



EMISSION SCENARIO DOCUMENT ON THE USE OF VAPOR DEGREASERS

Draft

Environment Directorate

Organization for Economic Co-operation and Development

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Purpose and background

This OECD draft Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns, and potential release pathways of chemicals used as vapor degreasers. The document presents standard approaches for estimating environmental releases and occupational exposures.

This ESD may be periodically updated to reflect changes in the industry and new information available, and extended to cover the industry area in countries other than the lead (the United States). Users of the document are encouraged to submit comments, corrections, updates, and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Task Force on Exposure Assessment (TFEA), which will review the comments every two years so that the lead country can update the document. Submitted information will also be made available to users within the OECD web site (<http://www.oecd.org/env/riskassessment>).

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to chemicals used as vapor degreasers. Some estimates might result in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in real world practice.

The users of this ESD should consider how the information contained in the document applies to the specific scenario being assessed. Where specific information is available, it should be used in lieu of the defaults presented in this document, as appropriate. All input values (default or chemical-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and methodology

EPA developed this ESD using relevant data¹ and available information on the solvent degreasing industry, including process descriptions, operating information, chemicals usage, wastes generation, worker activities, and exposure information. EPA supplemented the data collected with standard models² to develop the environmental release and occupational exposure estimates presented in this ESD.

This document is an update to EPA's draft Generic Scenario on the Use of Vapor Degreasers, dated September 2001. The primary sources of information cited in

¹ Please refer to Section 8 for a list of the specific references used in developing this methodology review draft.

² EPA has developed a series of "standard" models for use in performing conservative release and exposure assessments in the absence of chemical- or industry-specific data. Several of these standard models will be described in Appendix B of the final ESD.

this ESD include industry-specific journal articles, EPA's 2006 Risk Assessment for the Halogenated Solvent Cleaning Source Category, various EPA and other government sources, and the U.S. Census Bureau's Economic Census. Additional information on the sources investigated and the references cited in this document are presented in Section 8.

For the purpose of this document, a vapor degreaser is defined as a chemical or a component chemical formulation used in vapor degreasing machines to clean oils and greases from substrates. The vapor degreasing chemical is typically the primary or secondary solvent, but may also be a stabilizer or additive in the degreasing formulation. The terms "vapor degreaser", "vapor degreasing chemical" and "degreasing solvent" is used interchangeably in this document. Based on the design of the operation, vapor degreasers are expected to be volatile liquids, with many chemicals having vapor pressure above 35 torr at room temperature.

The ESD covers the end use of vapor degreasers. The ESD does not cover the manufacture and processing (formulation) of the chemicals prior to end use; degreasing chemicals may be used neat, or as a component in a formulation in the vapor degreasing machine. An illustration of the scope of this document within the context of the life cycle of the chemical of interest is provided below.

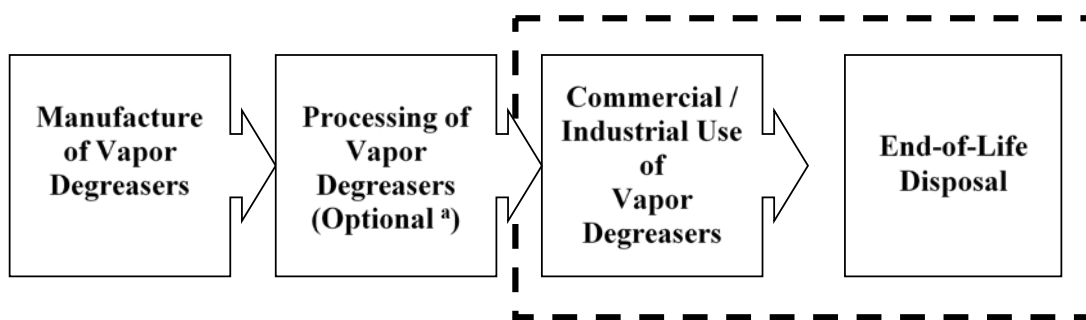


Figure ES-1-1. Scope of Emission Scenario Document for the Use of Vapor Degreasers

a – Based on past PMN case search, vapor degreasing chemicals can be used neat (i.e. as the primary solvent), without processing or dilution.

Many of the chemicals covered in the ESD can also be used in other non-vapor phase cleaning applications, such as aerosol spray degreasing and cold cleaning. These other cleaning applications are not included in the scope of the ESD.

Due to the chemical's volatility, evaporative emissions (i.e. air releases) and inhalation exposures to vapor are expected to be the primary release and exposure. Where specific information on equipment design is not available, this document provides default values associated with those for an open-top batch degreaser, as conservative. Release and exposure may be reduced if the degreasing machine is enclosed or equipped with a control technology (e.g. carbon adsorption).

The methods for estimating the following facility operating parameters, environmental releases, and occupational exposures are discussed in this ESD:

- Number of sites in the United States that are likely to have vapor degreasing operations;
- Number of operating days for the degreasing machines;
- Releases from unloading of transport container;
- Releases from the cleaning of transport containers;
- Releases during degreasing machine operation;
- Releases from equipment cleaning and waste solvent disposal;
- Number of workers involved in vapor degreasing operation;
- Dermal exposure to liquid during unloading of transport containers;
- Inhalation exposure to vapor during unloading of transport container;
- Dermal exposure to liquid during equipment cleaning and solvent changeout; and
- Inhalation exposure to vapor during vapor degreasing machine operation.

For highly volatile chemicals, exposure duration via the dermal route may be minimal as the chemical readily evaporates from the skin. However, dermal exposure may still be a significant exposure route if the chemical is quickly absorbed through the skin or if repeated contacts with the chemical occur.

How this document was developed

EPA, with support from Eastern Research Group, Inc. (ERG), has developed this ESD on the Use of Vapor Degreasers. The scope of the ESD is designed to serve the needs of both OECD programs as well as EPA. In the United States, the Risk Assessment Division (RAD) of EPA's Office of Pollution Prevention and Toxics (OPPT) is responsible for preparing occupational exposure and environmental release assessments of chemicals for a variety of programs under the Toxic Substances Control Act (TSCA), including Premanufacture Notice (PMN) reviews. While OECD ESDs traditionally focus on the potential releases of chemicals from industrial processes, this document also describes approaches for estimating potential occupational exposures to chemicals used for vapor degreasing applications. The occupational exposure methods are included so that the ESD may be used to fully support EPA's chemical review programs.

This document is published under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology of the OECD.

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1.0 INDUSTRY SUMMARY AND BACKGROUND

Vapor degreasing is one of several degreasing options for removing oils, greases, lubricants, coolants, and resins from metal surfaces. In addition to cleaning metals, vapor degreasing can be used to clean non-porous materials that are compatible with solvents, such as glass, ceramics plastics, and elastomers (USEPA 2001). It is an essential operation across a number of industries where surface cleaning is required.

The most widely used solvents for vapor degreasing have changed over the years. Until 1995, solvent usage for vapor degreasers was primarily 1,1,1 - trichloroethane (TCA) or trichloroethylene (TCE). In 1995, the U.S. government phased out production of TCA for being an ozone depleting substance. Today, chlorinated solvents such as TCE, perchloroethylene (PERC) and methylene chloride (MC) are most commonly used; these chemicals are clear, heavy liquids with excellent solvency and are virtually nonflammable. However, some companies have started to replace them with alternative solvents and solvent blends due to concerns for their hazard, safety, and the regulatory (Kanegsberg and Kanegsberg 2011).

1.1 Manufacturing and Formulation of Vapor Degreasing Chemicals

Vapor degreasing chemicals are manufactured as liquids. After manufacture, they could be used neat or could be further formulated. A typical vapor degreasing formulation contains more than 90 percent of the primary solvent and small amounts of secondary solvents and stabilizers. Formulators (i.e. solvent producers) may add organic stabilizers to chlorinated solvents to inhibit decomposition of the solvent from reaction with water, oxygen, or ultraviolet light (USEPA 2001).

1.2 Use of Vapor Degreasing Chemicals

Vapor degreasing chemicals are supplied to the end-use facilities as ready-to-use formulations. The use does not constitute a distinct industrial sector. Rather, it is an integral process in many metal and electronic industries where surface cleaning is required. For example, a facility that fabricates aircraft engine components may perform vapor degreasing to clean metal parts after shaping and machining (NIOSH 1992). A facility that manufactures electrolytic cells may perform vapor degreasing to clean and prepare the surface of anodes and cathodes prior to a coating process (NIOSH 1994). Figure 1-1 provides several examples of vapor degreasing across different industries.

Each end-use facility may use one or more vapor degreasing machine(s) and chemical(s) depending on the facility throughput and the type of substrates being cleaned. For example, facilities that only perform occasional parts cleaning in their process operations may use a small, batch vapor degreaser, while facilities that perform vapor degreasing on a regular basis may elect to use an in-line degreaser for increased throughput.

The degreasing process involves lowering the substrate to be cleaned into a solvent vapor zone. The hot solvent vapor condenses onto the cooler substrate, dissolving and removing organic contaminants on the substrate surface. In some processes, the substrate may be subsequently immersed into a solvent bath (with or without ultrasonics) for additional cleaning and washing. Vapor degreasing is particularly effective in cleaning substrates with recesses, blind holes, perforations, crevices, and welded seams (Kanegsberg and Kanegsberg 2011). The basic equipment design and chemical selection criteria are further discussed in Section 2.0.

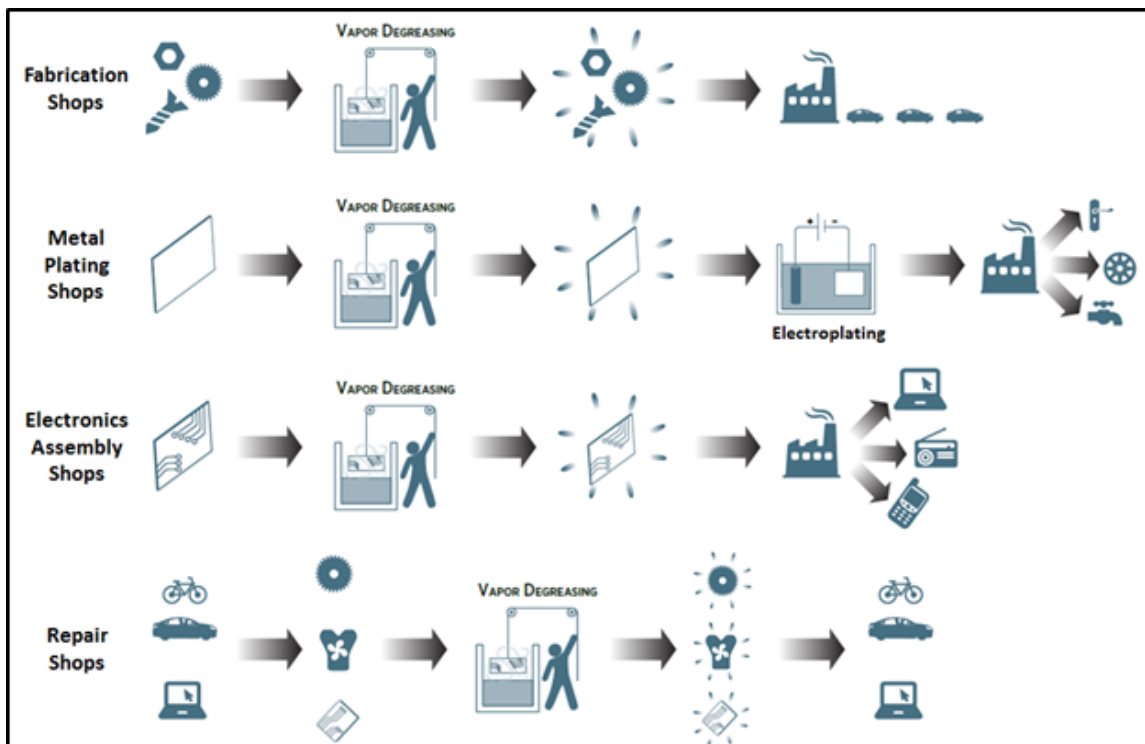


Figure 1-1. Use of Vapor Degreasing in a Variety of Industries

2.0 PROCESS DESCRIPTION

Vapor degreasing is a popular cleaning method in the electronic and metal processing industries because it is effective in removing organics such as oils, greases, lubricants, coolants, and resins from crevices and hard to clean parts. It can be a critical cleaning step at some facilities, or it can be performed on an occasional, as-needed basis in others. The following describes the process operations that take place at an example facility performing vapor degreasing:

[Facility] manufactures hydraulic door closers and employs approximately 175 employees on two shifts. The processes at this facility includes the machining, cleaning, assembling, painting, packing, and shipping of hydraulic door closers. Most of the metal parts used in this operation are composed of aluminum and steel. The machine parts are cleaned in an aqueous cleaning solution prior to the assembly process. After final assembly, some of the parts are cleaned in a conveyORIZED vapor degreaser, which uses trichloroethylene. The assembled and cleaned parts are then conveyed to the paint room.. where a water-based primer and a water-based color coat [are spray applied]... (NIOSH 1998)

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 degreasing machine. The selection of specific equipment will depend on several factors, including, but not limited to: degree of cleanliness required, type and shape of substrate to be cleaned, amount of workload, space, and costs (ASTM 1989). For example, the amount of workload to be cleaned will dictate whether a laboratory-sized batch unit or an in-line, conveyORIZED equipment is used. The shape, form, and size of substrate to be cleaned may dictate whether a vapor only, or a spray-vapor cycle is required. Batch and in-line systems are further described below.

2.1 Batch Systems

2.1.1 Open-Top Vapor Degreasers (OTVD)

The traditional batch degreaser is a tank with cooling coils and a cover at the top. Figure 2-1 is a diagram of an open-top batch vapor degreaser. Heating elements at the bottom of the degreaser heat the liquid solvent to above its boiling point. Solvent vapor rises to the height of the chilled condensing coils on the inside walls of the unit, producing a hot vapor zone below the coils. The condensing coils cool the vapor, causing it to condense and return to the bottom of the degreaser (USEPA 2006).

To clean dirty parts, the substrates are lowered into the vapor zone. The hot vapor condenses onto the substrate, which is cooler in temperature, and the condensation

dissolves the grease and carries it off the substrate surface as it drains into the solvent reservoir below. The process continues until the substrate temperature reaches that of the vapor, at which point the cleaned and dried substrate is lifted out of the vapor zone. The degreaser can also contain one or more immersion tanks below the vapor zone for additional cleaning and rinsing, either before or after vapor-phase cleaning. Transducers can also be installed to provide ultrasonic cleaning action to remove heavy oil deposits and solid soils (Kanegsberg and Kanegsberg 2011).

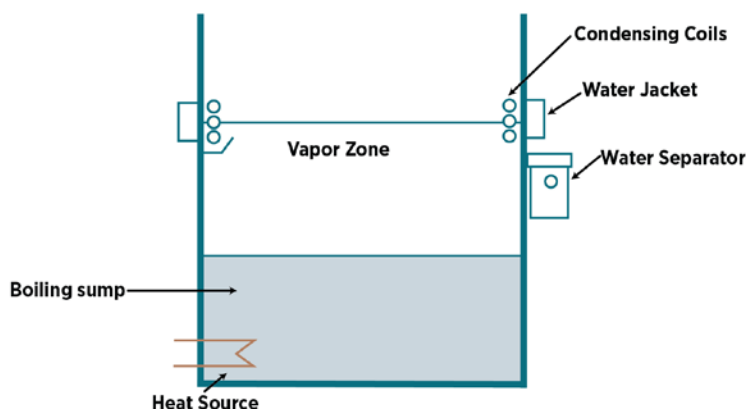


Figure 2-1. Open Top Vapor Degreaser

2.1.2 Open-Top Vapor Degreasers (OTVD) with Enclosure

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

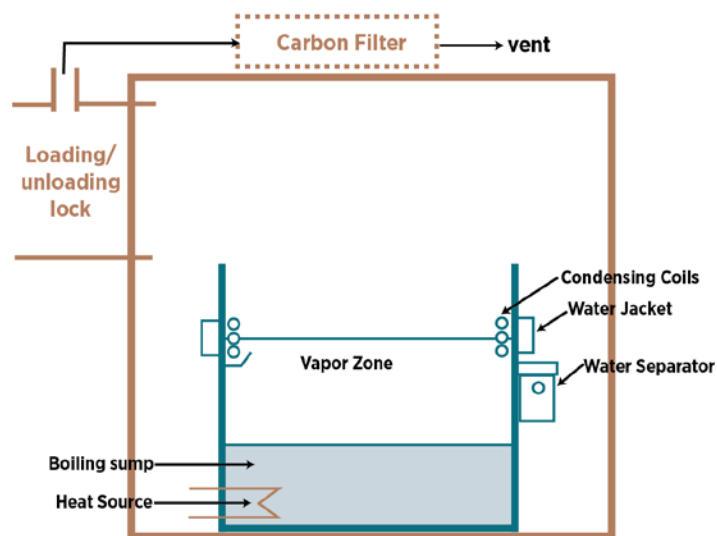


Figure 2-2. Open Top Vapor Degreaser with Enclosure

2.1.3 Closed-Loop Degreasers (Airtight)

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 2-3 illustrates a standard closed-loop vapor degreasing system.

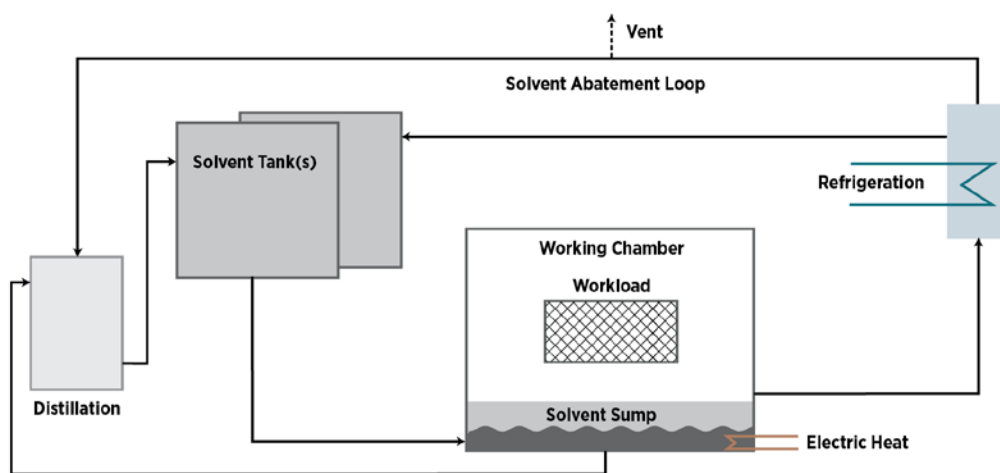


Figure 2-3. Closed-loop/Vacuum Vapor Degreaser

2.1.4 **Airless Degreasers (Vacuum Drying)**

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 (NEWMOA 2001, EPA 2001a, Kanegsberg and Kanegsberg 2011).

2.1.5 **Airless Vacuum-to-Vacuum Degreasers**

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 (NEWMOA 2001, Durkee 2014). This type of system was reported to emit less than 1 gal/month of solvent vapor. Users of these systems have also reported using the equipment for over five years without solvent changeout (Kanegsberg and Kanegsberg 2011).

The general design of vacuum vapor degreasers and airless vacuum degreasers is similar as illustrated in Figure 2-3 for closed-loop systems except that the work chamber is under vacuum during various stages of the cleaning process.

2.2 **In-Line Systems**

In-line systems covers conveyORIZED degreasers and web cleaners. ConveyORIZED degreasers are solvent cleaning machines that use an automated parts handling system, typically a conveyor, to automatically provide a continuous supply of parts to be cleaned. They are usually fully enclosed except for the conveyor inlet and outlet portals. ConveyORIZED degreasers are likely used in similar shop types as batch vapor degreasers except for repair shops, where the number of parts being cleaned is likely not large enough to warrant the use of a conveyORIZED system. 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 (USEPA 1977).

Continuous web cleaning machines differ from typical conveyORIZED degreasers 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). The following subsections describe the various types of conveyORIZED and web degreasers.

2.2.1 Monorail Degreaser

Monorail cleaning systems, shown in Figure 2-4, are typically used when parts are already being transported throughout the manufacturing areas by a conveyor (USEPA 1977). It is most useful for automatic cleaning via solvent spray or vapor (USEPA 1977, Morrison and Murphy 2013). They use a straight-line conveyor to transport parts into the cleaning zone and back out (Morrison and Murphy 2013). 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 (USEPA 1977).

