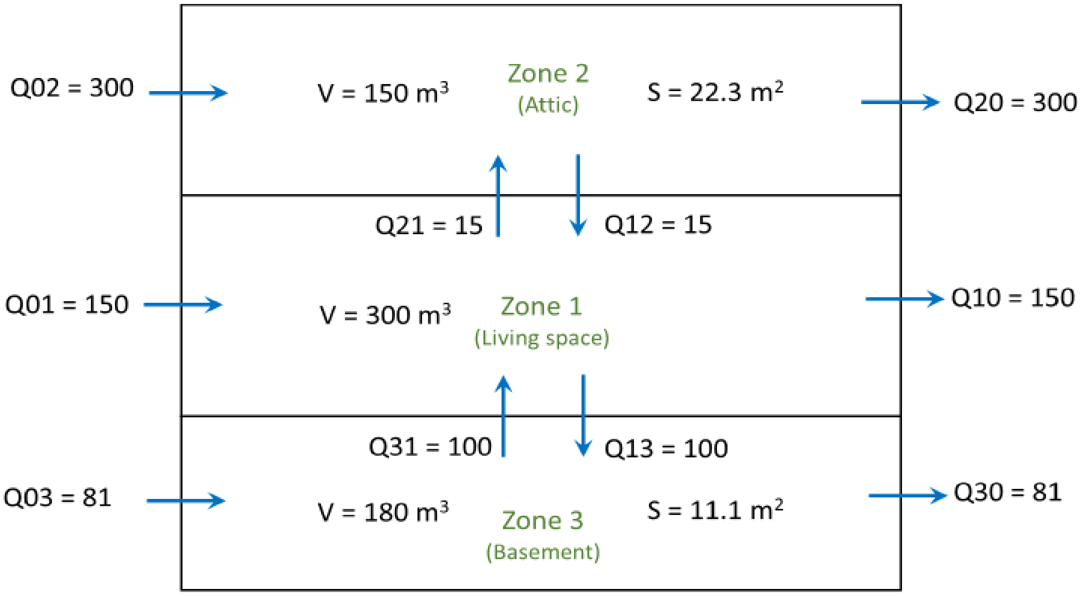
L.1 Parameter Estimation Methods

L.1.1 Building Configurations

Two configurations were considered in EPA's analysis: attic/living space/crawlspace (Figure_Apx L-2) and attic/living space/basement (Figure_Apx L-3). The zone volumes and air flows in Figure_Apx L-1 were based on the previous 1-BP model while those for the basement were based on the recent literature review.



Figure_Apx L-2. Zone Volumes (V), Source Areas (S) and Air Exchange Flows (Q, in m^3/h) for the Attic/Living Space/Crawlspace Configuration.



Figure_Apx L-3. Zone Volumes (V), Source Areas (S) and Air Exchange Flows (Q, in m^3/h) for the Attic/Living Space/Basement Configuration.

L.1.2 Source Areas

Given that both sides of the THERMAX panel are covered with aluminum facers, EPA assumed:

- There are no 1-BP emissions from the laminated surfaces because aluminum foil is impenetrable to 1-BP.

- 1-BP can be emitted only from the four edges because there is a ¼ inch gap between the adjacent panels after installation.

The surface area of exposed edges of each insulation panel can be calculated from Equation_Apx L-1,

Equation_Apx L-1

$$A_e = 2 \times (L + H) \times \theta$$

where

A_e is the total area of the four edges (i.e., the exposed foam area) of each panel (m^2);
L, H, and θ are, respectively, the length, width, and thickness of the panel (m).

For a single 4' × 8' × 2" panel, the total area of four edges is 0.372 m^2. The number of panels needed in each source zone was calculated from the total area of insulated surfaces and is given in Table_Apx L-1. In general, the total area of edges is an order of magnitude smaller than the area of the insulated surfaces.

Table_Apx L-1. Calculation of Total Source Area in Each Zone

Parameter	Air zone		
	Attic	Crawlspace	Basement
Insulated area (m^2)	180	120	75
Number of panels needed [1]	30	60	40
Source area (m^2)	22.3	14.9	11.1

[1] These are rounded-up numbers.

L.1.3 Gas-phase Mass Transfer Coefficient

The space (¼" wide and 2" deep) between two adjacent insulation boards creates a groove (indentation) where the air is more stagnant than in the bulk air. The commonly used air speed of indoor air for modeling purposes is 10 cm/s. In this analysis, EPA assumed that the average air speed in the indentation is 20% of that in bulk air (i.e., 2 cm/s). With this air speed, the calculated gas-phase mass transfer coefficient for 1-BP is 1.29 m/h.