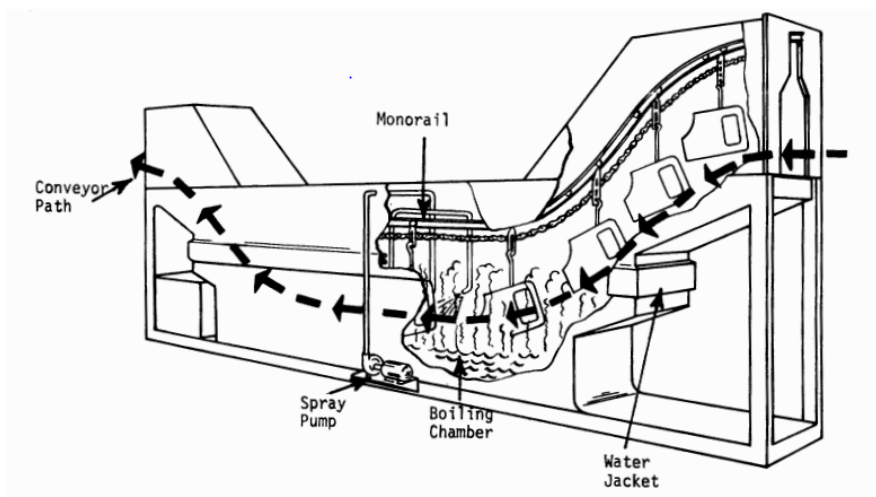


Figure 2-4. Monorail ConveyORIZED Degreaser (USEPA 1977)

2.2.2 Cross-Rod Degreaser

Cross-rod cleaning machines, shown in Figure 2-5, utilize two parallel chains connected by a rod that support the parts throughout the cleaning process (USEPA 1977, Morrison and Murphy 2006). 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 loaded and unloaded manually (USEPA 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 (USEPA 1977, Morrison and Murphy 2006).

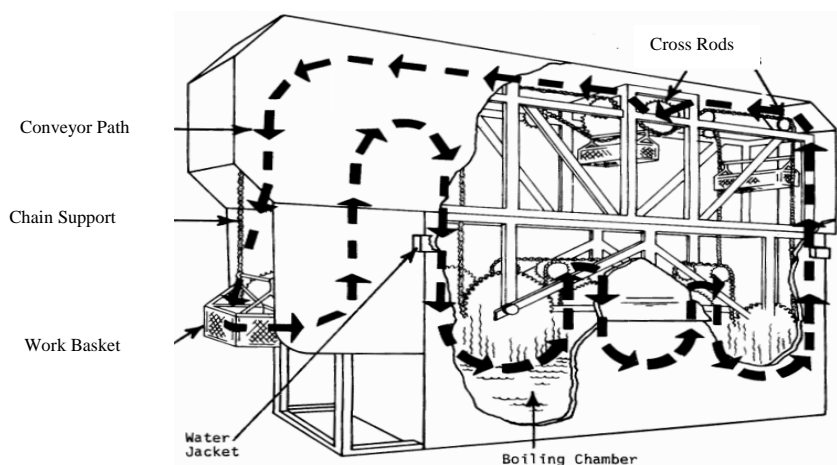


Figure 2-5. Cross-Rod Conveyorized Degreaser (USEPA 1977)

2.2.3 Vibra Degreaser

Vibra cleaning machines (Figure 2-6) have parts fed through a chute that leads to a pan flooded with solvent in the cleaning zone. The pan is connected to a spiral elevator, which are both vibrated continuously throughout the cleaning process. The vibrations cause the parts to travel up the elevator, where the solvent condenses and drying occurs, and eventually out of the machine. The vibrations cause the machine to be very loud and therefore engineering controls must be used to reduce the noise when operating these machines (USEPA 1977, Morrison and Murphy 2006).

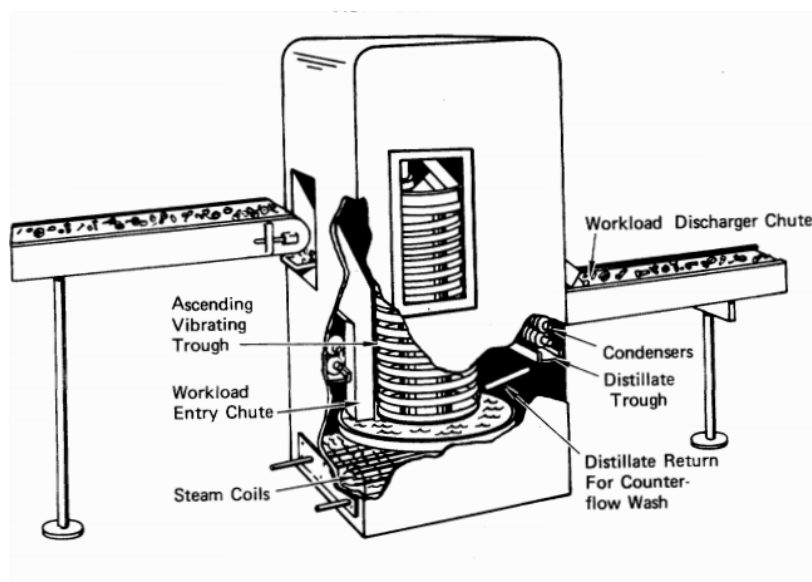


Figure 2-6. Vibra Conveyorized Degreaser (USEPA 1977)

2.2.4 Ferris Wheel Degreaser

Ferris wheel cleaning systems (Figure 2-7) are generally the smallest of all the conveyORIZED degreasers (USEPA 1977). In these systems, parts are manually loaded into perforated baskets or cylinders and then rotated vertically through the cleaning zone and back out (Morrison and Murphy 2013).

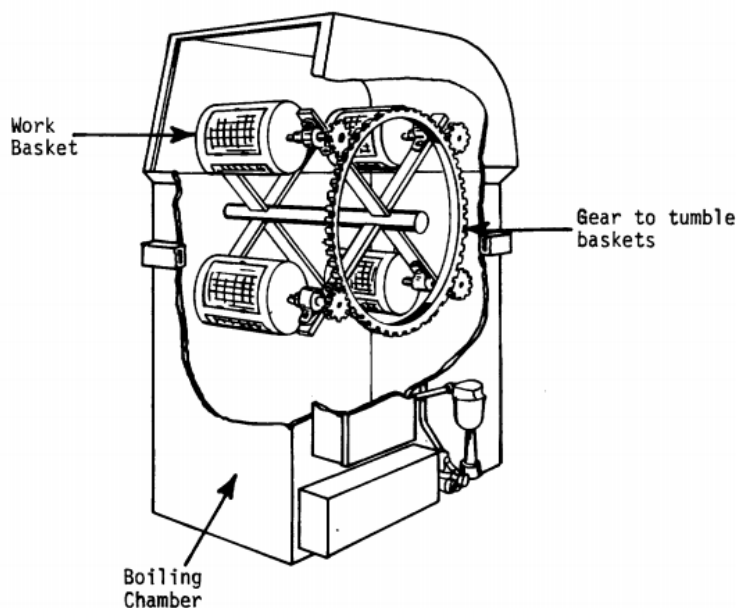


Figure 2-7. Ferris Wheel Conveyorized Degreaser (USEPA 1977)

2.2.5 Belt Degreaser

Belt degreaser cleaning systems (Figure 2-8 and Figure 2-9) 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 (EPA, 1977).

2.2.6 Strip Degreaser

Strip degreaser cleaning machines (Figure 2-8) are exactly the same as belt degreasers except that the belt itself is being cleaned rather than parts being loaded onto the belt for cleaning (EPA, 1977).

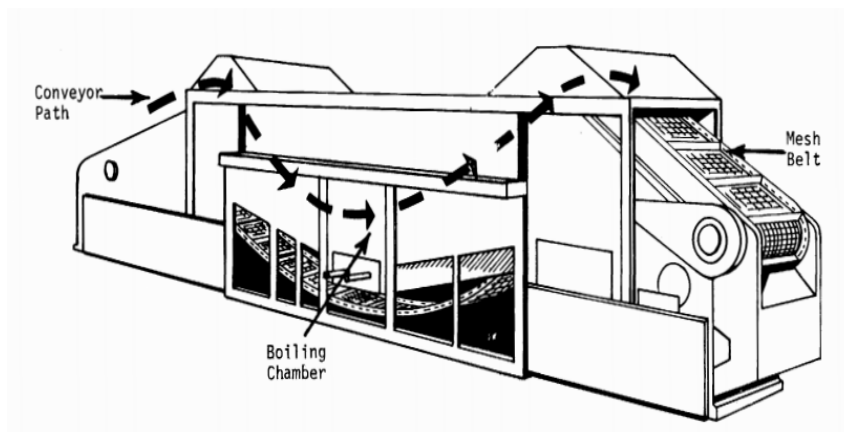


Figure 2-8. Belt/Strip Conveyorized Degreaser (USEPA 1977)



Figure 2-9. Belt Conveyorized Degreaser (Jenfab Aqueous Cleaning Systems 2015)

2.2.7 Circuit Board Degreasers

Circuit Board Degreasers use any of the above conveyorized designs. However, parts are cleaned in three different steps due to the manufacturing processes involved in circuit board production (USEPA 1977).

2.2.8 Continuous Web Cleaning Machines

Continuous web cleaning machines (Figure 2-10) are considered to be a subset of in-line cleaning machines and operate under the same general principles: there is a continuous supply of parts to be cleaned. Continuous web cleaning machines differ from typical conveyorized degreasers in that they are specifically designed for cleaning films, coils, wires, and metal strips. The parts are cleaned at speeds in excess of 11 ft/min and generally entered uncoiled such that the same part is simultaneously entering and exiting the liquid or vapor cleaning zone. The parts are then recoiled or cut (FL DEP). The parts are typically loaded onto rollers that transport the parts through the cleaning zone. The rollers vary in size depending on the type of parts being cleaned. Many continuous web cleaning machines incorporate air knives to improve drying (Kanegsberg and Kanegsberg 2011).

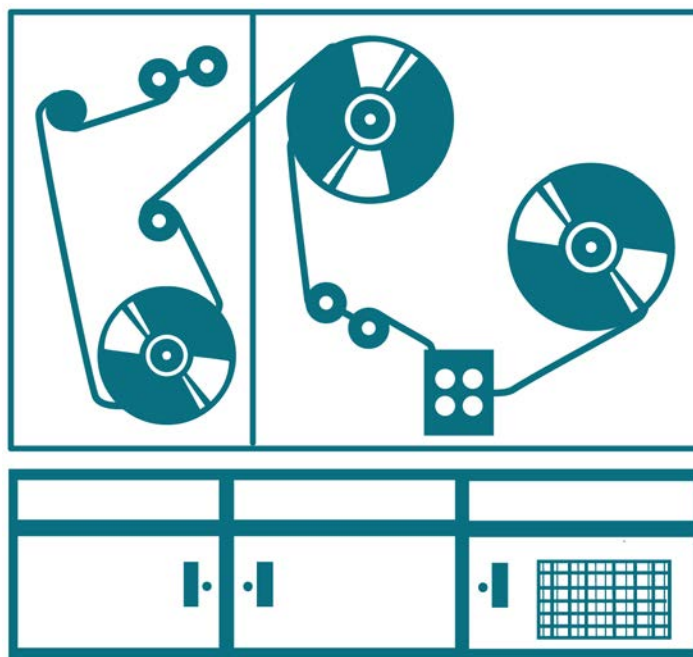


Figure 2-10. Continuous Web Cleaning Machine

2.3 Types of Chemicals

Historically, chlorinated solvents such as TCE, PERC, and methylene chloride have been the standard for vapor phase cleaning. These chemicals are clear, heavy liquids with excellent solvency, and are virtually nonflammable since they have no flash point as determined by standard test methods. In recent years, a number of new solvents have become available. Table 2-1 provides a list of available solvents on the market that are acceptable vapor degreasers. In addition to the list, several manufacturers supply solvent blends for specific purposes. For example, hydrofluorocarbon (HFC) and

hydrofluoroether (HFE) can be blended with trans-1,2,-dichloroethylene to provide additional solvency. In addition, some of these solvents can be mixed to form an azeotrope such that once mixed, stay together in the same ratio throughout boiling, rinsing, and vapor degreasing phases (Kanegsberg and Kanegsberg 2011).

Chemical and physical properties are important considerations when choosing a vapor degreaser for the metal cleaning operation. For example, chemicals with lower boiling point (e.g. methylene chloride) are suitable for cleaning temperature-sensitive parts such as thermal switches or thermometers. The Kauri-butanol (KB) value is a rough measure of solvency power. Chemicals with higher KB-value are more effective in removing heavy organics such as oils and greases, while those with lower KB-value are used in critical cleaning where particle removal and light organics are found. Vapor density is a measure of the weight of the vapor to air. Any chemical selected as a vapor degreasing solvent should be heavier than air to minimize emissions from the degreasing machine (Kanegsberg and Kanegsberg 2011).

Based on the design of the operation, vapor degreasing chemicals are expected to have high volatility, with many chemicals having vapor pressure above 35 mm Hg at room temperature (i.e. highly volatile).

Table 2-1. Physical Properties of Commercially Available Vapor Degreasing Solvent

Chemical	Kauri-Butanol Value	Boiling Point (°C)	Vapor Density	Vapor Pressure at 25°C (mm Hg)
Trichloroethylene (TCE)	129	87	4.53	70
Perchloroethylene (PERC)	90	121	5.76	20
Methylene chloride (MC)	136	39.8	2.93	350
n-Propyl bromide (n-PB or 1-BP)	125	71	4.25	111
HCFC (AK-225 AES)	41	52	7	291
HFC (Vertrel XP)	9.4	52	7.86	253
HFE-711IPA	10	54.8	7.51	207
Acetone	NA	56	2	229
Cyclohexane	58	80.7	2.9	95
Isopropyl alcohol	NA	82	2.1	40
N-methyl pyrrolidone (NMP)	350	204.3	3.4	0.24
p-Limonene	67	154	4.73	2
Trans-1,2-dichloroethylene	117	47.8	3.34	330

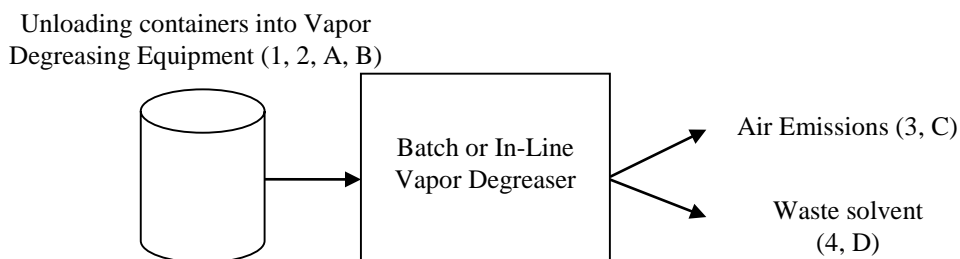
Source: (Kanegsberg and Kanegsberg 2011)

2.4

Release and Exposure Considerations

Figure 2-11 illustrates the typical release and exposure sources from vapor degreasing operation. For batch, open-top degreasers, releases during degreaser operation can occur from solvent dragout or vapor displacement when the substrates to be cleaned are raised out of or lowered into the equipment (Kanegsberg and Kanegsberg 2011). For in-line degreasers, emission points may be limited to the conveyor inlet and outlet portals, if the system is fully enclosed. Additional releases can occur from charging of solvent (degreasing chemical) and disposal of spent solvent.

Similarly, worker exposure can occur while charging the degreasing chemical, cleaning the degreasing machine (i.e. disposing spent solvent), and working in a surrounding area while the machine is in operation. Inhalation exposure to vapor is expected to be the primary exposure route. Dermal exposure to liquid may also occur while handling degreasing chemicals; however, the duration of exposure may be limited for highly volatile chemicals that quickly evaporates from the skin.



Environmental Releases:

1. Release to air from unloading container into vapor degreasing equipment.
2. Release to uncertain media from cleaning of transport container.
3. Release to air during vapor degreasing operation (including release to air during cleaning activities).
4. Release to incineration from equipment cleaning and waste solvent disposal.

Occupational Exposure:

- A. Inhalation exposure to vapor during unloading of containers.
- B. Dermal exposure to liquid during unloading of containers.
- C. Inhalation exposure to vapor during vapor degreasing operations.
- D. Dermal exposure to liquid during equipment cleaning and/or solvent changeout.

Figure 2-11. Typical Release and Exposure Points during the Use of Vapor Degreasing Chemicals

3.0 OVERALL APPROACH AND GENERAL FACILITY ESTIMATES

This ESD presents EPA's standard approach for estimating environmental releases of and occupational exposures to chemicals used as vapor degreasers.

The aim of this section is to utilize available industry-specific information and data to the greatest extent possible in developing any estimation method. Where information is not available to distinguish between different types of vapor degreasing machines, EPA's standard approach estimates release and exposure assuming a batch, open-top vapor degreasing (OTVD) machine because OTVDs are expected to have the highest evaporative losses during degreasing operation. This default assumption will provide conservative, screening-level estimates of release and occupational exposure. The default values cited throughout this document are intended to be used only when appropriate site-specific or chemical-specific information is not available.

This section of the ESD presents general facility calculations for degreasing facilities, which include estimates of the daily use rates of vapor degreasers, the number of facilities performing vapor degreasing operations, and the number of operating days at these facilities.

Section 4 of the ESD presents environmental release assessments from the use of vapor degreasers. This section utilizes the general facility estimates to determine the quantity of chemical released from various points at the degreasing facilities and the most likely media of release for each source.

Section 5 of the ESD presents occupational exposure assessments. Because vapor degreasing chemicals are expected to be volatile, inhalation is expected to be primary route of exposure.

3.1 Introduction to the General Facility Estimates

Through the remainder of this section, EPA utilized available industry and U.S. Census data to estimate the number of vapor degreasing facilities in the U.S. For the purpose of this document, the term "facility" and "site" is used interchangeably. This section also describes the methods used and the assumptions made to estimate the typical use rate for a vapor degreasing chemical and the number of transport containers used annually to transfer a potential chemical of interest.

Table 3-1 summarizes the general facility estimates and the ESD section in which they are discussed.

Table 3-1: Summary of General Facility Parameters

Parameter	Description	ESD Section
TIME _{operating_days}	Number of operating days at a facility that performs vapor degreasing operation (days/yr)	3.2
F _{chem}	Concentration of vapor degreasing chemical as received at the end-use facilities (kg chemical/kg formulation)	3.3
Q _{chem_site_yr}	Annual use rate of vapor degreasing chemical (kg/site-yr)	3.4
Q _{chem_site_day}	Daily use rate of vapor degreasing chemical (kg/site-day)	3.5
N _{sites}	Number of sites using the vapor degreasing chemical (sites)	3.6
N _{container_unload_site_yr}	Number of transport containers unloaded at each site per year (containers/site-yr)	3.7

3.2 Days of Operation (TIME_{operating_days})

Table 3-2 presents the typical operating schedule for vapor degreasing machines. The data were obtained through an analysis of actual equipment operating schedules reported to the 2011 National Emissions Inventory (NEI). As shown in the table, open-top vapor degreasers and conveyorized degreasers typically operate 260 days per year. The data suggests that web cleaning machines operate 312 days per year on average; however, only four data points are available for this subcategory. In lieu of chemical-specific information, EPA recommends assuming **260 days per year operation** as default for batch open-top vapor degreasers (USEPA 2011).

Table 3-2. Reported Vapor Degreaser Operation in the 2011 NEI

Reported Operating Schedule	Batch System		In-line System			
	Open-top Vapor Degreaser ^b		Conveyorized Degreaser ^c		Web Cleaner ^d	
	Mean	Median	Mean	Median	Mean	Median
Hours per Year	3,621	2,080	5,980	7,200	8,040	8,040
Days per Week	5	5	6	6	6	6
Hours per Day	12	8	19	24	24	24
Weeks per Year	50	52	50	52	52	52
Days per Year ^a	266	260 (default)	279	260	312	312

a – Calculated by multiplying the reported days per week by the reported weeks per year for each facility in NEI. The table presents the distribution (mean and median) from the resulting calculations across all facilities. Therefore, the mean number of days per week multiplied by the mean number of weeks per year may not equal to the mean number of days per year presented in the table.

b – There are 397 records of operating data for open-top vapor degreaser in the 2011 NEI.

c – There are 41 records of operating data for conveyorized vapor degreaser in the 2011 NEI.

d – There are 4 data points from 2 unique facilities in the 2011 NEI for web cleaner/degreaser.

Source: (USEPA 2011)

3.3 **Physical Form and Concentration of Vapor Degreasing Chemical (F_{chem})**

The majority of vapor degreasing chemicals are supplied to end use facilities as neat liquids³. In some cases, these chemicals may also be supplied as part of a formulation (i.e. solvent blends). Table 3-3 provides information on the typical concentration of vapor degreasing formulations. Where chemical-specific information on the physical form and concentration is not available, EPA recommends assuming the chemical is the primary solvent at **100 percent concentration (i.e. neat liquid)** as supplied and used in the vapor degreasing machine.

Table 3-3. Composition of Vapor Degreasing Chemicals

Component	Weight %	
	Range	Typical
Primary Solvent*	80-99	>90
Stabilizer	0.05-0.25	0.15
Secondary Solvents (each)	1-10	<2

Source: DuPont Technical Info, 2000 and Petroferm Technical Datasheets, 2001, as referenced in (USEPA 2001).

Note: The composition provided in the table is consistent with Jones and Nicas, which reported a single component ranging from 2.5 to 96.5 percent in the formulation (Jones and Nicas 2005).

3.4 **Annual Use Rate of Vapor Degreasing Chemical ($Q_{\text{chem site yr}}$)**

EPA's 2006 residual risk analysis for the National Emission Standard for Hazardous Air Pollutants (NESHAP) for halogenated solvent cleaning machines contains solvent use rate data collected in maximum achievable control technology (MACT) compliance reports submitted to states and EPA regions. The data include solvent consumption at 96 facilities pre- and post-MACT implementation, covering a wide range of industry sectors including defense, aerospace, metal plating and processing, semiconductor, and electronics. Of the facilities, 78 perform vapor-phase degreasing; 62 of the 78 facilities (79 percent) have only one machine (see Table 3-4).

Table 3-4. Number of Vapor Degreasing Machines per Facility

Number of Facility with Vapor Degreasing Machine	Number of Machine per Facility			
	Minimum	Maximum	Average	Median
78	1	7	1.4	1

Source: (USEPA 2006)

*Includes batch vapor, batch closed loop, in-line, and vapor web machines.

³ In pre-manufacture notices submitted from 1999 to 2015 under EPA's New Chemicals Programs, 80 percent of submissions indicate the vapor degreasing chemical is supplied as a neat liquid.

Table 3-5 presents the estimated machine-level annual solvent use rate for batch and in-line vapor degreasing machines. These use rates represent the makeup solvent rate, i.e. amount of solvent added on an annual basis. As default, this ESD assumes each facility has only one machine and that the machine-level use rate equals the facility-level use rate. Solvent use rates are available for three categories of vapor degreasing machines: batch, in-line, and closed-loop. The MACT document defines closed-loop cleaning system as a subset of batch cleaner with a closed system capable of reusing solvent. Compared to regular batch machines, closed-loop machines have a substantially lower solvent use rate, likely due to the machine's reduced solvent loss during operation.

For batch vapor degreasers, the data suggests a reduction in the average solvent use rate after MACT implementation. In the post-MACT scenario, the overall emissions are reduced due to presence of control equipment, thereby reducing the amount of makeup solvent needed. There is insufficient data for in-line systems to provide an accurate comparison of pre- and post-MACT solvent use rate.

While post-MACT data are likely more representative of chemicals that are a hazardous air pollutant (HAP), or chemicals that are used in existing MACT-compliant machines, pre-MACT data may be representative of use rate for new chemicals not currently subject to the NESHAP. Users of the ESD should refer to the decision logic in Figure 3-1 to determine whether pre- or post-MACT solvent use rate data may be more appropriate for the chemical of interest. Where chemical-specific information is not available, EPA recommends assuming the median (i.e. 50th percentile value) use rate for batch systems, or **2,083 kg/site-yr** as default to estimate annual facility-level use rate.

Table 3-5. Annual Machine-level Solvent Use Rate

Machine Type	Solvent Use Rate (kg/yr) ^a					No. Data Points
	Min	Max	Average	50 th %-tile	95 th %-tile	
<i>Pre-MACT</i>						
Batch ^b	272	23,950	7,580	4,990	20,556	9
Batch, Closed Loop	Not applicable					
In-Line ^c	2,702	2,702	2,702	2,702	2,702	1
<i>Post-MACT</i>						
Batch ^b	78	79,120	6,072	2,083 (default)	25,852	45
Batch, Closed Loop	28	778	403	403	740	2
In-Line ^c	9,281	26,943	18,112	18,112	26,060	2

Source: (USEPA 2006)

a – Represents the use rate for a single solvent; data are for facility-level use rate of trichloroethylene, methylene chloride, perchloroethylene, or 1,1,1-trichloroethane.

b – Batch vapor degreaser.

c – The source document did not specify whether in-line machines involve vapor- or liquid-phase cleaning.

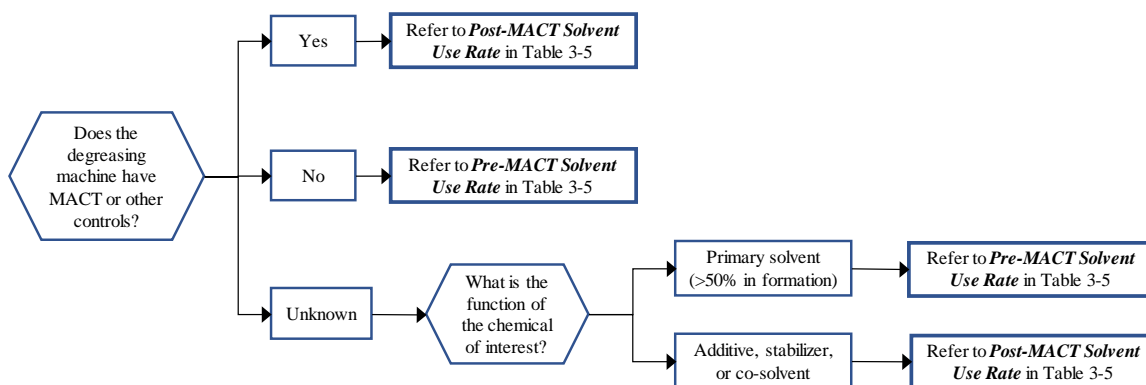


Figure 3-1. Logic Diagram for Determining Solvent Use Rate

3.5 Daily Use Rate of Vapor Degreasing Chemical ($Q_{\text{chem_site_day}}$)

As shown in Table 3-4, the annual and daily use rate of a vapor degreasing chemical depends on the type of degreasing machine and the scale of operation at the end-use facility. Based on the annual use rates shown above ($Q_{\text{chem_site_yr}}$), the daily use rate of a vapor degreasing chemical can be calculated using the following equation:

$$Q_{\text{chem_site_day}} = \frac{Q_{\text{chem_site_yr}}}{\text{TIME}_{\text{operating_days}}} \quad (3-1)$$

Where:

$Q_{\text{chem_site_day}}$	=	Daily use rate of vapor degreasing chemical (kg/site-day)
$Q_{\text{chem_site_yr}}$	=	Annual use rate of vapor degreasing chemical (Default value: 2,083 kg/site-yr)
$\text{TIME}_{\text{operating_day}}$	=	Number of operating days for the degreasing machine (Default: 260 days/yr)

Because this parameter is highly process dependent, estimates for the daily use rate should always be made on a case-specific basis when possible. When information is not readily available, an open-top batch degreaser should be assumed as default to provide a more conservative release and exposure assessment.

3.6 Number of Sites (N_{sites})

The number of facilities using the chemical of interest (N_{sites}) depends on the total annual production of the chemical of interest ($Q_{\text{chem_yr}}$), the daily use rate of the chemical of interest ($Q_{\text{chem_site_day}}$), and the annual operating days ($\text{TIME}_{\text{operating_days}}$). Equation 3-2 demonstrates how the number of degreasing facilities using a chemical of interest could be determined.

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$$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}} \quad (3-2)$$

Where:

N_{sites}^4	=	Number of sites using the vapor degreasing chemical (sites)
$Q_{\text{chem_yr}}$	=	Annual production volume of vapor degreasing chemical (kg chemical/yr)
$Q_{\text{chem_site_day}}$	=	Daily use rate of vapor degreasing chemical (kg chemical/site-day) (see Equation 3-1)
$\text{TIME}_{\text{operating_days}}$	=	Number of operating days for degreasing machines (days/yr) (Default: 260 days/yr)

Note that the calculated value of N_{sites} should not exceed the total number of degreasing facilities known to operate in the United States. The 2006 NESHAP document estimated 3,800 cleaning machines located at 1,900 facilities in the U.S. based on 1998 ICR data (USEPA 2006). Therefore, the calculated value for N_{sites} should not exceed 1,900⁵.

⁴The value for N_{sites} , calculated using Equation 3-2 should be rounded up to the nearest integer value. $Q_{\text{chem_site_day}}$ should then be adjusted for the N_{sites} integer value (to avoid errors due to rounding):

$$Q_{\text{chem_site_day}} = \frac{Q_{\text{chem_yr}}}{N_{\text{sites}} \times \text{TIME}_{\text{operating_days}}}$$

Note: If the number of sites is known, the previous equation may also be used to estimate the resulting average annual production rate for use in subsequent calculations.

⁵ More recently, the EPA estimated approximately 109,966 facilities (establishments) could have degreasing operations; however, this value was determined by estimating the number of facilities within those NAICS industry codes that may have metal processing operations, and is likely to overestimate the actual number of vapor degreasing facilities (USEPA 2016).

Summary of the Relationship of General Facility Parameters

The values for days of operation ($TIME_{operating_days}$), daily use rate of the chemical of interest ($Q_{chem_site_day}$), and number of sites (N_{sites}) are related. This ESD presents one method for estimating N_{sites} using estimated default values for: 1) the annual production quantity of a vapor degreasing chemical; 2) the total number of operating days per year at the end-use site; 3) the mass fraction of the chemical in the transport container; and 4) the daily use rate of a vapor degreasing chemical at a single site.

If N_{sites} and $TIME_{operating_days}$ are known, $Q_{chem_site_day}$ can be calculated directly without using Equation 3-2. This alternative calculation is:

$$Q_{chem_site_day} = \frac{Q_{chem_yr}}{N_{sites} \times TIME_{operating_days}}$$

If N_{sites} is known and $TIME_{operating_days}$ is unknown, EPA recommends that using the default assumption that degreaser operations occur 260 days per year and $Q_{chem_site_day}$ be calculated using the above equation.

EPA recommends calculating the chemical of interest throughput based on the methodology presented in Section 3.5, and compare it to the throughput based on number of sites and operating days, as calculated above.

3.7 Number of Transport Containers Unloaded per Site ($N_{container_unload_site_yr}$)

Vapor degreasing chemicals can be supplied in a variety of container sizes, typically ranging from 1- to 55-gallon containers (Gallade Chemical 2016, Tech Spray 2016). The distribution of container type and sizes is not known, but EPA recommends **assuming chemicals are supplied in 55-gallon drums** where information is not available. The number of transport containers unloaded annually per site can be estimated based on the daily use rate, container size, and the purity of the precursor.

$$N_{container_unload_site_yr} = \frac{Q_{chem_site_day} \times TIME_{operating_days}}{F_{chem} \times V_{container} \times \rho_{formulation} \times 3.785 \frac{L}{gal}} \quad (3-3)$$

Where:

$N_{container_unload_site_yr}$	=	Number of transport containers unloaded at each site per year (containers/site-yr)
$Q_{chem_site_day}$	=	Daily use rate of vapor degreasing chemical (kg/site-day)
F_{chem}	=	Weight fraction of vapor degreasing chemical in the formulation as received (Default: 1 kg chemical/kg formulation)
$TIME_{operating_days}$	=	Number of operating days (days/yr) (Default: 260 days/yr)

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$V_{\text{container}}$	=	Volume of transport container (Default: 55-gallon drums)
$\rho_{\text{formulation}}$	=	Density of chemical formulation (kg/L formulation; Default: 1 kg/L)

4.0 ENVIRONMENTAL RELEASE ASSESSMENTS

This section presents an approach to quantify the releases of vapor degreasing chemicals at the end-use facility. The release sources are discussed in the order that they occur in the process (see Figure 2-11). The most likely media of release (i.e., air, water, landfill, or incineration) are also identified. Table 4-1 presents the release sources, the likely media of release, and the models used to estimate the release. Air release due to evaporative losses from degreasing operation is expected to be the primary source of environmental release.

Table 4-1. Summary of Environmental Releases and Likely Media of Release

Release	Description	Model	Standard EPA Model (✓)
1	Release to air from unloading of transport container	<i>EPA/OAQPS AP-42 Loading Model</i>	✓
2	Release to water, incineration, or land from cleaning of transport container.	<i>EPA/OPPT Drum Residual Model</i>	✓
3	Release to air from vapor degreaser machine	<i>User-defined model (see Equation 4-3)</i>	
4	Release to incineration from cleaning degreasing machine and disposing waste solvent disposal	<i>User-defined model (see Equation 4-4)</i>	

OPPT – Office of Pollution Prevention and Toxics.

All release equations below estimate daily release rates for a given site. To estimate annual releases for all sites for a given source, the daily release rates must be multiplied by the number of days of release and by the total number of sites using the vapor degreasing chemical (N_{sites}).

The entire volume of vapor degreasing chemical is expected to be either released to air (i.e. evaporative losses) or disposed/reclaimed in the spent solvent. Therefore, this document presents release estimation method for a 100 percent release scenario.

4.1 Control Technologies

Evaporative losses can be a significant source of air release and worker exposure during vapor degreasing operations. Equipment design changes, add-on controls, and work practices can be made to reduce air releases and associated occupational exposure.

The Halogenated Solvent Cleaning Machine NESHAP (40 CFR Part 63, Subpart T)⁶ provides three general compliance strategies for owners or operators of batch vapor or in-line degreasing machines to meet the emission standard. One compliance option is to meet the control equipment standards, which includes as many as 10 combination of emission control equipment such as freeboard refrigeration devices, freeboard ratio, and working-mode covers. Some of these controls are described below (USEPA 2004, MN TAP 2011, VADEQ 2016):

- **Covers** – Flat or rolling covers can be installed on the top of open-top vapor degreaser to reduce air emissions. Automatic biparting covers that enclose the tank while the work load is being cleaned are also available.
- **Freeboard Refrigeration Device** – Installing refrigerated coils on the freeboard above the primary condenser coils can reduce air emissions from the degreasing tank.
- **Increased Freeboard Ratio** – The freeboard ratio is the height of the freeboard divided by the smallest interior freeboard width. Increasing the freeboard ratio reduces idling emissions.
- **Carbon Adsorption System** – Installing a solvent recovery device such as a carbon adsorption system can capture solvent in the exhaust and reduce emissions into the workplace.

Table 4-2 is a summary of reported emission reduction for several add-on controls. As the table shows, air emissions from vapor degreasing machines can be reduced by up to 80 percent with properly maintained and operated control technology.

Table 4-2. Summary of Reported Air Emission Reduction with Add-on Controls

Type of Control	Reduction in Air Emissions	Source
Adding covers	35 – 50%	(MN TAP 2011)
Refrigerated freeboard coils	20 – 50% (above-freezing coils) 30 – 80% (below-freezing coils)	(VADEQ 2016)
Carbon adsorption system	50%	(Kanegsberg and Kanegsberg 2011)

Note: The post-MACT solvent use rate presented in Table 3-5 already accounts for the reduction in emissions and solvent usage from control technology. A control efficiency should not be applied if post-MACT data are used to estimate solvent use rate.

The European Chlorinated Solvent Association (ECSA) also provides classification of degreasing and surface cleaning machines based equipment configuration and level of control, ranging from Type I open-top machines to Type V machines that are closed, non-vented, and operate under vacuum. Appendix D presents information on ECSA classifications (ECSA 2013).

In addition to the control technologies discussed above, changes in work practices such as reducing room draft from general facility ventilation can also minimize

⁶ For additional information on the NESHAP, see <https://www.epa.gov/stationary-sources-air-pollution/halogenated-solvent-cleaning-national-emission-standards-hazardou-0>

air disturbances around the degreaser, which may reduce excessive diffusion of solvent vapors from the freeboard region.

4.2 **Release to Air from Unloading of Transport Container (Release 1)**

Vapor degreasing chemicals are supplied to the end-use facilities as either neat solvent or as part of a solvent formulation. For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible during transfer.

If the vapor degreasing chemical is volatile, releases to air ($E_{\text{local,air}}$) may occur from the displacement of saturated air when the chemical is transferred from the container to the vapor degreasing machine. The following EPA standard model (included in ChemSTEER) is recommended to estimate fugitive emission to air from unloading activities:

EPA/OAQPS AP-42 Loading Model – this model estimates air release from displacement of saturated vapor during transfer operations, assuming evaporation rate is negligible in comparison to the displacement rate.

The transfer operations model provides worst and typical case estimates for releases and exposures during transfer operations (e.g., transferring liquids from transport containers into storage tanks or mixers). Table 4-3 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Note the default model assumption of negligible evaporation may not be representative for highly volatile chemicals. Therefore, this model may not accurately estimate release for chemicals with vapor pressures above 35 mmHg. EPA does not otherwise have a standard method for estimating air release from transfer operations for highly volatile chemicals.

Table 4-3. EPA/OAQPS AP-42 Loading Model Parameter Default Values for Air Releases During Unloading

Input Parameter	Default Values
Saturation Factor	EPA defaults 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (USEPA 2002b) (See Appendix B for alternative default saturation factors)
Frequency of Release	Equal to the lesser of $N_{\text{container_unload_site_yr}}$ or $TIME_{\text{operating_days}}$, See Sections 3.7.
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Operating Hours for the Activity	Number of containers per site, per day (see Section 3.7) divided by the unload rate (USEPA 2002b) (default unload rates are found in Appendix B)
Unloading Rate	EPA default 20 containers/hr for volumes between 20 and 1,000 gallons (USEPA 1991) (Alternative default unload rates are found in Appendix B)
Container Volume	Default: 55-gallon drum (208 L) (consistent with Section 3.7)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions

4.3 **Release to Wastewater Treatment, Incineration, or Landfill from Cleaning of Transport Container (Release 2)**

Vapor degreasing chemicals can be supplied in a variety of container sizes, typically ranging from 1- to 55-gallon containers (Gallade Chemical 2016, Tech Spray 2016). The amount of vapor degreasing chemical remaining in transport containers will likely depend on the size of the transport container. Therefore, the following standard EPA models may be used to estimate container residue releases:

EPA/OPPT Bulk Transport Residual Model may be used for large containers (e.g., totes, tank trucks, rail cars) containing greater than or equal to 100 gallons of liquid;

EPA/OPPT Drum Residual Model may be used for drums containing between 20 and 100 gallons of liquid;

EPA/OPPT Small Container Residual Model may be used for liquid containers containing less than 20 gallons; and

Note that these models estimate between 0.2 (bulk containers) and 3 percent (drums) of the received material may be released to the environment. The rationale, defaults, and limitations of these models are further explained in Appendix B. The release estimates are based on the current version of the models. Standard EPA/OPPT models are subject to change; therefore, the current version of the standard EPA/OPPT model should be used.

Where chemical-specific information is not available, vapor degreasing chemicals are assumed to be supplied in 55-gallon drums to maximize the fraction of container residue. The *EPA/OPPT Drum Residual Model* assumes liquids are pumped from drums and that up to 3% (a central tendency of 2.5%) of the liquid originally in the drums remains as residual after unloading. Alternative assumptions include 0.6% high-end and 0.3% central tendency when pouring liquids from drums.

If the number of containers used per site per year ($N_{\text{container_unload_site_yr}}$) is fewer than the days of operation ($\text{TIME}_{\text{operating_days}}$), the days of release equals the number of containers and the daily release is calculated based on the following equation:

$$\text{Elocal}_{\text{container_residue}} = V_{\text{container}} \times \rho_{\text{formulation}} \times F_{\text{chem}} \times F_{\text{container_disp}} \times 1 \frac{\text{container}}{\text{site} - \text{day}} \quad (4-1a)$$

This release will occur over $[N_{\text{container_unload_site_yr}}]$ days/year from $[N_{\text{sites}}]$ sites.

Where:

$\text{Elocal}_{\text{container_residue}}$	Daily release of chemical from container residue (kg chemical/site-day)
$V_{\text{container}}$	Volume of transport container (Default: 208.1 L, equivalent to 55 gal)
$\rho_{\text{formulation}}$	Density of chemical formulation (kg/L formulation; Default: 1 kg/L)
F_{chem}	Weight fraction of the chemical in formulation (Default: 1 kg chemical/kg formulation)
$F_{\text{container_disp}}$	Fraction of chemical remaining in the container as residue (Default: 0.03 kg container residue/kg formulation supplied in drums)

If the number of containers used per site per year ($N_{\text{container_unload_site_yr}}$) is greater than the days of operation, the days of release equal the days of operation, and the average daily release is calculated based on Equation 4-1b. Note this may also be used if a container size is not assumed in Equation 4-1a and the number of containers used per site-year is unknown.

$$\text{Elocal}_{\text{container_residue}} = Q_{\text{chem_site_day}} \times F_{\text{container_disp}} \quad (4-1b)$$

This release will occur over $[\text{TIME}_{\text{operating_days}}]$ days/year from $[N_{\text{sites}}]$ sites.