L.1.4 Partition Coefficient

The material/air partition coefficient for 1-BP in the insulation foam was calculated by the Guo (2000) method available in IECCU. With the vapor pressure of 110.8 torr at 20 ºC, the calculated partition coefficient for the neat polymer is 158 (dimensionless), which was then adjusted by the density of the foam (Equation_Apx L-2).

Equation_Apx L-2

$$K_{foam} = K_{neat} \frac{d_{foam}}{d_{neat}}$$

where

K_{foam} is the partition coefficient for the insulation foam (dimensionless),
K_{neat} is the partition coefficient for the neat polymer (dimensionless),
d_{foam} is the density of the insulation foam (g/cm^3),

d_{neat} is the density of the neat polymer (g/cm^3).

.

The calculated partition coefficient for the foam at 20 ºC is 4.13 if the board density is 2.5 lb./ft^3 and 3.30 if the density is 2.0 lb./ft^3. In this work, I used the latter value. The partition coefficient at 30 ºC was calculated with the Tian et al. (2017) method and the result is 1.23 for density of 2.0 lb./ft^3.

L.1.5 Solid-Phase Diffusion Coefficient

The experimentally determined diffusion coefficient for 1-BP in polyiso insulation foam boards is not available. EPA estimated this parameter by using the QSAR model developed by Huang et al. (2017), which is implemented in IECCU. To reduce uncertainty, EPA estimated the diffusion coefficient with two reference materials: (1) using polystyrene foam as a surrogate of polyiso foam, and (2) estimating the diffusion coefficient for the neat polymer and then adjusting the value by foam density (Equation_Apx L-3).

Equation_Apx L-3

$$D_{foam} = D_{neat} \frac{d_{neat}}{d_{foam}}$$

where

D_{foam} is the diffusion coefficient for the insulation foam (m^2/h),
D_{neat} is the diffusion coefficient for the neat polymer (m^2/h),
d_{neat} is the density of the neat polymer (g/cm^3).
d_{foam} is the density of the insulation foam (g/cm^3).

The results are shown in Table_Apx L-2. I used the geometric mean of the two results as the input of IECCU.

Table_Apx L-2. Estimated Diffusion Coefficient for 1-BP in Insulation Foam (Units: m^2/h)

Temperature (ºC)	Reference Material Category		Geometric Mean
	Polystyrene foam	Rigid polymers [1]	
20	1.76×10^{-10}	2.02×10^{-12}	1.88×10^{-11}
30	2.81×10^{-10}	3.22×10^{-12}	3.01×10^{-11}

[1] The values have been adjusted by foam density (Equation 2).

L.2 Results

The estimated 1-BP concentrations, given in both (µg/m^3) and (ppm), are summarized in Table_Apx L-3, Table_Apx L-4, and Table_Apx L-5.

Table_Apx L-3. Estimated 1-BP Concentrations for the Attic/Living Space/Crawlspace Configuration with Temperature at 20°C for All Air Zones

TWA Period	Predicted 1-BP TWA Concentrations					
	(µg/m^3)			(ppm)		
	Living space	Attic	Crawlspace	Living space	Attic	Crawlspace
First 8 hours	2.63	16.1	20.1	5.15E-04	3.15E-03	3.93E-03
First day	1.79	9.76	12.4	3.50E-04	1.91E-03	2.42E-03
First month	0.34	1.76	2.27	6.65E-05	3.44E-04	4.44E-04
First year	0.1	0.51	0.65	1.95E-05	9.97E-05	1.27E-04

Table_Apx L-4. Estimated 1-BP Concentrations for the Attic/Living Space/Basement Configuration with Temperature at 20°C for All Air Zones

TWA Period	Predicted 1-BP TWA Concentrations					
	(µg/m^3)			(ppm)		
	Living space	Attic	Basement	Living space	Attic	Basement
First 8 hours	6.52	16.3	16.6	1.27E-03	3.19E-03	3.24E-03
First day	4.52	9.89	10.8	8.83E-04	1.93E-03	2.11E-03
First month	0.85	1.75	1.96	1.66E-04	3.42E-04	3.83E-04
First year	0.25	0.52	0.57	4.89E-05	1.02E-04	1.11E-04

Table_Apx L-5. Estimated 1-BP Concentrations for the Attic/Living Space/Basement Configuration with Temperature at 30°C in Attic and Basement

TWA Period	Predicted 1-BP TWA Concentrations					
	(µg/m^3)			(ppm)		
	Living space	Attic	Basement	Living space	Attic	Basement
First 8 hours	8.18	20.3	20.8	1.65E-03	4.10E-03	4.20E-03
First day	5.53	12.1	13.2	1.12E-03	2.45E-03	2.67E-03
First month	1.07	2.18	2.45	2.16E-04	4.41E-04	4.95E-04
First year	0.3	0.63	0.7	6.06E-05	1.27E-04	1.41E-04