Where:

$E_{\text{local_container_residue}}$	=	Daily release of chemical from container residue (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily use rate of vapor degreasing chemical (kg chemical/site-day)
$F_{\text{container_disp}}$	=	Fraction of chemical remaining in the container as residue (Default: 0.03 kg container residue/kg formulation supplied in drums)

There is no industry-specific information on container cleaning and waste disposal practices. Because vapor degreasing chemicals are solvents or component of solvent formulations, any residue is likely handled as hazardous wastes and disposed according to RCRA regulations (i.e. incineration). Environmental release and waste management information reported in the 2015 Toxics Release Inventory (TRI) suggests that less than one percent of on-site releases are discharged to water for common degreasing chemicals such as TCE, PERC, and methylene chloride. As such, it is unlikely that releases to water will occur directly at facilities performing vapor degreasing.

In some cases, however, empty containers could be sent to recyclers and reconditioners where they are cleaned and/or water-washed, resulting in trace amount of residue being routed to wastewater treatment. Wastewater treatment sludge may be subsequently landfilled. As conservative, the default release from container cleaning should be assessed to water, incineration, or landfill.

4.4 **Release to Air during Vapor Degreasing Operation (Release 3)**

Evaporative emissions are expected to be the major source of release from vapor degreasing due to the high volatility of the solvents used and the design of the operation. Recent literature estimates that up to 70 percent of solvent in a traditional OTVD can be lost over a year through factors such as air drafts in the area surrounding the machine and disturbances in the solvent/air interface when parts are loaded (Mertens 2010). The study does not further describe how the estimated loss fraction was derived.

Table 4-4 summarizes the solvent loss fraction by machine type as obtained from the 2006 NESHAP document. These loss fractions were calculated by dividing the estimated facility-level post-MACT solvent emissions by the post-MACT solvent use rate, and covers all evaporative emissions that occur at the degreasing facility. On average, 85 percent of solvent used in a batch vapor degreaser could be emitted to air. Similar levels of evaporative losses are observed for in-line degreasers; however, only two data points are available for this degreaser type. Evaporative losses for closed loop machines approach 100 percent; however, closed loop machines also have a substantially lower solvent use rate compared to other machine types, likely because very little solvent is lost during machine operation.

Table 4-4. Summary of Post-MACT Solvent Loss Fraction by Machine Type

Machine Type	Min	Max	Average	50th Percentile	95th Percentile	No. Data Points
Batch Vapor	0.64	1.00	0.85 (default)	0.82	1.00	52
Batch, Closed Loop ^a	0.98	1.00	0.99	0.99	1.00	2
In-Line	0.77	0.89	0.83	0.83	0.88	2

Source: (USEPA 2006)

Note: It is unclear whether the post-MACT solvent use rate accounts for an initial solvent charge, or only reflects ongoing solvent replenishment. In some cases where the estimated post-MACT solvent emission exceeded 100 percent, EPA assumed a solvent loss fraction of 1.0. The document does not contain information to calculate loss fraction for web cleaners.

^a While solvent losses for closed loop degreasers approach 100 percent, actual solvent use rate are lower than other machine types. This is likely due to the fact that little solvent is needed to replenish the system.

In the absence of chemical- or industry-specific data, EPA recommends assuming 85 percent evaporative loss during vapor degreaser operation. If pre-MACT data were previously used to calculate the solvent use rate, the control efficiency (see Table 4-2) can be applied if the specific type of control is known. Equation 4-2 calculates the quantity of the vapor degreasing chemical released to air.

$$E_{\text{local}_{\text{evap}}} = Q_{\text{chem_site_day}} \times LF_{\text{air}} \times (1 - EF_{\text{control}}) \quad (4-2)$$

Where:

$E_{\text{local}_{\text{evap}}}$ =	Daily release of chemical of interest to air due to evaporative losses (kg chemical released/site-day)
$Q_{\text{chem_site_day}}$ =	Daily use rate of chemical of interest (kg chemical/site-day) (Default: see Section 3.5)
LF_{air} =	Fraction of chemical evaporated to air (Default: 0.85 kg chemical released / kg chemical used)
EF_{Control} =	Engineering control efficiency (see Table 4-2 only if pre-MACT solvent use rate data are used; default: 0 for open-top vapor degreaser with no control)

This release will occur over $[TIME_{\text{operating_days}}]$ days/year from each of $[N_{\text{sites}}]$ sites. Where information on the specific equipment design and control technology is not known, an open-top vapor degreaser with no emission control should be assumed as default.

4.5 Release to Air from Equipment Cleaning

The release described in Section 4.4 (Release 3) covers releases to air from all process activities related to the degreasing operation; therefore, this ESD does not separately assess air release from equipment cleaning for volatile chemicals (e.g., the

vapor pressure is > 0.001 torr). Note the use of the *EPA/OPPT Penetration Model* (EPA default for indoor operations) to separately estimate air release from equipment cleaning will likely result in an overestimate, and that the total releases to all environmental media may be greater than the use rate for the chemical of interest.

4.6 **Release to Incineration from Equipment Cleaning and Waste Solvent Disposal (Release 4)**

The degreasing tank is cleaned periodically to replace dirty solvent. The frequency of equipment cleaning and solvent changeout will depend on the type of operation and the facility's volume throughput, and could vary from once in several weeks to less than once per year. For example, a 1994 study estimates an 80-gallon degreasing tank with a 1.5 gallon per day oil loading rate being replaced every two to three weeks, but noted that degreasers used for critical parts cleaning will be cleaned more frequently (Callahan 1994). Another study estimates solvent changeout occurring four times per year (Morrison and Murphy 2006).

Dirty solvent removed from the degreasing machine is usually recycled on-site or sent off-site for reclamation. For recycling and reclaim, distillation yields are on the order of 70 percent, with 30 percent sent off-site for use as a cement kiln fuel (Callahan 1994). Eventually, the vapor degreasing chemical will be either recycled, reused, or disposed as waste solvent. Sludge from the vapor degreaser consisting of the vapor degreasing chemical, oil, tar, metal particles, buffing compounds, and other contaminants will also be disposed as waste. Equation 4-3 calculates the quantity of the vapor degreasing chemical disposed in the spent solvent or waste sludge.

$$E_{\text{local}}_{\text{incin}} = \frac{Q_{\text{chem_site_yr}} - (E_{\text{local}}_{\text{air}} + E_{\text{local}}_{\text{container_residue}}) \times N_{\text{container_unload_site_yr}} - E_{\text{local}}_{\text{evap}} \times \text{TIME}_{\text{operating_days}}}{\text{FT}_{\text{changeout}}} \quad (4-3)$$

Where:

$E_{local,incin}$	=	Daily release of chemical of interest to incineration (kg chemical released/site-day)
$E_{local,air}$	=	Daily release of chemical of interest to air from container unloading (kg chemical released/site-day)
$E_{local,evap}$	=	Daily release of chemical of interest to air due to evaporative losses during degreaser operation (kg chemical released/site-day)
$E_{local,container_residue}^7$	=	Daily release of chemical of interest as container residue (kg chemical released/site-day)
$Q_{chem_site_yr}$	=	Annual use rate of chemical of interest (kg chemical/site-year) (Default: see Section 3.4)
$FT_{changeout}$	=	Frequency of solvent changeout (Default: 26 day/yr)
$N_{container_unload_site_yr}$	=	Number of transport containers unloaded at each site per year (containers/site-yr)
$TIME_{operating_days}$	=	Number of operating days (days/yr) (Default: 260 days/yr)

In lieu of chemical-specific data, EPA recommends assuming the solvent tank changeout occurs **once every two weeks, or 26 times per year**. This release will occur over $[FT_{changeout}]$ days/year from each of $[N_{sites}]$ sites.

⁷ Calculated using either Equation 4-1a (if the number of containers per day is greater than or equal to 1) or Equation 4-1b (if the number of containers per day is less than 1).

5.0 OCCUPATIONAL EXPOSURE ASSESSMENTS

As shown in Figure 2-11, workers may come into contact with the vapor degreasing chemical while unloading chemical from transport containers (i.e. charging the degreasing tank), during degreaser operation, and during cleaning and maintenance activities. This section presents methodologies for estimating occupational exposures during these activities. Table 5-1 summarizes the source, physical state encountered, route, and model used to assess each exposure.

Table 5-1: Summary of Occupational Exposures

Exposure	Description	Route of Exposure/Physical Form	Model	Standard EPA Model (✓)
A	Unloading transport containers	Inhalation exposure to vapor emitted during unloading/filling.	<i>EPA/OPPT Mass Balance Model</i>	✓
B	Unloading transport containers	Dermal exposure to liquid chemical.	<i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model</i>	✓
C	Vapor degreaser operation	Inhalation exposure to vapor emitted from degreaser.	Personal breathing zone monitoring data reported in literature.	
D	Equipment cleaning and solvent changeout	Dermal exposure to liquid chemical.	<i>EPA/OPPT 2-Hand Dermal Immersion with Liquid Model</i>	✓

Because vapor degreasing chemicals are volatile, inhalation exposure to vapor is expected to be the primary exposure route. While dermal exposure to the liquid form will also occur, the volatility of the chemical of interest and the time it takes to evaporate from the skin after dermal contact should be considered when assessing dermal exposure. The duration for dermal exposure for highly volatile chemicals may be short, but exposure may not be negligible if there is repeated dermal contact. Where available, industry-specific data are provided in this section.

5.1 Personal Protective Equipment

Worker exposure to vapor degreasing chemicals can be prevented by the use of engineering controls and best work practices. As a general rule of thumb, PPE is the least preferred method of controlling worker exposure.

A recent monitoring study of worker exposure at five vapor degreasing facilities across several industries indicated that respiratory protection was used at only one of five facilities studied. At this facility, one worker (out of 31) effectively used the respirator for less than 15 to 20 minutes for the entire work shift. Two other workers at the facility briefly wore air-purifying respirator but did not wear it properly and failed quantitative fit testing. Respirator was not used by other employees or in other facilities. The study also reported that only few workers occasionally wore gloves, and those who wore gloves did not choose the proper glove material for the vapor degreasing chemical (Hanley, Petersen et al. 2010).

Based on these observations, worker exposure should be assessed assuming PPE is not worn in lieu of chemical-specific data.

5.2 Number of Workers Per Site

Table 5-2 presents a list of North American Industry Classification System (NAICS) industry sectors that may have vapor degreasing operations. Because degreasing encompasses a large number of industry sectors, not all facilities in the identified NAICS code will perform surface cleaning via vapor degreasing (USEPA 2016).

Table 5-2. List of Industry Sectors Likely to Perform Vapor Degreasing

NAICS Code	NAICS Description
314999	All Other Miscellaneous Textile Product Mills
321113	Sawmills
323111	Commercial Printing (except Screen and Books)
325180	Other Basic Inorganic Chemical Manufacturing
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing
326299	All Other Rubber Product Manufacturing
331110	Iron and Steel Mills and Ferroalloy Manufacturing
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
331410	Nonferrous Metal (except Aluminum) Smelting and Refining
331420	Copper Rolling, Drawing, Extruding, and Alloying
332111	Iron and Steel Forging
332112	Nonferrous Forging
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)
332117	Powder Metallurgy Part Manufacturing
332215	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing
332216	Saw Blade and Handtool Manufacturing
332311	Prefabricated Metal Building and Component Manufacturing
332313	Plate Work Manufacturing
332431	Metal Can Manufacturing
332510	Hardware Manufacturing
332618	Other Fabricated Wire Product Manufacturing
332721	Precision Turned Product Manufacturing

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NAICS Code	NAICS Description
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing
332811	Metal Heat Treating
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring
332912	Fluid Power Valve and Hose Fitting Manufacturing
332913	Plumbing Fixture Fitting and Trim Manufacturing
332919	Other Metal Valve and Pipe Fitting Manufacturing
332994	Small Arms, Ordnance, and Ordnance Accessories Manufacturing
332996	Fabricated Pipe and Pipe Fitting Manufacturing
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing
333132	Oil and Gas Field Machinery and Equipment Manufacturing
333249	Other Industrial Machinery Manufacturing
333318	Other Commercial and Service Industry Machinery Manufacturing
333415	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333921	Elevator and Moving Stairway Manufacturing
333994	Industrial Process Furnace and Oven Manufacturing
333999	All Other Miscellaneous General Purpose Machinery Manufacturing
334220	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing
334413	Semiconductor and Related Device Manufacturing
334416	Capacitor, Resistor, Coil, Transformer, and Other Inductor Manufacturing
334417	Electronic Connector Manufacturing
334419	Other Electronic Component Manufacturing
334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables
334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
335120	Lighting Fixture Manufacturing
335121	Residential Electric Lighting Fixture Manufacturing
335210	Small Electrical Appliance Manufacturing
335312	Motor and Generator Manufacturing
335313	Switchgear and Switchboard Apparatus Manufacturing
335911	Storage Battery Manufacturing
335921	Fiber Optic Cable Manufacturing
335929	Other Communication and Energy Wire Manufacturing
335999	All Other Miscellaneous Electrical Equipment and Component Manufacturing
336320	Motor Vehicle Electrical and Electronic Equipment Manufacturing
336340	Motor Vehicle Brake System Manufacturing
336411	Aircraft Manufacturing
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing
336414	Guided Missile and Space Vehicle Manufacturing
336510	Railroad Rolling Stock Manufacturing
337125	Household Furniture (except Wood and Metal) Manufacturing
337127	Institutional Furniture Manufacturing
339114	Dental Equipment and Supplies Manufacturing
339990	All Other Miscellaneous Manufacturing
339992	Musical Instrument Manufacturing

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NAICS Code	NAICS Description
339995	Burial Casket Manufacturing
339999	All Other Miscellaneous Manufacturing
488111	Air Traffic Control
493110	General Warehousing and Storage
811310	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance

Source: (U.S. Census Bureau 2014)

Table 5-3 presents total employment for the industry sectors identified above that are likely to perform degreasing as part of their business operation. The data show a total of 105,967 facilities with an average of 33 employees per facility. It should be noted that not all 105,977 facilities will perform vapor degreasing operations. In addition, not all employees at the facility will be potentially exposed to the vapor degreasing chemical.

Table 5-3. Total Employment by Size Class within Vapor Degreasing Industry Sectors

Employment Size Class	Total Employment in Affected NAICS			
	Number of Facilities	Number of Employees	Employee per Facility	% of Total Employees
1-4	42,930	80,843	1.9	2%
5-9	19,024	126,169	6.6	4%
10-19	15,614	213,733	13.7	6%
20-49	14,404	449,690	31.2	13%
50-99	6,691	466,522	69.7	13%
100-249	4,880	736,950	151.0	21%
250-499	1,538	522,129	339.5	15%
500-999	660	411,577	623.6	12%
1,000+	226	522,662	2,312.7	15%
Total	105,967	3,530,275	33.3	100%

Source: (Bureau of Labor Statistics 2014, U.S. Census Bureau 2014)

The Bureau of Labor Statistics' (BLS') Occupational Employment Statistics (OES) 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. Table 5-4 identifies the occupations among the affected NAICS codes where the employee may come into contact with the vapor degreasing chemical. Workers may be exposed via the dermal and inhalation routes through direct contact with the vapor degreasing chemical. Other employees (bystander) present at the facility who work in the vicinity of vapor degreasing operation may also be exposed via inhalation of vapor or through incidental contact.

Table 5-4. SOC Codes with Potential Exposure to Vapor Degreaser

SOC	Occupation	Type of Exposure
17-2000	Engineers	Bystander
17-3000	Drafters, Engineering Technicians, and Mapping Technicians	Bystander
19-4000	Life, Physical, and Social Science Technicians	Bystander
49-1000	Supervisors of Installation, Maintenance, and Repair Workers	Bystander
49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	Worker
49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	Worker
49-9010	Control and Valve Installers and Repairers	Worker
49-9020	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	Worker
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	Worker
49-9060	Precision Instrument and Equipment Repairers	Worker
49-9070	Maintenance and Repair Workers, General	Worker
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	Worker
51-1000	Supervisors of Production Workers	Bystander
51-2000	Assemblers and Fabricators	Worker
51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	Worker

Source: (Bureau of Labor Statistics 2014)

Table 5-5 presents the number of potentially exposed employees for the NAICS and SOC combinations identified previously. On average, **approximately 11 employees per facility** are potentially exposed to the vapor degreasing chemical in the industry sectors of interest. See Appendix C for additional details in the methods used to estimate number of potentially exposed workers and bystanders.

Table 5-5. Number of Potentially Exposed Employees within Vapor Degreasing Industry Sectors

Total Employment in Affected NAICS			Employees with Potential Exposure ^a			
Facilities	Number of Employees	Employee per Facility	Workers	Bystanders	Total Exposed	Total Exposed per Facility
105,967	3,530,275	33.3	717,023	443,041	1,160,064	11 (rounded)

Source: (Bureau of Labor Statistics 2014, U.S. Census Bureau 2014)

a – Number of workers and bystanders associated with the relevant SOC codes under the NAICS industry sectors for vapor degreasing.

Note: NAICS codes are available at the 6-digit level. However, some of the BLS employment data are only available at the 4-digit or 5-digit NAICS level. In this case, the employment estimates were refined using total employment data in the U.S. Census' Statistics of U.S. Businesses (SUSB) by adjusting for granularity. This adjustment is done by calculating the employment in specific 6-digit NAICS of interest as a percentage of employment in the BLS 5-digit NAICS.

5.3 Dermal Exposure Duration

Dermal exposure to liquid is expected for workers involved in vapor degreasing operations. Workers may come into contact with the degreasing chemical while unloading the chemical from transport containers into the degreasing tank, or while changing out spent solvent or performing maintenance and cleaning activities. Based on the design of the operation, vapor degreasing chemicals are expected to be volatile, with many chemicals having vapor pressure above 35 mmHg at room temperature (i.e. highly volatile). See Table 2-1 for vapor pressures of several common vapor degreasing chemicals.

Highly volatile chemicals may evaporate rapidly from the hand upon dermal contact. As such, the duration of dermal exposure may not exceed the duration of the activity (USEPA 1991). Table 5-6 below provides the estimated evaporation time for several common vapor degreasing chemicals. The evaporation time is calculated using the volatilization model at a typical skin surface temperature of 32°C (Frasch, Dotson et al. 2014). As shown in the table, a thin layer of semi and highly volatile chemicals will evaporate from the hand within several minutes.

Table 5-6. Estimated Evaporation Time after Dermal Contact for Select Vapor Degreasing Chemicals

Chemical	Molecular Weight (g/mol)	Vapor Pressure, 32°C (mmHg)	Temperature (K)	Vapor Generation Rate, G (g/s)	Skin Loading (mg/cm ²)	2-Hand Surface Area (cm ²)	Evaporation Time (min)
1-BP	123	184	305	0.111	2.1	1,070	0.34
TCE	131	96	305	0.061	2.1	1,070	0.61
PERC	166	27	305	0.020	2.1	1,070	1.84
MC	85	569	305	0.257	2.1	1,070	0.15
Acetone	58	307	305	0.104	2.1	1,070	0.36
Cyclohexane	84	133	305	0.060	2.1	1,070	0.63

Source for molecular weight and vapor pressure: (NIST 2016)

Estimation of Evaporation Time after Dermal Contact

The estimated evaporation time in Table 5-6 is calculated using the following EPA volatilization model (USEPA 1991):

$$G = \frac{8.24E-8 \times MW^{0.835} \times X \times VP \times (1/29 + 1/MW)^{0.25} \times v_z^{0.5} \times A}{T^{0.05} \times d^{0.5} \times P^{0.5}}$$

G	= Vapor generation rate (g/s)
MW	= Molecular weight (g/mol)
X	= Vapor pressure correction factor (EPA/OPPT default: 1; dimensionless)
VP	= Vapor pressure (mmHg)
v _z	= Air velocity (assumed as 59.05 ft/min or 0.3 m/s; (Frasch, Dotson et al. 2014))
A	= Area (cm ² ; calculated based on diameter of pool opening)
T	= Temperature (assumed as 305K, or 32°C for typical skin surface)
d	= Diameter of pool opening (assumed as 16 cm, approximate length of hand)
A	= Area of liquid pool (cm ² ; assumed to approximate a circle)
P	= Pressure (EPA/OPPT Default: 1 atm)

The EPA/OPPT 2-Hand Contact with Liquid Model assumes a skin loading of 2.1 mg/cm² per exposure event and a surface area of 1,070 cm² for two hands. Using default values provided by the model, the evaporation time can be calculated as follow:

$$\text{Evaporation time (min)} = \frac{2.1 \text{ mg/cm}^2 \times 1,070 \text{ cm}^2}{G \times 1,000 \text{ mg/g} \times 60 \text{ s/min}}$$

Despite the short exposure duration, it is not conservative to assume the dermal exposure is negligible, because actual exposure will depend whether the chemical is rapidly absorbed through the skin and whether the exposed surface area is replenished through repeated contacts. For example, the workers may come into dermal contact with a specified amount of vapor degreasing chemical after unloading a drum containing the chemical into the solvent tank. Even though the chemical on the hands will quickly evaporate, the worker may be exposed repeatedly if he or she unloads additional drums throughout the day.

As such, this ESD recommends that users follow standard EPA/OPPT dermal exposure models to calculate exposure dose, regardless of the chemical volatility. These models calculate exposure dose based on the amount of chemical adhering to the skin (i.e. surface loading) after a contact event, assuming one contact event per day.

While the default surface loading in standard EPA/OPPT models may be overly conservative for highly volatile chemicals in a single exposure event, workers may be exposed to highly volatile chemicals repeatedly after initial chemical evaporation from the skin such that multiple exposure events are expected within a work day.

5.4 **Inhalation Exposure to Vapor from Unloading of Transport Containers (Exposure A)**

The method used to calculate inhalation exposure ($EXP_{\text{inhalation}}$) depends on the volatility and the physical state of the chemical of interest. Inhalation exposure to vapor is assumed negligible for nonvolatile chemicals of interest (e.g., the partial pressure of the chemical of interest in the formulation is < 0.001 torr).

For volatile chemicals, workers may be exposed to vapor emitted during unloading of chemicals from transport containers into the solvent tank. For this activity, the *EPA/OAQPS AP-42 Loading Model* can be used to estimate vapor generation from the displacement of saturated vapor during transfer and filling activities. This model calculates vapor generation using the chemical's physical-chemical properties and assume that the rate of evaporation during unloading is negligible compared to the rate of displacement.

The vapor generation rate can then be used with the *EPA/OPPT Mass Balance Inhalation Model* to estimate the amount of chemical inhaled by the worker during unloading activities. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during transfer operations. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5-7 lists the model inputs and default values. Note that the exposure hours per day is equivalent to the operating hours per day for this activity (consistent with Section 4.2 calculations), but EPA assumes an exposure duration of eight hours per day for a given worker if the actual exposure duration or work shift duration is not known. Similarly, EPA assumes that the number of exposure days per year is the same as the number of days of transfer, although EPA often assumes 250 exposure days per year if the number of days of transfer significantly exceeds 250 days per year. These exposure duration maximum defaults are based on full-time employment and considers an individual worker's vacation, sick, and weekend time (i.e., a 40-hour work week over 50 weeks per year).

Table 5-7. EPA/OPPT Mass Balance Model Parameter Default Values During Transfers

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m ³ /hr (USEPA 1991)
Exposure Days	Consistent with the Frequency of Release determined in Section 4.2, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OAQPS AP-42 Loading Model</i> (Section 4.2)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.2, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (USEPA 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Ventilation Rate	EPA defaults 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (default for containers less than 1,000 gallons (USEPA 1991) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

5.5 Dermal Exposure to Liquid from Unloading of Transport Containers (Exposure B)

Workers who unload vapor degreasing chemicals to into degreasing machine are expected to come into contact with the chemical via the dermal route. For this activity, the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* can be used to estimate dermal exposure during unloading activity. The rationale, defaults, and limitations of these models are further explained in Appendix B. The following equation can be used to estimate the potential worker exposure to the chemical of interest:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chemm}} \quad (5-1)$$

This exposure will occur over [$N_{\text{container_unload_site_yr}}$] days per year, up to 250 days per year.

Where:

EXP_{dermal} = Potential dermal exposure to the chemical of interest per day (mg chemical/day)

$Q_{\text{liquid_skin}}$	=	Quantity of liquid component remaining on skin (Defaults: 2.1 mg component/cm ² -incident (high-end) and 0.7 mg component/cm ² -incident (low-end) for routine or incidental contact (USEPA 2000))
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 1,070 cm ² for 2 hands (USEPA 2013))
$N_{\text{exp_incident}}$ ⁸	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem}	=	Mass fraction of the chemical of interest in the vapor degreasing formulation (Default: 1 mg chemical/mg formulation)

When assessing dermal exposure to highly volatile chemicals, the estimated exposure duration (i.e. time for the chemical to evaporate from two hands) and the likelihood of repeated dermal contact should be noted.

5.6 Inhalation Exposure to Vapor during Degreasing Operation (Exposure C)

Employees may be exposed via inhalation of vapor emitted from the degreasing machine while performing degreasing tasks, or while performing other work activities in proximity of the machine. Table 5-8 below summarizes available full-shift personal breathing zone monitoring data for several vapor degreasing chemicals since 1990. The data were collected across 7 studies and 14 facilities. Most studies involved exposure monitoring at facilities that operated one or more batch vapor degreasers (typically open-top); two studies did not report the specific type of degreaser present.

The data cover employees who directly operate the vapor degreaser (workers), as well as employees who perform work near the degreasing area (bystanders). The studies do not contain sufficient detail on all job activities for the employees monitored to enable a breakdown analysis of worker and bystander exposure. None of the exposure level measured exceeded the applicable OSHA Permissible Exposure Limit (PEL) for the chemical being monitored. However, exposure to TCA was found to approach 200 ppm in some cases.

⁸Only one contact per day ($N_{\text{exp_incident}} = 1$ event/worker-day) is assumed because $Q_{\text{liquid_skin}}$, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (i.e., wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

Table 5-8. Summary of Personal Breathing Zone Concentrations for Vapor Degreasing reported in Literature since 1990

Chemical	MW (g/mol)	VP at 20°C (mmHg)	Full-shift TWA (ppm)					Data Points	OSHA PEL
			Min	Max	Average	50th %-tile	95th %-tile		
1,1,1-trichloroethane (TCA)	133	100	1.92	198	112	110	191	22	350 ppm TWA
1-bromopropane (1-BP)	123	146	0.01	74.0	13.2	6.50	48.7	147	None
1, 4-Dioxane	88	29	2.00	13.3	4.00	3.30	6.46	20	100 ppm TWA
Tetrachloroethylene (PERC)	166	14	0.03	5.30	2.66	3.00	5.09	15	100 ppm TWA
Trichloroethylene (TCE)	131	58	4.50	5.2	4.9	4.9	5.2	2	100 ppm TWA
All Data			0.01	198	22.0	5.60	110.0	206	
<i>All Data Excluding TCA</i>			0.01	74	11.3	4.80 (typical)	44.0 (high-end)	184	

MW – Molecular weight.

VP – Vapor pressure.

OSHA PEL – OSHA Permissible Exposure Limit at time of study.

Source: (NIOSH 1985, NIOSH 1986, NIOSH 1986, NIOSH 1987, NIOSH 1987, NIOSH 1987, NIOSH 1989, NIOSH 1991, NIOSH 1992, NIOSH 1992, NIOSH 1992, NIOSH 1994, NIOSH 1994, NIOSH 1994, NIOSH 1994, NIOSH 1995, NIOSH 1998, NIOSH 2001, NIOSH 2003, USEPA 2006)

While actual measured breathing zone concentrations may be impacted by several factors, including the number and type of vapor degreasing machines, presence of engineering control, and duration of vapor degreasing operation, chemicals with higher volatility evaporate more readily into the workplace air, generally resulting in higher worker breathing zone concentrations. EPA recommends the user compares the molecular weight and vapor pressure for the chemical of interest to the available surrogate data in Table 5-8 to determine the appropriate worker exposure level. In lieu of chemical-specific data, EPA recommends assessing an **exposure concentration of 4.80 ppm (typical) to 44.0 ppm (high-end)** based on all available data reported in literature. The data excludes TCA, because TCA is no longer used in vapor degreasing. Data prior to 1990 are excluded from the summary as dated exposure information may not be representative of present-day exposure levels. EPA recommends assuming workers are exposed for the entire duration of the work shift, **or 8 hours per day**.

5.7 Inhalation Exposure to Vapor from Equipment Cleaning

The exposure described in Section 5.6 (Exposure C) covers potential inhalation exposure from all degreasing-related activities; therefore, this ESD does not separately assess inhalation exposure to vapor for workers during equipment cleaning.

5.8 **Dermal Exposure to Liquid from Equipment Cleaning and Solvent Changeout (Exposure D)**

Workers may be exposed to the vapor degreasing chemical via the dermal route while draining, cleaning, and performing maintenance on the solvent tank. Workers have been reported to reach into the solvent bath area while fixing broken machine parts (CSAC 2016), which could lead to substantial dermal exposure when the worker's hands are immersed in the degreasing solvent. To assess exposure during this activity, the *EPA/OPPT 2-Hand Dermal Immersion with Liquid Model* can be used. The model estimates potential worker exposure using the following equation:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chemm}} \quad (5-2)$$

This exposure will occur over [FT_{changeout}], or 26 days per year.

Where:

- EXP_{dermal} = Potential dermal exposure to the chemical of interest per day (mg chemical/day)
- Q_{liquid_skin} = Quantity of liquid degreasing formulation remaining on skin (Defaults: 10.3 mg component/cm²-incident (high-end) and 1.3 mg component/cm²-incident (low-end) for routine or incidental contact (USEPA 2000))
- AREA_{surface} = Surface area of contact (Default: 1,070 cm² for 2 hands (USEPA 2000))
- N_{exp_incident} = Number of exposure incidents per day (Default: 1 incident/day)
- F_{chem} = Mass fraction of the chemical of interest (Default: 1 mg chemical/mg formulation) (See Section 3.3)

6.0 SAMPLE CALCULATIONS

This section presents an example of how the equations described in Sections 3 through 5 may be used to estimate releases of and exposures to a chemical used in vapor degreasing. The default values used in these calculations are presented in Sections 3, 4, and 5 and should be used only in the absence of site-specific information. Sample calculations are based on the following assumptions:

1. Vapor degreasing chemical production volume ($Q_{\text{chem_yr}}$) is 50,000 kg chemical/yr.
2. The chemical is a liquid and is received at end-use site neat, or 100 percent by weight ($F_{\text{chem}} = 1.0$).
3. The end use occurs at 25 sites.
4. The chemical has a molecular weight of 120 g/mol and vapor pressure of 45 torr at room temperature.

6.1 General Facility Estimates

6.1.1 Days of Operation ($\text{TIME}_{\text{operating_days}}$)

If specific information is not available to estimate the days of operation ($\text{TIME}_{\text{operating_days}}$), a default value of 260 days per year should be assumed.

6.1.2 Daily Use Rate of Vapor Degreasing Chemical ($Q_{\text{chem_site_day}}$)

The daily use rate of a vapor degreasing can be calculated using the Equation 3-1 based on the default use rate for a batch open-top vapor degreaser.

$$\begin{aligned} Q_{\text{chem_site_day}} &= \frac{Q_{\text{chem_site_yr}}}{\text{TIME}_{\text{working_days}}} \\ Q_{\text{chem_site_day}} &= \frac{2,083 \text{ kg/site - yr}}{260 \text{ day/yr}} = 8.01 \frac{\text{kg}}{\text{site - day}} \end{aligned} \quad (3-1)$$

Where:

$Q_{\text{chem_site_day}}$	=	Daily use rate of vapor degreasing chemical (kg/site-day)
$Q_{\text{chem_site_yr}}$	=	Annual use rate of vapor degreasing chemical (Default: 2,083 kg/site-yr for batch systems, post-MACT)
$\text{TIME}_{\text{operating_day}}$	=	Number of operating days (Default: 260 days/yr)

For the assumptions in the example, the chemical use rate is 7.69 kg/site-day.

6.1.3 Number of Sites (N_{sites})

The number of end-use facilities using the chemical of interest (N_{sites}) can be estimated using Equation 3-2:

$$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}} \quad (3-2)$$

$$N_{\text{sites}} = 50,000 \frac{\text{kg}}{\text{yr}} \times \frac{\text{site-day}}{8.01 \text{ kg}} \times \frac{\text{yr}}{260 \text{ day}}$$

$$N_{\text{sites}} = 24 \text{ sites}$$

Where:

N_{sites}	=	Number of sites using the precursor chemical (sites)
$Q_{\text{chem_yr}}$	=	Annual production volume of precursor chemical (kg chemical/yr)
$Q_{\text{chem_site_day}}$	=	Daily use rate of CVD precursor (kg chemical/site-day)
$\text{TIME}_{\text{working_days}}$	=	Number of operating days at semiconductor manufacturing sites (days/yr) (Default: 260 days/yr)

The estimated number of sites using default values for a batch open-top vapor degreaser is 24 sites, which appears to be reasonable when compared to the assumption of 25 sites in the example. For the remaining sample calculations, the assumption of 25 sites and a use rate of 7.69 kg/site-day is used.

6.1.4 Number of Transport Containers Unloaded per Site ($N_{\text{container_unload_site_yr}}$)

The number of transport containers unloaded annually per site can be estimated based on the daily use rate, container size, and the purity of the chemical:

$$N_{\text{container_unload_site_yr}} = \frac{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}}{F_{\text{chem}} \times V_{\text{container}} \times \rho_{\text{formulation}}} \quad (3-3)$$

$$N_{\text{container_unload_site_yr}} = 7.69 \frac{\text{kg}}{\text{site-day}} \times \frac{260 \text{ day}}{\text{yr}} \times \frac{1 \text{ kg formulation}}{1 \text{ kg chemical}} \times \frac{\text{container}}{208 \text{ L}} \times \frac{\text{L}}{1 \text{ kg formulation}}$$

$$N_{\text{container_unload_site_yr}} = 9.6 \text{ (rounded to 10) container/site-yr}$$

Where:

$N_{\text{container_unload_site_yr}}$	=	Number of transport containers unloaded at each site per year (containers/site-yr)
$Q_{\text{chem_site_day}}$	=	Daily use rate of vapor degreasing chemical (kg/site-day)

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F_{chem}	=	Weight fraction of chemical in the formulation as received (Default: 1 kg chemical/kg formulation)
$\text{TIME}_{\text{operating_days}}$	=	Number of operating days (days/yr) (Default: 260 days/yr)
$V_{\text{container}}$	=	Volume of transport container (Default: 208 L container)
$\rho_{\text{formulation}}$	=	Density of chemical formulation (Default: 1kg/L)

6.2 Environmental Releases

6.2.1 Release to Air from Unloading of Transport Container (Release 1)

[Eqn. B-5]

$$Q_{\text{vapor_generation}} = \frac{F_{\text{saturation_factor}} \times \text{MW}_{\text{chem}} \times \left(V_{\text{container}} \times \frac{3785.4 \text{ cm}^3}{\text{gal}} \right) \times \left(\frac{\text{RATE}_{\text{fill}}}{3600 \text{ sec/hour}} \right) \times F_{\text{correction_factor}} \times \left(\frac{\text{VP}_{\text{chem}}}{760 \text{ torr/atm}} \right)}{R \times \text{TEMP}_{\text{ambient}}}$$

Table 6-1. Summary of ChemSTEER Inputs for Release 1

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$\text{MW}_{\text{chem.}}$	g/mol	120
Saturation Factor	$F_{\text{saturation_factor}}$	Dimensionless	Typical = 0.5 Worst Case = 1
Vapor Pressure	$\text{VP}_{\text{chem.}}$	Torr	45
Container Volume	$V_{\text{container}}$	Gal	55
Fill Rate	$\text{RATE}_{\text{fill}}$	containers/hour	20
Temperature	$\text{TEMP}_{\text{ambient}}$	K	298
Vapor Correction Factor	$F_{\text{correction_factor}}$	Dimensionless	1
Gas Constant	R	$\text{Atm} \cdot \text{cm}^3/\text{K} \cdot \text{mol}$	82.05

Therefore:

$$Q_{\text{vapor_generation}} = 1.7 \times 10^{-1} \text{ g/s for typical and } Q_{\text{vapor_generation}} = 3.4 \times 10^{-1} \text{ g/s for worst case}$$

Using $Q_{\text{vapor_generation}}$ calculated in Equation B-5 and the other standard default values presented in Table 4-3 for container unloading, the model then estimates the daily release to air using the following equation:

$$\text{Elocal}_{\text{air}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{Eqn. B-7}]$$

$$\text{Elocal}_{\text{air}} = (1.7 \times 10^{-1} \text{ to } 3.4 \times 10^{-1}) \text{ g chem./sec} \times \left(\frac{10 \text{ containers/site - yr}}{10 \text{ days/yr} \times 20 \text{ containers/hr}} \right) \times \frac{3600 \text{ sec/hr}}{1000 \text{ g/kg}}$$

$E_{\text{local air}} = 3.0 \times 10^{-2}$ to 6.1×10^{-2} kg chem. emitted/site-day
...over 10 days/year from 1 site.

6.2.2 Release to Water, Incineration, or Landfill from Cleaning of Transport Container (Release 2)

Since the number of containers used per site per year ($N_{\text{container_unload_site_yr}}$, Equation 3-3) is fewer than the days of operation ($TIME_{\text{operating_days}}$), the days of release equals the number of containers and the daily release is calculated based on the following equation:

$$E_{\text{local container_residue}} = V_{\text{container}} \times \rho_{\text{formulation}} \times F_{\text{chem}} \times F_{\text{container_disp}} \times 1 \frac{\text{container}}{\text{site - day}}$$
$$E_{\text{local container_residue}} = \frac{208 \text{ L formulation}}{\text{container}} \times \frac{1 \text{ kg}}{\text{L}} \times 1.0 \times \frac{0.03 \text{ kg disposed}}{\text{kg formulation}} \times \frac{1 \text{ container}}{\text{site - day}}$$
$$E_{\text{local container_residue}} = 6.24 \frac{\text{kg chemical disposed}}{\text{site - day}}$$

The release will occur over 10 day/yr.

Media of release: water, incineration, or landfill

6.2.3 Release to Air from Vapor Degreasing Operation (Release 3)

The amount of vapor degreasing chemical released as a result of evaporative losses can be calculated using Equation 4-3:

$$E_{\text{local evap}} = Q_{\text{chem_site_day}} \times LF_{\text{air}} \times (1 - EF_{\text{control}}) \quad (4-2)$$

$$E_{\text{local evap}} = 7.69 \text{ kg/site-day} \times 0.85 \times 1 = 6.54 \text{ kg/site-day}$$

Where:

$E_{\text{local evap}}$	=	Daily release of chemical of interest to air from evaporative losses (kg chemical released/site-day)
$Q_{\text{chem_site_day}}$	=	Daily use rate of chemical of interest (kg chemical/site-day)
LF_{air}	=	Fraction of chemical evaporated to air (Default: 0.85 kg chemical released / kg chemical used)
EF_{Control}	=	Engineering control efficiency (Default: 0 for open-top vapor degreaser with no control)

This release will occur over 260 days/year from each of 25 sites.

Media of release: air.

6.2.4 Release to Incineration from Equipment Cleaning and Waste Solvent Disposal (Release 4)

The amount of vapor degreasing chemical released from equipment cleaning and solvent changeout can be calculated using Equation 4-4. Based on chemical-specific use rate of 2,000 kilograms per site-year (50,000 kg/yr and 25 sites):

$$\text{Elocal}_{\text{incin}} = \frac{Q_{\text{chem_site_yr}} - (\text{Elocal}_{\text{air}} + \text{Elocal}_{\text{container_residue}}) \times N_{\text{container_unload_site_yr}} - \text{Elocal}_{\text{evap}} \times \text{TIME}_{\text{operating_days}}}{\text{FT}_{\text{changeout}}} \quad (4-3)$$

$$\text{Elocal}_{\text{incin}} = \frac{2,000 \text{ kg site/yr} - (0.061 + 6.24) \times 10 \text{ day/yr} - 6.54 \times 260 \text{ day/yr}}{26 \text{ day/yr}}$$

$$\text{Elocal}_{\text{incin}} = 9.1 \text{ kg/site-day}$$

Where:

$\text{Elocal}_{\text{incin}}$	Daily release of chemical of interest to incineration (kg chemical released/site-day)
$\text{Elocal}_{\text{air}}$	Daily release of chemical of interest to air from container unloading (kg chemical released/site-day)
$\text{Elocal}_{\text{evap}}$	Daily release of chemical of interest to air due to evaporative losses during degreaser operation (kg chemical released/site-day)
$\text{Elocal}_{\text{container_residue}}$	Daily release of chemical of interest as container residue (kg chemical released/site-day)
$Q_{\text{chem_site_yr}}$	Annual use rate of chemical of interest (kg chemical/site-year) (Default: see Section 3.4)
$\text{TIME}_{\text{operating}}$	Number of operating days per year (Default: 260 day/yr)
$\text{FT}_{\text{changeout}}$	Frequency of solvent changeout (Default: 26 day/yr)
$N_{\text{container_unload_site_yr}}$	Number of transport containers unloaded at each site per year (containers/site-yr)

This release will occur over 26 days/year from each of 25 sites.

Media of release: incineration.

6.3 Occupational Exposures

6.3.1 Duration of Dermal Contact

Highly volatile chemicals (vapor pressure > 35 torr) may evaporate quickly from the skin, thereby reducing the duration of dermal exposure. If the chemical of interest is highly volatile, the EPA volatilization model can be used to estimate the vapor generation rate (USEPA 1991):

$$G = \frac{8.24E-8 \times MW^{0.835} \times X \times VP \times (1/29 + 1/MW)^{0.25} \times vz^{0.5} \times A}{T^{0.05} \times d^{0.5} \times P^{0.5}}$$

$$G = \frac{8.24E-8 \times 120^{0.835} \times 1 \times 45 \times (1/29 + 1/120)^{0.25} \times 59^{0.5} \times 201}{305^{0.05} \times 16^{0.5} \times 1^{0.5}}$$

$$G = 0.027 \text{ g/s}$$

- G = Vapor generation rate (g/s)
MW = Molecular weight (g/mol)
X = Vapor pressure correction factor (EPA/OPPT default: 1; dimensionless)
VP = Vapor pressure (mmHg)
vz = Air velocity (assumed as 59.05 ft/min or 0.3 m/s; (Frasch, Dotson et al. 2014))
T = Temperature (assumed as 305K, or 32°C for typical skin surface)
d = Diameter of pool opening (assumed as 16 cm, approximate length of hand)
A = Area of liquid pool (cm²; assumed to approximate a circle with diameter d)
P = Pressure (EPA/OPPT Default: 1 atm)

The EPA/OPPT 2-Hand Contact with Liquid Model assumes a skin loading of 2.1 mg/cm² per exposure event and a surface area of 1,070 cm² for two hands. Using default values provided by the model, the evaporation time can be calculated as follow:

$$\text{Evaporation time (min)} = \frac{2.1 \text{ mg/cm}^2 \times 1,070 \text{ cm}^2}{G \times 1,000 \text{ mg/g} \times 60 \text{ s/min}}$$

$$\text{Evaporation time} = 1.40 \text{ minutes}$$

6.3.2 Inhalation Exposure to Vapor from Unloading of Transport Containers (Exposure A)

Inhalation exposure to vapor during container unloading can be calculated using the *EPA/OPPT Mass Balance Inhalation Model* (with vapor generation rate from the *EPA/OAQPS AP-42 Loading Model*):

$$C_v = \text{lesser of } 170,000 \times T \times G / (MW \times Q \times k) \text{ or } 1,000,000 \times X \times VP / 760$$

$$C_v = 47.3 \text{ to } 2,838 \text{ ppm}$$

$$C_m = C_v \times MW / V_m = (47.3 \text{ to } 2,838 \text{ ppm}) \times (120 \text{ g/mol}) / (24.45 \text{ L/mol})$$

$$C_m = 232.1 \text{ to } 13,928 \text{ mg/m}^3$$

$$I = C_m \times b \times h = (232.1 \text{ to } 13,928 \text{ mg/m}^3) \times 1.25 \text{ m}^3/\text{hr} \times 0.0018 \text{ hr/day}$$

$$I = 0.0536 \text{ to } 32.2 \text{ mg/day}$$

...over 250 days/year

6.3.3 Dermal Exposure to Liquid from Unloading of Transport Containers (Exposure B)

The potential for dermal exposure during unloading of transport containers can be calculated using the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem}}$$

$$= \frac{2.1 \text{ mg}}{\text{cm}^2 - \text{incident}} \times 1,070 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times 1$$

$$EXP_{\text{dermal}} = 2,247 \text{ mg/day}$$

...over 250 days/year

6.3.4 Inhalation Exposure to Vapor during Degreasing Operation (Exposure C)

Based on the default values recommended in Section 5.6 and Table 5-6, the exposure concentration is 6.9 (typical) to 44 (high-end) ppm. Therefore:

$$C_m = C_v \times MW / V_m = (6.9 \text{ to } 44 \text{ ppm}) \times (120 \text{ g/mol}) / (24.45 \text{ L/mol})$$

$$C_m = 33.9 \text{ to } 216 \text{ mg/m}^3$$

$$I = C_m \times b \times h = (33.9 \text{ to } 216 \text{ mg/m}^3) \times 1.25 \text{ m}^3/\text{hr} \times 8 \text{ hr/day}$$

$$I = 339 \text{ to } 2,160 \text{ mg/day}$$

...over 250 days/year

6.3.5 Dermal Exposure to Liquid from Equipment Cleaning and Solvent Changeout (Exposure D)

The potential for dermal exposure during equipment cleaning can be calculated using the *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model*:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem}}$$

$$= \frac{10.3 \text{ mg}}{\text{cm}^2 - \text{incident}} \times 1,070 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times 1$$

$$EXP_{\text{dermal}} = 11,021 \text{ mg/day}$$

...over 250 days/year

7.0

DATA GAPS/UNCERTAINTIES AND FUTURE WORK

EPA wishes to make this ESD as detailed and up-to-date as possible, such that the risk-screening assessments reflect current industrial practices. EPA is most interested in obtaining information about the vapor degreasing industry that is characterized as “typical” or “conservative” (i.e., worse case), such that the information can be used to assess a generic site performing vapor degreasing.

This ESD relies heavily on data obtained from the 2011 NEI, and the 2006 EPA Risk Assessment for the halogenated solvent cleaning source category, NIOSH health hazard evaluations, and journal articles. Reviewers should feel free to provide additional information and data that could further enhance and improve the methods described in this ESD, as well as to recommend additional resources that may be useful to the development of this ESD.

The key data gaps are summarized below. Note that the data gaps are listed in order of importance (the first being most important):

1. It is unclear whether the post-MACT solvent consumption data in the 2006 Risk Assessment includes an initial solvent charge (i.e. filling the degreasing tank when purchasing and using a new solvent), or whether the data only reflects ongoing solvent replenish rate. If the data does not include the initial charge, the use of such data to calculate loss fraction to air may be overly conservative.
2. EPA believes container residue is likely handled as a hazardous waste; however, TRI data suggests that some releases to water for vapor degreasing chemicals do occur. In addition, there is some uncertainty on container handling and cleaning practices. Additional information on how containers are typically handled in the industry and the potential release media will be helpful in determining the release media associated with this activity.
3. EPA does not currently have a standard method for quantifying dermal exposure to highly volatile chemicals. While such exposure can be quantified by calculating the dermal absorption dose (i.e. mass of chemical absorbed through the skin), EPA expects that users of this document will not have all parameters needed for such a calculation, such as the permeability coefficient for the chemical of interest. Additional information, data, or methods on quantifying such exposure will be useful in enhancing the dermal exposure assessment approach presented in this ESD.
4. EPA does not currently have industry-specific information on container selection and container handling procedures. It is unclear whether the container type or handling practices will differ depending on the volatility of the chemicals in order to minimize evaporative losses.

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APPENDIX A: ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES

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Table A-1 summarizes the equations introduced in Sections 3, 4, and 5 of this document. These equations may be used in evaluating releases of and exposures to vapor degreasing chemicals. A description of each input variable and associated default is provided in Table A-2.

Table A-1. Vapor Degreaser Release and Exposure Calculation Summary

General Facility Estimates	
Daily Use Rate per Site of Vapor Degreasing Chemical ($Q_{\text{chem_site_day}}$)	
$Q_{\text{chem_site_day}} = \frac{Q_{\text{chem_site_yr}}}{\text{TIME}_{\text{operating_days}}}$	(Eqn. 3-1)
Number of Sites (N_{sites})	
$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}}$	(Eqn. 3-2)
Number of Containers Unloaded per Site ($N_{\text{container_unload_site_yr}}$)	
$N_{\text{container_unload_site_yr}} = \frac{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}}{F_{\text{chem}} \times V_{\text{container}} \times \rho_{\text{formulation}} \times 3.785 \frac{\text{L}}{\text{gal}}}$	(Eqn. 3-3)

Table A-2. Environmental Release Calculation Summary

Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Transfer Operations (Release 1)	Air	EPA/OAQPS AP-42 Loading Model (See Section 4.2)
Container Residue (Release 2)	Water Land Incineration	<p>If $N_{\text{container_unload_site_yr}}$ is less than $TIME_{\text{operating_days}}$:</p> $E_{\text{local}}_{\text{container_residue}} = V_{\text{container}} \times \rho_{\text{formulation}} \times F_{\text{chem}} \times F_{\text{container_disp}} \times 1 \frac{\text{container}}{\text{site} - \text{day}}$ <p style="text-align: right;">(Eqn. 4-1a)</p> <p>This release will occur over $N_{\text{container_unload_site_yr}}$ day/year from $[N_{\text{sites}}]$ sites.</p> <p>If $N_{\text{container_unload_site_yr}}$ is greater than $TIME_{\text{operating_days}}$:</p> $E_{\text{local}}_{\text{container_residue}} = Q_{\text{chem_site_day}} \times F_{\text{container_disp}}$ <p style="text-align: right;">(Eqn. 4-1b)</p> <p>This release will occur over $[TIME_{\text{operating_days}}]$ days/year from $[N_{\text{sites}}]$ sites.</p>
Vapor Degreasing Operation (Release 3)	Air	$E_{\text{local}}_{\text{evap}} = Q_{\text{chem_site_day}} \times LF_{\text{air}} \times (1 - EF_{\text{control}})$ <p style="text-align: right;">(Eqn. 4-2)</p> <p>This release will occur over $[TIME_{\text{operating_days}}]$ days from $[N_{\text{sites}}]$ sites.</p>
Equipment Cleaning and Waste Solvent Disposal (Release 4)	Incineration	$E_{\text{local}}_{\text{incin}} = \frac{Q_{\text{chem_site_yr}} - (E_{\text{local}}_{\text{air}} + E_{\text{local}}_{\text{container_residue}}) \times N_{\text{container_unload_site_yr}} - E_{\text{local}}_{\text{evap}} \times TIME_{\text{operating_days}}}{FT_{\text{changeout}}}$ <p style="text-align: right;">(Eqn. 4-3)</p> <p>This release will occur over $[FT_{\text{changeout}}]$ days from $[N_{\text{sites}}]$ sites.</p>

Table A-3. Occupational Exposure Calculation Summary

Occupational Exposure Calculations	
Number of Workers Exposed Per Site:	
As an estimate, EPA recommends assuming 11 workers per site for all sites, absent site-specific information.	
Inhalation Exposure to Vapor from Unloading of Transport Containers (Exposure A):	
EPA/OPPT Mass Balance Inhalation Model (See Section 5.4)	
Dermal Exposure to Liquid from Unloading of Transport Containers (Exposure B):	
<p style="text-align: center;"><i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chemm}}$ <p style="text-align: right;">(Eqn. 5-1)</p> <p style="text-align: center;">This exposure will occur over $N_{\text{container_unload_site_yr}}$, up to 250 days per year.</p>	
Inhalation Exposure to Vapor during Degreasing Operation (Exposure C):	
User-defined model (see Section 5.6)	
Dermal Exposure to Liquid from Equipment Cleaning and Solvent Changeout (Exposure D):	
<p style="text-align: center;"><i>EPA/OPPT 2-Hand Immersion with Liquid Model</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chemm}}$ <p style="text-align: right;">(Eqn. 5-2)</p> <p style="text-align: center;">This exposure will occur over $FT_{\text{changeout}}$, up to 250 days per year.</p>	

Table A-4. Parameter Declaration and Documentation Summary

Variable	Variable Description	Default Value	Data Source
AREA _{surface}	Surface area of contact (cm ²)	1,070 (2 hands)	(USEPA 2013)
Elocal _{air}	Daily release of vapor degreasing chemical to air from transfer operations (kg chemical/site-day)	Calculated	Section 4.2
Elocal _{container_residue}	Daily release of vapor degreasing chemical from container residue (kg chemical/site-day)	Calculated	Section 4.3
Elocal _{evap}	Daily release of vapor degreasing chemical to air due to evaporative losses (kg/site-day)	Calculated	Section 4.4
Elocal _{incin}	Daily release of vapor degreasing chemical from equipment cleaning and solvent changeout (kg/site-day)	Calculated	Section 4.6
EF _{control}	Engineering control efficiency	0	Section 4.4

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Variable	Variable Description	Default Value	Data Source
EXP _{inhalation}	Inhalation exposure to the chemical of interest per day (mg chemical/day)	Calculated	Sections 5.4, 5.6, 5.7
EXP _{dermal}	Potential dermal exposure to the chemical of interest per day (mg chemical/day)	Calculated	Sections 5.5, 5.8
F _{chem}	Mass fraction of the chemical of interest in the vapor degreasing formulation (kg chemical/kg formulation).	1	Section 3.3
F _{container_disp}	Fraction of vapor degreasing formulation remaining in the container as residue	0.03	(USEPA 2002a)
FT _{changeout}	Frequency of equipment cleaning and solvent changeout (day/yr)	26	Section 4.6
LF _{air}	Fraction of vapor degreasing chemical evaporated to air	0.85	Section 4.4
N _{container_unload_site_yr}	Number of transport containers unloaded at each site per year (containers/site-yr)	Calculated	Section 3.7
N _{exp_incident}	Number of exposure incidents per day (incident/day)	1	(USEPA 2000)
N _{sites}	Number of sites using the chemical of interest (sites).	Calculated	Section 3.6
Q _{chem_yr}	Annual use rate for the chemical of interest (kg chemical/yr)	Calculated	Section 3.6
Q _{chem_site_yr}	Annual use rate for the chemical of interest per site (kg chemical/site-yr)	Calculated	Section 3.4
Q _{chem_site_day}	Daily use rate for the chemical of interest per site (kg chemical/site-day)	Calculated	Section 3.5
Q _{liquid_skin}	Quantity of liquid component remaining on skin (mg/cm ² -incident)	0.7 (low end) 2.1 (high end)	(USEPA 2000)
RATE _{container_unloading}	Container unloading rate (containers/hr)	20 containers/hr (drums)	(USEPA 1991)
RATE _{breathing}	Typical worker breathing rate (m ³ /hr)	1.25	(USEPA 1991)
ρ _{formulation}	Density of the vapor degreasing formulation (kg/L)	1	EPA assumption
TIME _{exposure}	Duration of exposure (hr/day)	8	Appendix B
TIME _{operating_days}	Number of operating days at vapor degreasing facilities (day/yr)	260	Section 3.2
TIME _{unloading_hours}	Number of hours unloading containers per day (hr/day)	8	(USEPA 1991)
V _{container}	Volume of transport container (L/container)	208	Section 4.3

**APPENDIX B: BACKGROUND INFORMATION AND EQUATIONS/DEFAULTS FOR THE
STANDARD RAD ENVIRONMENTAL RELEASE AND WORKER EXPOSURE MODELS**

B.1. INTRODUCTION

This appendix provides background information and a discussion of the equations, variables, and default assumptions for each of the standard release and exposure models used by EPA in estimating environmental releases and worker exposures. The models described in this appendix are organized into the following three sections:

- Section B.2: Chemical Vapor Releases & Associated Inhalation Exposures;
- Section B.3: Container Residue Release Models (non-air); and
- Section B.4: Dermal Exposure Models.

Please refer to the guidance provided in the ESD for estimating environmental releases and worker exposures using these standard models, as it may suggest the use of certain overriding default assumptions to be used in place of those described for each model within this appendix.

This appendix includes a list of the key reference documents that provide the background and rationale for each of the models discussed. These references may be viewed in their entirety through the ChemSTEER Help System. To download and install the latest version of the ChemSTEER software and Help System, please visit the following EPA web site:

<https://www.epa.gov/tsca-screening-tools/chemsteer-chemical-screening-tool-exposures-and-environmental-releases>

B.2. CHEMICAL VAPOR RELEASES & ASSOCIATED INHALATION EXPOSURES

This section discusses the models used by EPA to estimate chemical vapor generation rates and the resulting volatile releases to air and worker inhalation exposures to that chemical vapor. The volatile air release models (discussed in B.2.1) calculate both a vapor generation rate ($Q_{\text{vapor_generation}}$; g/sec) and the resulting daily release rate of the chemical vapors to air. The *EPA/OPPT Mass Balance Inhalation Model* (discussed in Section B.2.2) uses the value of $Q_{\text{vapor_generation}}$, calculated by the appropriate release model, to estimate the resulting inhalation exposure to that released vapor.

B.2.1 Vapor Generation Rate and Volatile Air Release Models

The following models utilize a series of equations and default values to calculate a chemical vapor generation rate ($Q_{\text{vapor_generation}}$; g/sec) and the resulting daily volatile air release rate ($E_{\text{local_air}}$; kg/site-day):

- *EPA/OPPT Penetration Model* – evaporative releases from an exposed liquid surface located indoors;

- *EPA/OPPT Mass Transfer Coefficient Model* – evaporative releases from an exposed liquid surface located outdoors; and
- *EPA/OAQPS AP-42 Loading Model* – releases of volatile chemical contained in air that is displaced from a container being filled.

Each of these models is described in greater detail in the following sections:

B.2.1.1 EPA/OPPT Penetration Model

Model Description and Rationale:

The *EPA/OPPT Penetration Model* estimates releases to air from evaporation of a chemical from an open, exposed liquid surface. This model is appropriate for determining volatile releases from activities that are performed *indoors*¹ or when air velocities are expected to be *less than or equal to 100 feet per minute*.

A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this model and the *Mass Transfer Coefficient Model* against experimentally measured evaporation rates described laminar airflow conditions existing up to 100 feet per minute. The paper compared the *Penetration Model* to experimental evaporation rate data measured under laminar (less than 100 feet per minute) and turbulent (above 100 feet per minute) airflow conditions. While the *Penetration Model* did not provide accurate estimates of evaporation rates under turbulent air flow conditions (relative to the *Mass Transfer Coefficient Model*), the results modeled under laminar flow conditions were found to more closely approximate the experimental data (usually within 20 percent). It is assumed that the conditions of an indoor work area most closely approximate laminar airflow conditions.

The model was originally developed using Fick's second law of diffusion. Model results were tested against experimental results of a study on evaporation rates for 15 compounds studied at different air velocities and temperatures in a test chamber. The experimental data confirmed the utility and accuracy of the model equation. Sample activities in which the *Penetration Model* may be used to estimate volatile releases to air are sampling liquids and cleaning liquid residuals from smaller transport containers (e.g., drums, bottles, pails).

¹Similar air releases from surfaces located at *outdoor* locations (air speeds > 100 ft/min) are calculated using the *Mass Transfer Coefficient Model* (see the description provided in this section of Appendix B).

Model Equations:

The model first calculates the average vapor generation rate of the chemical from the exposed liquid surface using the following equation:

$$Q_{\text{vapor_generation}} = \frac{(8.24 \times 10^{-8}) \times MW_{\text{chem}}^{0.835} \times F_{\text{correction_factor}} \times VP_{\text{chem}} \times \left(\frac{1}{29} + \frac{1}{MW_{\text{chem}}} \right)^{0.25} \times RATE_{\text{air_speed}}^{0.5} \times AREA_{\text{opening}}}{TEMP_{\text{ambient}}^{0.05} \times D_{\text{opening}}^{0.5} \times P_{\text{ambient}}^{0.5}} \quad [\text{B-1}]$$

Where:

- $Q_{\text{vapor_generation}}$ = Average vapor generation rate (g of chemical/sec)
- MW_{chem} = Molecular weight of the chemical of interest (g/mol)
- $F_{\text{correction_factor}}$ = Vapor pressure correction factor (EPA default = 1)¹
- VP_{chem} = Vapor pressure of the chemical of interest (torr)
- $RATE_{\text{air_speed}}$ = Air speed (EPA default = 100 feet/min; value must be ≤ 100 feet/min for this model)
- $AREA_{\text{opening}}$ = Surface area of the static pool or opening (cm^2 ; $B \times D_{\text{opening}}^2 / 4$)
- $TEMP_{\text{ambient}}$ = Ambient temperature (EPA default = 298 K)
- D_{opening} = Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)
- P_{ambient} = Ambient pressure (EPA default = 1 atm)

Note: The factor 8.24×10^{-8} in Equation B-1 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapor generation rate ($Q_{\text{vapor_generation}}$) calculated in Equation B-1, the model then estimates the daily release to air for the activity using the following equation:

$$E_{\text{local_air}} = Q_{\text{vapor_generation}} \times TIME_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{B-2}]$$

Where:

- $E_{\text{local_air}}$ = Daily release of the chemical vapor to air from the activity (kg/site-day)
- $Q_{\text{vapor_generation}}$ = Average vapor generation rate (g of chemical/sec; see Equation B-1)
- $TIME_{\text{activity_hours}}$ = Operating hours for the release activity per day (hours/site-day; See Table B-1 for appropriate EPA default values)

¹The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

References:

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-24 and Appendix K). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.2 EPA/OPPT Mass Transfer Coefficient Model

Model Description and Rationale:

The *EPA/OPPT Mass Transfer Model* estimates releases to air from the evaporation of a chemical from an open, exposed liquid surface. This model is appropriate for determining this type of volatile release from activities that are performed *outdoors*¹ or when air velocities are expected to be *greater than 100 feet per minute*. A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this and the *Penetration Model* against experimentally measured evaporation rates, described laminar airflow conditions existing up to 100 feet per minute. It is assumed that the conditions of an indoor process area most closely approximate laminar air flow conditions, while outdoor conditions approximate turbulent airflow conditions above 100 feet per minute.

As discussed in the draft paper, the model is predicated on the solution of the classical mass transfer coefficient model with the gas-phase mass transfer coefficient estimated by the correlation of Mackay and Matsugu. Results were tested against experimental results on 19 compounds generated by four different experimenters over a wide range of experimental conditions. While the *Mass Transfer Coefficient Model* matched the data well (usually within 20 percent), it was found that the *Penetration Model* (see description in previous section) outperformed the *Mass Transfer Coefficient Model* under laminar flow (i.e., “indoor”) conditions. Therefore, the *Penetration Model* is used as a default for estimating indoor evaporation rates, while the *Mass Transfer Coefficient Model* is used for outdoor rates. Sample activities in which the *Mass Transfer Coefficient Model* may be used to estimate volatile releases to air are cleaning liquid residuals from process equipment and bulk transport containers (e.g., tank trucks, rail cars).

¹Similar air releases from surfaces located at *indoor* locations (air speeds \leq 100 ft/min) are calculated using the *Penetration Model* (see the description provided in this section of Appendix B).

Model Equations:

The model first calculates the average vapor generation rate of the chemical from the shallow pool using the following equation:

$$Q_{\text{vapor_generation}} = \frac{(1.93 \times 10^{-7}) \times MW_{\text{chem}}^{0.78} \times F_{\text{correction_factor}} \times VP_{\text{chem}} \times \left(\frac{1}{29} + \frac{1}{MW_{\text{chem}}} \right)^{0.33} \times RATE_{\text{air_speed}}^{0.78} \times AREA_{\text{opening}}}{TEMP_{\text{ambient}}^{0.4} \times D_{\text{opening}}^{0.11} \times (TEMP_{\text{ambient}}^{0.5} - 5.87)^{2/3}} \quad [\text{B-3}]$$

Where:

$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical of interest/sec)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default = 1) ¹
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{\text{air_speed}}$	=	Air speed (EPA default = 440 feet/min; value must be > 100 feet/min for this model)
$AREA_{\text{opening}}$	=	Surface area of the static pool or opening (cm ² ; $B \times D_{\text{opening}}^2 / 4$)
$TEMP_{\text{ambient}}$	=	Ambient temperature (EPA default = 298 K)
D_{opening}	=	Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)

Note: The factor 1.93×10^{-7} in Equation B-3 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapor generation rate ($Q_{\text{vapor_generation}}$) calculated in Equation B-3, the model then estimates the daily release to air for the activity using the following equation:

$$E_{\text{local_air}} = Q_{\text{vapor_generation}} \times TIME_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{B-4}]$$

Where:

$E_{\text{local_air}}$	=	Daily release of the chemical vapor to air from the activity (kg/site-day)
$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-3)
$TIME_{\text{activity_hours}}$	=	Operating hours for the release activity per day (hours/site-day; See Table B-1 for appropriate EPA default values)

¹The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

References:

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.3 EPA/OAQPS AP-42 Loading Model

Model Description and Rationale:

The EPA's Office of Air Quality Planning and Standards (OAQPS) *AP-42 Loading Model* estimates releases to air from the displacement of air containing chemical vapor as a container/vessel is filled with a liquid. This model assumes that the rate of evaporation is negligible compared to the vapor loss from the displacement.

This model is used as the default for estimating volatile air releases during both loading activities and unloading activities. This model is used for unloading activities because it is assumed while one vessel is being unloaded another is assumed to be loaded. The *EPA/OAQPS AP-42 Loading Model* is used because it provides a more conservative estimate than either the *EPA/OPPT Penetration Model* or the *Mass Transfer Coefficient Model* for unloading activities.

Model Equations:

The model first calculates the average vapor generation rate of the chemical from the displacement during loading/filling operation using the following equation:

$$Q_{\text{vapor_generation}} = \frac{F_{\text{saturation_factor}} \times MW_{\text{chem}} \times \left(V_{\text{cont_empty}} \times \frac{3785.4 \text{ cm}^3}{\text{gal}} \right) \times \left(\frac{\text{RATE}_{\text{fill}}}{3600 \text{ sec/hour}} \right) \times F_{\text{correction_factor}} \times \left(\frac{VP_{\text{chem}}}{760 \text{ torr/atm}} \right)}{R \times \text{TEMP}_{\text{ambient}}} \quad [\text{B-5}]$$

Where:

$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical/sec)
$F_{\text{saturation_factor}}$	=	Saturation factor (See Table B-1 for appropriate EPA default values)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$V_{\text{cont_empty}}$	=	Volume of the container (gallons; see Table B-1 for appropriate EPA default values)
$\text{RATE}_{\text{fill}}$	=	Fill rate (containers/hour; see Table B-1 for appropriate EPA default values)

$F_{\text{correction_factor}}$ = Vapor pressure correction factor (EPA default =1)¹
 VP_{chem} = Vapor pressure of the chemical of interest (torr)
 R = Universal Gas Constant (82.05 atm-cm³/mol-K)
 $TEMP_{\text{ambient}}$ = Ambient temperature (EPA default = 298 K)

Using the vapor generation rate ($Q_{\text{vapor_generation}}$) calculated in Equation B-5, the model then estimates the daily release to air for the activity using the following equation:

$$E_{\text{local_air}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{B-6}]$$

Where:

$E_{\text{local_air}}$ = Daily release of the chemical vapor to air from the activity (kg/site-day)
 $Q_{\text{vapor_generation}}$ = Average vapor generation rate (g of chemical/sec; see Equation B-5)
 $\text{TIME}_{\text{activity_hours}}$ = Operating hours for the release activity per day (hours/site-day; see Table B-1 for appropriate EPA default values)

Reference:

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

¹The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

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Table B-1. Standard EPA Default Values Used in Vapor Generation Rate/Volatile Air Release Models

Activity Type (Location)	V _{cont_empty} (gallons)	D _{opening} (cm)	RATE _{fill} (containers/hour)	F _{saturation_factor}	TIME _{activity_hours} (hours/site-day)
Container-Related Activities (e.g., filling, unloading, cleaning, open surface/evaporative losses):					
Bottles (Indoors)	1 (Range: <5)	5.08 (<5,000 gals)	60	Typical: 0.5 Worst Case: 1	Number of containers handled per site-day) RATE _{fill}
Small Containers (Indoors)	5 (Range: 5 to <20)				
Drums (Indoors)	55 (Range: 20 to <100)		20		
Totes (Indoors)	550 (Range: 100 to <1,000)				
Tank Trucks (Outdoors)	5,000 (Range: 1,000 to <10,000)	7.6 (≥5,000 gals)	2	1	
Rail Car (Outdoors)	20,000 (Range: 10,000 and up)		1		
Equipment Cleaning Activities:					
Multiple Vessels (Outdoors)	Not applicable	92	Not applicable	1	4
Single, Large Vessel (Outdoors)					1
Single, Small Vessel (Outdoors)					0.5
Sampling Activities:					
Sampling Liquids (Indoors)	Not applicable	Typical: 2.5 ^a Worst Case: 10	Not applicable	1	1

Application of Radiation Curable Coatings, Inks, and Adhesives via Spray, Vacuum, Roll, or Curtain Coating
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Table B-1 (Continued)

Activity Type (Location)	V _{cont_empty} (gallons)	D _{opening} (cm)	RATE _{fill} (containers/hour)	F _{saturation_factor}	TIME _{activity_hours} (hours/site-day)
Other Activities:					
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate/air release models described in this section, the ESD will describe the model and provide appropriate default values for the model parameters.			1	24
Batch Operation					Lesser of: (Hours/batch × Batches/site-day) or 24

a - The "typical" diameter default value of 2.5 cm was adopted as a policy decision in 2002, which supersedes the previous default value of 7 cm shown in the 1991 U.S. EPA reference document.

B.2.2 Chemical Vapor Inhalation Model

The following sections describe the EPA standard model for estimating worker inhalation exposures to a chemical vapor, utilizing a vapor generation rate ($Q_{\text{vapor_generation}}$).

B.2.2.1 EPA/OPPT Mass Balance Model

Model Description and Rationale:

The *EPA/OPPT Mass Balance Model* estimates a worker inhalation exposure to an estimated concentration of chemical vapors within the worker's breathing zone. The model estimates the amount of chemical inhaled by a worker during an activity in which the chemical has volatilized and the airborne concentration of the chemical vapor is estimated as a function of the source vapor generation rate ($Q_{\text{vapor_generation}}$). This generation rate may be calculated using an appropriate standard EPA vapor generation model (see Equation B-1, Equation B-3, or Equation B-5) or may be an otherwise known value.

The *EPA/OPPT Mass Balance Model* also utilizes the volumetric ventilation rate within a given space and includes simplifying assumptions of steady state (i.e., a constant vapor generation rate and a constant ventilation rate) and an assumed mixing factor for non-ideal mixing of air. The default ventilation rates and mixing factors provide a typical and worst case estimate for each exposure. The airborne concentration of the chemical cannot exceed the level of saturation for the chemical.

An evaluation of the model was performed against collected monitoring data for various activities (see the 1996 AIHA article). This evaluation confirmed that the Mass Balance Model is able to conservatively predict worker inhalation exposures within one order of magnitude of actual monitoring data and is an appropriate model for screening-level estimates.

Model Equations:

The model first calculates the volumetric concentration of the chemical vapor in air using the following equation:

$$C_{\text{chem_volumetric}} = \frac{(1.7 \times 10^5) \times \text{TEMP}_{\text{ambient}} \times Q_{\text{vapor_generation}}}{\text{MW}_{\text{chem}} \times \text{RATE}_{\text{ventilation}} \times F_{\text{mixing_factor}}} \quad [\text{B-7}]$$

Where:

$C_{\text{chem_volumetric}}$	=	Volumetric concentration of the chemical vapor in air (ppm)
$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-1, Equation B-3, or Equation B-5, as appropriate)
$\text{TEMP}_{\text{ambient}}$	=	Ambient temperature (EPA default = 298 K)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$\text{RATE}_{\text{ventilation}}$	=	Ventilation rate (ft ³ /min; see Table B-2 for appropriate EPA default values)
$F_{\text{mixing_factor}}$	=	Mixing factor (dimensionless; see Table B-2 for appropriate EPA default values)

Note: The factor 1.7×10^5 in Equation B-7 accounts for various unit conversions. See Fehrenbacher and Hummel, 1996, for the derivation of this constant.

Note that the airborne concentration of the chemical vapor cannot exceed the saturation level of the chemical in air. Equation B-8 calculates the volumetric concentration at the saturation level based on Raoult's Law. Use the lesser value for the volumetric concentration of the chemical vapor ($C_{\text{chem_volumetric}}$) calculated in either Equation B-7 or Equation B-8 in calculating the mass concentration of the chemical of interest in the air (see Equation B-9).

$$C_{\text{chem_volumetric}} = F_{\text{correction_factor}} \times VP_{\text{chem}} \times \frac{10^6 \text{ ppm}}{P_{\text{ambient}}} \quad [\text{B-8}]$$

Where:

$C_{\text{chem_volumetric}}$ = Volumetric concentration of the chemical of interest in air (ppm)

$F_{\text{correction_factor}}$ = Vapor pressure correction factor (EPA default = 1)¹

VP_{chem} = Vapor pressure of the chemical of interest (torr)

P_{ambient} = Ambient pressure (Default = 760 torr)

Note: Raoult's law calculates the airborne concentration as a mole fraction. The factor 10^6 in Equation B-8 accounts for the unit conversion from mole fraction to ppm.

The volumetric concentration of the chemical of interest in air (calculated in either Equation B-7 or Equation B-8) is converted to a mass concentration by the following equation:

$$C_{\text{chem_mass}} = \frac{C_{\text{chem_volumetric}} \times MW_{\text{chem}}}{V_{\text{molar}}} \quad [\text{B-9}]$$

Where:

$C_{\text{chem_mass}}$ = Mass concentration of the chemical vapor in air (mg/m^3)

$C_{\text{chem_volumetric}}$ = Volumetric concentration of the chemical vapor in air (ppm, see Equation B-7 or B-8, as appropriate)

MW_{chem} = Molecular weight of the chemical of interest (g/mol)

V_{molar} = Molar volume (Default = 24.45 L/mol at 25°C and 1 atm)

Assuming a constant breathing rate for each worker and an exposure duration for the activity, the inhalation exposure to the chemical vapor during that activity can be estimated using the following equation:

$$EXP_{\text{inhalation}} = C_{\text{chem_mass}} \times RATE_{\text{breathing}} \times TIME_{\text{exposure}} \quad [\text{B-10}]$$

¹The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

Where:

$EXP_{\text{inhalation}}$ = Inhalation exposure to the chemical vapor per day (mg chemical/worker-day)
 $C_{\text{chem_mass}}$ = Mass concentration of the chemical vapor in air (mg/m³; see Equation B-9]
 $RATE_{\text{breathing}}$ = Typical worker breathing rate (EPA default = 1.25 m³/hr)
 $TIME_{\text{exposure}}$ = Duration of exposure for the activity (hours/worker-day; see Table B-2 for appropriate EPA default values (≤ 8 hours/worker-day))

References:

- Fehrenbacher, M.C. and Hummel, A.A.¹. "Evaluation of the Mass Balance Model Used by the EPA for Estimating Inhalation Exposure to New Chemical Substances". *American Industrial Hygiene Association Journal*. June 1996. 57: 526-536.
- U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

¹Note: This reference is currently not available for viewing in the ChemSTEER Help System.

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Table B-2. Standard EPA Default Values Used in the *EPA/OPPT Mass Balance Inhalation Model*

Activity Type (Location)	V _{cont_empty} (gallons)	RATE _{fill} (containers/hour)	RATE _{air_speed} (feet/min)	RATE _{ventilation} ^a	F _{mixing_factor}	TIME _{exposure} (hours/day)
Container-Related Activities (e.g., filling, unloading, cleaning, open surface/evaporative losses):						
Bottles (Indoors)	1 Range: <5	60	100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	Lesser of: (Number of containers handled per site-day)) RATE _{fill} or 8
Small Containers (Indoors)	5 Range: 5 to <20					
Drums (Indoors)	55 Range: 20 to <100					
Totes (Indoors)	550 Range: 100 to <1,000					
Tank Trucks (Outdoors)	5,000 Range: 1,000 to <10,000	2	440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × RATE _{air_speed}) 5,280) ³ (Outdoors)		
Rail Car (Outdoors)	20,000 Range: 10,000 and up	1				
Equipment Cleaning Activities:						
Multiple Vessels (Outdoors)	Not applicable		440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × RATE _{air_speed}) 5,280) ³ (Outdoors)	Typical: 0.5 Worst Case: 0.1	4
Single, Large Vessel (Outdoors)						1
Single, Small Vessel (Outdoors)						0.5

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Activity Type (Location)	V _{cont_empty} (gallons)	RATE _{fill} (containers/hour)	RATE _{air_speed} (feet/min)	RATE _{ventilation} ^a	F _{mixing_factor}	TIME _{exposure} (hours/day)
Sampling Activities:						
Sampling Liquids (Indoors)	Not applicable		100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	1
Other Activities:						
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate models with the <i>Mass Balance Inhalation Model</i> described in this section, the ESD will describe the models and provide appropriate default values for the model parameters.				Typical: 0.5 Worst Case: 0.1	≤8
Batch Operation						

a - If the appropriate vapor generation rate model is the *EPA/OAQPS AP-42 Loading Model* (see Equation B-5) for an outdoor activity, the RATE_{air_speed} should be set to 440 feet/min, as a default in determining the worst case RATE_{ventilation}.

B.3. CONTAINER RESIDUE RELEASE MODELS (NON-AIR)

Model Description and Rationale:

EPA has developed a series of standard models for estimating the quantity of residual chemical remaining in emptied shipping containers that is released to non-air media (e.g., water, incineration, or landfill) when the container is either rinsed or disposed. All of the residue models assume a certain portion or fraction of the chemical remains in the emptied container to be later rinsed or discarded with the empty container.

The default parameters of model are defined based upon the particular size/type of container (e.g., small containers, drums, or large bulk), as well as the physical form of the chemical residue (e.g., liquid or solid). These defaults are based upon data collected during a 1988 EPA-sponsored study of residuals in containers from which materials have been poured or pumped.

Model Equation:

All of the models discussed in this section utilize the following common equation for calculating the amount of chemical residue:

$$E_{\text{local_container_residue_disp}} = F_{\text{container_residue}} \times Q_{\text{total_daily_container}} \quad [\text{B-11}]$$

Where:

$E_{\text{local_container_residue_disp}}$ = Daily release of the chemical residue to water, incineration, or landfill from the cleaning or disposal of empty shipping containers (kg/site-day)

$F_{\text{container_residue}}$ = Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table B-1 for appropriate EPA default values)

$Q_{\text{total_daily_container}}$ = Total (daily) quantity of the chemical contained in the shipping containers prior to emptying (kg of chemical/site-day; see Table B-2 for appropriate EPA default values)

Each model, however, utilizes unique default values within that equation based upon the relative size of the container and the physical form of the chemical residue. These default values are summarized in Table B-1 and Table B-2. The following models are the standard EPA models for estimating container residues:

- *EPA/OPPT Small Container Residual Model;*
- *EPA/OPPT Drum Residual Model;*
- *EPA/OPPT Bulk Transport Residual Model;* and
- *EPA/OPPT Solid Residuals in Transport Containers Model.*

The default frequency with which the container residues are released ($\text{TIME}_{\text{days_container_residue}}$, days/site-year) must be appropriately “paired” with the total daily quantity of chemical contained in the containers ($Q_{\text{total_daily_container}}$) used in calculating the daily

release. Thus, Table B-2 also contains the appropriate EPA default values for
 $TIME_{days_container_residue}$.

References:

U.S. EPA. Chemical Engineering Branch. Memorandum: *Standard Assumptions for PMN Assessments*. From the CEB Quality Panel to CEB Staff and Management. October 1992.

U.S. EPA. Office of Pesticides and Toxic Substances. *Releases During Cleaning of Equipment*. July 1988.

Table B-3. Standard EPA Default Values for Use in the Container Residual Release Models

Chemical Form	Container Type	V _{cont_empty} (gallons)	Model Title	F _{container_residue} ^a
Liquid	Bottle	1 Range: <5	<i>EPA/OPPT Small Container Residual Model</i>	Central Tendency: 0.003 High End: 0.006
	Small Container	5 Range: 5 to <20		
	Drum	55 Range: 20 to <100	<i>EPA/OPPT Drum Residual Model</i>	Central Tendency: 0.025 High End ^b : 0.03 (for <u>pumping</u> liquid out of the drum) Alternative defaults: Central Tendency: 0.003 High End: 0.006 (for <u>pouring</u> liquid out of the drum)
	Tote	550 Range: 100 to <1,000	<i>EPA/OPPT Bulk Transport Residual Model</i>	Central Tendency: 0.0007 High End: 0.002
	Tank Truck	5,000 Range: 1,000 to <10,000		
	Rail Car	20,000 Range: 10,000 and up		
Solid	Any	Any	<i>EPA/OPPT Solid Residuals in Transport Containers Model</i>	0.01

a - These defaults are based on the 1988 EPA study investigating container residue and summarized in the 1992 internal EPA memorandum (see *References* in this section for the citations of these sources).

b - The 1992 EPA memorandum reference document contains the previous default of 0.04 for the high-end loss fraction (F_{container_residue}) for the *Drum Residual Model*; however, this value was superseded by an internal policy decision in 2002. Per 40 CFR 261.7(b)(1) of the Resource Conservation and Recovery Act (RCRA), “a container or an inner liner removed from a container that has held any hazardous wastes, except waste that is a compressed gas or that is identified as an acute hazardous waste...is empty if...(ii) no more than 2.5 centimeters (1 inch) remain on the bottom of the container or liner or (iii)(A) no more than 3 percent by weight of the total capacity of the container remains in the container or inner liner if the container is equal to or less than 110 gallons in size...”. The 3 percent high-end default is consistent with the range of experimental results documented in the 1988 EPA study (see *References* in this section for a citation of this study).

Table B-4. Standard EPA Methodology for Calculating Default $Q_{\text{total_daily_container}}$ and $\text{TIME}_{\text{days_container_residue}}$ Values for Use in the Container Residual Models

Number of Containers Emptied per Day	$Q_{\text{total_daily_container}}$ (kg/site-day)	$\text{TIME}_{\text{days_container_residue}}$ (days/year)
1 or more	(Mass quantity of chemical in each container (kg/container)) × (Number of containers emptied per day)	Total number of operating days for the facility/operation
Less than 1	Mass quantity of chemical in each container (kg/container)	Total number of containers emptied per site-year

B.4. DERMAL EXPOSURE MODELS

Model Description and Rationale:

EPA has developed a series of standard models for estimating worker dermal exposures to liquid and solid chemicals during various types of activities. All of these dermal exposure models assume a specific surface area of the skin that is contacted by a material containing the chemical of interest, as well as a specific surface density of that material in estimating the dermal exposure. The models also assume *no use of controls or gloves* to reduce the exposure. These assumptions and default parameters are defined based on the nature of the exposure (e.g., one hand or two hand, immersion in material, contact with surfaces) and are documented in the references listed in this section.

In the absence of data, the EPA/OPPT standard models for estimating dermal exposures from industrial activities described in this section can be used. The models for exposures to liquid materials are based on experimental data with liquids of varying viscosity and the amount of exposure to hands was measured for various types of contact. Similar assessments were made based on experimental data from exposure to solids.

Model Equation:

All of the standard EPA models utilize the following common equation for calculating worker dermal exposures:

$$\text{EXP}_{\text{dermal}} = \text{AREA}_{\text{surface}} \times Q_{\text{remain_skin}} \times F_{\text{chem}} \times N_{\text{event}} \quad [\text{B-12}]$$

Where:

$\text{EXP}_{\text{dermal}}$	=	Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)
$\text{AREA}_{\text{surface}}$	=	Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm ² ; see Table B-2 for appropriate EPA default values)
$Q_{\text{remain_skin}}$	=	Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm ² -event; see Table B-2 for appropriate EPA default values)
F_{chem}	=	Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
N_{event}^1	=	Frequency of events for the activity (EPA default = 1 event/worker-day)

¹Only one contact per day ($N_{\text{event}} = 1$ event/worker-day) is assumed because $Q_{\text{remain_skin}}$, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (i.e., wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

Each model, however, utilizes unique default values within that equation based upon the nature of the contact and the physical form of the chemical material. These default values are summarized in Table B-9. The following models are the standard EPA models for estimating worker dermal exposures:

- *EPA/OPPT 1-Hand Dermal Contact with Liquid Model;*
- *EPA/OPPT 2-Hand Dermal Contact with Liquid Model;*
- *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model;*
- *EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model;* and
- *EPA/OPPT 2-Hand Dermal Contact with Solids Model.*

For several categories of exposure, EPA uses qualitative assessments to estimate dermal exposure. Table B-5 summarizes these categories and the resulting qualitative dermal exposure assessments.

References:

U.S. EPA. Chemical Engineering Branch. *Options for Revising CEB's Method for Screening-Level Estimates of Dermal Exposure – Final Report*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. June 2000.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

Table B-5. Standard EPA Default Values for Use in the Worker Dermal Exposure Models

Default Model	Example Activities	AREA _{surface} ^a (cm ²)	Q _{remain_skin} ^b (mg/cm ² -event)	Resulting Contact AREA _{surface} × Q _{remain_skin} (mg/event)
Physical Form: Liquids				
<i>EPA/OPPT 1-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> • Liquid sampling activities • Ladling liquid/bench-scale liquid transfer 	535 (1 hand mean)	Low: 0.7 High: 2.1	Low: 380 High: 1,100
<i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> • Maintenance • Manual cleaning of equipment and containers • Filling drum with liquid • Connecting transfer line 	1,070 (2 hand mean)	Low: 0.7 High: 2.1	Low: 750 High: 2,200
<i>EPA/OPPT 2-Hand Dermal Immersion in Liquid Model</i>	<ul style="list-style-type: none"> • Handling wet surfaces • Spray painting 	1,070 (2 hand mean)	Low: 1.3 High: 10.3	Low: 1,100 High: 11,000
Physical Form: Solids				
<i>EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model</i>	<ul style="list-style-type: none"> • Handling bags of solid materials (closed or empty) 	No defaults	No defaults	< 1,100 ^c
<i>EPA/OPPT 2-Hand Dermal Contact with Solids Model</i>	<ul style="list-style-type: none"> • Solid sampling activities • Filling/dumping containers of powders, flakes, granules • Weighing powder/scooping/mixing (i.e., dye weighing) • Cleaning solid residues from process equipment • Handling wet or dried material in a filtration and drying process 	No defaults	No defaults	< 3,100 ²³

a - These default values were adopted in the 2013 EPA updates on screening-level dermal exposure estimates (USEPA 2013) and are the mean values for men taken from the EPA Exposure Factors Handbook, 2011.

b - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived the selected ranges of values for liquid handling activities from: U.S. EPA. A Laboratory Method to Determine the Retention of Liquids on the Surface of Hands. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Exposure Evaluation Division. EPA 747-R-92-003. September 1992.

c - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived values for dermal contact for solids handling activities from: Lansink, C.J.M., M.S.C. Breelen, J. Marquart, and J.J. van Hemmen: Skin Exposure to Calcium Carbonate in the Paint Industry. Preliminary Modeling of Skin Exposure Levels to Powders Based on Field Data (TNO Report V 96.064). Rijswijk, The Netherlands: TNO Nutrition and Food Research Institute, 1996.

Table B-6. EPA Default Qualitative Assessments for Screening-Level Estimates of Dermal Exposure

Category	Dermal Assessment
Corrosive substances (pH>12, pH<2)	Negligible
Materials at temperatures >140°F (60°C)	Negligible
Cast Solids (e.g., molded plastic parts, extruded pellets)	Non-Quantifiable (Some surface contact may occur if manually transferred)
“Dry” surface coatings (e.g., fiber spin finishes, dried paint)	Non-Quantifiable (If manual handling is necessary and there is an indication that the material may abrade from the surface, quantify contact with fingers/palms as appropriate)
Gases/Vapors	Non-Quantifiable (Some contact may occur in the absence of protective clothing)

Source: U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

**APPENDIX C: SUMMARY OF 2015 TOXICS RELEASE INVENTORY DATA FOR COMMON
VAPOR DEGREASING CHEMICALS**

This section summarizes the reported environmental release and waste management information reported under the Toxics Release Inventory (TRI) program for compliance year 2015. TRI data for several common vapor degreasing chemicals are presented below: Trichloroethylene (TCE), Perchloroethylene (PERC), Methylene Chloride (MC); and N-Methylpyrrolidone (NMP). As Table C-1 shows, some industrial and commercial facilities manufacturing, processing, or otherwise using these chemicals reported some releases to water, either as on-site water discharges or off-site transfers to wastewater treatment. However, on-site water discharges are less than one percent of all reported on-site releases. The quantity of waste transferred to off-site wastewater treatment, with the exception of NMP, are less than two percent of all wastes transferred off-site.

More detailed TRI data including breakdowns by industry sectors (NAICS codes) are presented in Table C-2 through Table C-5. Further review of the TRI data suggests that the majority of reported on-site releases are reported by facilities with primary NAICS codes that are unlikely to conduct vapor degreasing operations, when compared to the list of NAICS codes presented in Table 5-2. As an example, for methylene chloride, facilities classified under NAICS 325412 *Pharmaceutical Preparation Manufacturing* reported 2,008 pounds of methylene chloride released to water on-site; these releases make up more than 80 percent of all on-site water releases for the chemical in the 2015 TRI. For PERC, facilities classified under NAICS 324110 *Petroleum Refineries* reported 146 pounds released to water on-site; these releases make up more than 40 percent of all on-site releases to water for this chemical.

Table C-1. Summary of TRI On-site Water Release and Off-site Wastewater Treatment for Common Vapor Degreasing Chemicals

CAS Number	Chemical Name	On-site Releases		Off-site Transfers	
		Water Discharge (lb)	% of Total On-site Release	Wastewater Treatment (lb)	% of Total Off-site Transfer
79-01-6	Trichloroethylene (TCE)	52	<<0.1%	34,975	1.5%
127-18-4	Perchloroethylene (PERC)	349	<<0.1%	9,794	0.1%
75-09-2	Methylene Chloride (MC)	2,366	0.1%	205,264	0.8%
872-50-4	N-Methylpyrrolidone (NMP)	14,092	0.3%	2,552,326	7.4%

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Table C-2. Summary of 2015 TRI On-site Releases and Off-site Waste Transfer for Trichloroethylene

CAS 79016: Trichloroethylene		On-site Releases (lb)						Off-site Transfers (lb)				
NAICS	NAICS Description	# of Forms		Air Emissions		Water Discharges	Land Disposal	Land Disposal	Wastewater Treatment	Incineration	Recycled	Other
		# Form R	# Form A	Fugitive	Stack							
314999	All Other Miscellaneous Textile Product Mills	1	0	18,660	0	0	0	0	0	0	0	0
324110	Petroleum Refineries	2	0	23,000	180	0	0	0	0	1	0	0
325110	Petrochemical Manufacturing	2	0	13,012	0	0	0	2	0	16	0	0
325120	Industrial Gas Manufacturing	1	0	5	0	0	0	0	0	640	0	0
325180	Other Basic Inorganic Chemical Manufacturing	5	0	92,011	8,515	44	0	5	8	42,234	0	0
325199	All Other Basic Organic Chemical Manufacturing	9	1	1,539	456	2	5	0	0	7,899	0	128
325211	Plastics Material and Resin Manufacturing	5	0	1,594	1,036	0	0	0	0	22,980	0	0
325212	Synthetic Rubber Manufacturing	1	0	5,280	0	0	0	0	0	0	0	0
325510	Paint and Coating Manufacturing	1	0	129	451	0	0	0	0	5,153	0	30
325520	Adhesive Manufacturing	5	1	4,156	18,287	0	0	1,754	0	15,849	0	0
325611	Soap and Other Detergent Manufacturing	1	1	156	128	0	0	0	0	8,406	0	900
325612	Polish and Other Sanitation Good Manufacturing	2	0	5	844	0	0	0	0	2,954	0	0
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	8	2	1,446	826	0	0	0	0	25,514	3,716	0
326113	Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing	2	0	438,102	82,545	5	0	0	5	6,393	14	0
326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing	0	1	0	0	0	0	0	0	0	0	0
326199	All Other Plastics Product Manufacturing	1	0	5	5	0	5	0	0	0	0	0
326220	Rubber and Plastics Hoses and Belting Manufacturing	1	0	16,876	0	0	0	0	0	0	0	0
326299	All Other Rubber Product Manufacturing	3	1	23,180	115,500	0	0	750	1	345	2,700	0
327310	Cement Manufacturing	8	1	2,097	681	0	0	4	0	23,593	0	5,289
327992	Ground or Treated Mineral and Earth Manufacturing	1	0	3	0	0	0	0	0	5	4	0
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	6	0	70,828	151,475	0	0	99	0	57,007	72,588	4,633
331420	Copper Rolling, Drawing, Extruding, and Alloying	1	0	69,427	0	0	0	0	0	0	0	0
331491	Nonferrous Metal (except Copper and Aluminum) Rolling, Drawing, and Extruding	1	0	14,034	4,033	0	0	0	0	0	6,892	0
331523	Nonferrous Metal Die-Casting Foundries	2	0	0	13,747	0	0	0	0	0	9,176	0

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332117	Powder Metallurgy Part Manufacturing	1	0	250	9,462	0	0	0	0	1,368	0	0
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)	8	0	17,345	67,339	0	0	0	0	0	70,375	403
332215	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing	1	0	43,573	5,627	0	0	0	0	2,318	0	0
332216	Saw Blade and Handtool Manufacturing	1	0	245	24,280	0	0	0	0	1,001	13,400	0
332321	Metal Window and Door Manufacturing	1	0	148	14,650	0	0	0	0	0	3,088	0
332410	Power Boiler and Heat Exchanger Manufacturing	1	0	96	9,464	0	0	0	0	0	5,365	0
332618	Other Fabricated Wire Product Manufacturing	1	0	2,430	5	0	0	0	0	750	0	0
332721	Precision Turned Product Manufacturing	3	0	52,562	17,691	0	0	0	0	6,445	0	3,922
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing	1	0	13,600	0	0	0	0	0	0	4,000	0
332811	Metal Heat Treating	3	0	20,487	12,090	0	0	0	0	19,143	2,200	0
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	1	0	1	6,956	0	0	0	0	445	0	0
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	11	0	95,393	40,151	0	0	2,405	0	5,797	11,383	5,958
332994	Small Arms, Ordnance, and Ordnance Accessories Manufacturing	1	0	6,175	0	0	0	0	0	0	0	0
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	1	0	5	22,597	0	0	0	0	0	869	0
333132	Oil and Gas Field Machinery and Equipment Manufacturing	1	0	8,910	1,920	0	0	0	0	0	0	0
333515	Cutting Tool and Machine Tool Accessory Manufacturing	2	0	7,285	0	0	0	0	0	0	23,428	0
333911	Pump and Pumping Equipment Manufacturing	1	0	8,795	0	0	0	0	0	13,823	0	0
333996	Fluid Power Pump and Motor Manufacturing	1	0	2,003	0	0	0	0	0	0	7,320	0
334511	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing	1	0	4,209	0	0	0	0	0	0	10,311	0
335312	Motor and Generator Manufacturing	1	0	0	9,053	0	0	0	0	3,166	0	0
335912	Primary Battery Manufacturing	2	0	0	2,041	0	0	0	0	9,163	32,870	0
335991	Carbon and Graphite Product Manufacturing	1	0	250	12,500	0	0	0	5	16,500	0	0
336320	Motor Vehicle Electrical and Electronic Equipment Manufacturing	1	0	9,398	0	0	0	0	0	1,162	0	0
336340	Motor Vehicle Brake System Manufacturing	1	0	700	13,000	0	0	0	0	0	4,600	0
336411	Aircraft Manufacturing	4	0	79,154	5,930	0	0	3,556	0	15,524	64,865	0
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing	3	0	11,960	14,572	1	0	0	1	24,011	1,294	0
336414	Guided Missile and Space Vehicle Manufacturing	1	0	0	471	0	0	0	0	0	615	0
339114	Dental Equipment and Supplies Manufacturing	1	0	9,160	0	0	0	4,318	0	0	2,122	0

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424690	Other Chemical and Allied Products Merchant Wholesalers	6	14	381	422	0	0	332	0	674	0	0
424710	Petroleum Bulk Stations and Terminals	0	2	0	0	0	0	0	0	0	0	0
562211	Hazardous Waste Treatment and Disposal	16	0	883	696	0	48,236	663	34,954	1,564,231	477	3,610
562213	Solid Waste Combustors and Incinerators	1	0	0	1	0	0	0	0	622	0	0
	TOTAL	148	24	1,190,943	689,627	52	48,246	13,887	34,975	1,905,130	353,673	24,872

Table C-3. Summary of 2015 TRI On-site Releases and Off-site Waste Transfer for Perchloroethylene

CAS 000127184: Perchloroethylene (Tetrachloroethylene)		On-site Releases (lb)						Off-site Transfers (lb)				
NAICS	NAICS Description	# of Forms		Air Emissions		Water Discharges	Land Disposal	Land Disposal	Wastewater Treatment	Incineration	Recycled	Other
		# Form R	# Form A	Fugitive	Stack							
212393	Other Chemical and Fertilizer Mineral Mining	1	0	0	0	0	0	0	0	0	0	0
221112	Fossil Fuel Electric Power Generation	1	0	4	0	0	0	0	0	0	0	0
314999	All Other Miscellaneous Textile Product Mills	1	0	28,240	0	0	0	0	0	0	0	0
324110	Petroleum Refineries	67	2	14,694	13,736	146	23	1,746	265	8,168	1,047	1,077
324191	Petroleum Lubricating Oil and Grease Manufacturing	2	1	261	0	0	0	0	153	10,813	0	0
325110	Petrochemical Manufacturing	6	0	2,580	7	0	0	5	0	131	17	0
325120	Industrial Gas Manufacturing	2	0	12,936	653	18	0	0	0	40,698	0	0
325180	Other Basic Inorganic Chemical Manufacturing	3	0	31,014	43,387	55	0	17	76	137,605	0	0
325199	All Other Basic Organic Chemical Manufacturing	14	1	19,160	11,993	34	42	0	0	617,638	0	734
325211	Plastics Material and Resin Manufacturing	5	0	1,031	1,745	0	0	0	0	96,149	0	0
325311	Nitrogenous Fertilizer Manufacturing	1	0	0	0	0	0	0	0	0	0	0
325510	Paint and Coating Manufacturing	2	0	30	372	0	0	250	0	3,961	0	20
325520	Adhesive Manufacturing	5	0	1,355	10,144	0	0	0	1,485	78,147	628,454	1,459
325611	Soap and Other Detergent Manufacturing	3	0	161	55	0	0	0	0	10,994	0	1,177
325612	Polish and Other Sanitation Good Manufacturing	2	1	752	66	0	0	345	0	0	0	0
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	11	2	5,547	1,700	96	0	251	1	73,869	6,321	9,329
326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing	0	1	0	0	0	0	0	0	0	0	0
327310	Cement Manufacturing	10	1	238	344	0	0	8	0	7,671	0	843
327992	Ground or Treated Mineral and Earth Manufacturing	1	0	12	2	0	0	0	0	22	18	0

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332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)	1	0	0	4,939	0	0	0	0	10,576	22,144	0
332215	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing	1	0	1,200	11,100	0	0	0	0	0	0	2,400
332721	Precision Turned Product Manufacturing	1	0	5,641	0	0	0	962	0	0	0	0
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	1	0	1,124	2,413	0	0	0	0	0	7,700	0
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	2	0	0	12,949	0	0	0	0	0	8,305	0
332992	Small Arms Ammunition Manufacturing	1	0	1,924	9,620	0	0	0	0	0	0	0
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	1	0	0	14,486	0	0	0	0	0	0	0
333992	Welding and Soldering Equipment Manufacturing	1	0	575	8	0	0	0	0	0	424	0
335991	Carbon and Graphite Product Manufacturing	1	0	0	0	0	0	0	0	0	2	0
336214	Travel Trailer and Camper Manufacturing	1	0	37,845	0	0	0	0	0	0	0	0
336411	Aircraft Manufacturing	3	0	58,884	140,480	0	0	2,897	0	43,630	4,218,295	0
336412	Aircraft Engine and Engine Parts Manufacturing	1	0	17,097	0	0	0	0	0	5,686	0	0
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing	7	0	29,360	70,511	0	0	68	11	19,693	748,158	0
336611	Ship Building and Repairing	1	0	364	1	0	0	0	0	0	0	0
339992	Musical Instrument Manufacturing	1	0	5,117	0	0	0	0	1	0	6,631	0
424690	Other Chemical and Allied Products Merchant Wholesalers	8	16	427	967	0	0	108,418	0	19,624	660	10,764
424710	Petroleum Bulk Stations and Terminals	0	1	0	0	0	0	0	0	0	0	0
541712	Research and Development in the Physical, Engineering, and Life Sciences (except Biotechnology)	1	0	0	0	0	0	0	0	0	0	0
562211	Hazardous Waste Treatment and Disposal	16	0	1,250	721	0	73,433	322	7,797	607,687	10,135	5,449
562213	Solid Waste Combustors and Incinerators	1	0	0	0	0	0	0	0	438	0	0
562219	Other Nonhazardous Waste Treatment and Disposal	1	0	0	0	0	0	0	0	19,399	0	3,172
562920	Materials Recovery Facilities	2	0	250	39,751	0	0	0	6	5,019	243,359	216,691
928110	National Security	1	0	0	43,406	0	0	9,542	0	0	0	0
	TOTAL	191	26	279,073	435,558	349	73,498	124,832	9,794	1,817,617	5,901,670	253,116

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Table C-4. Summary of 2015 TRI On-site Releases and Off-site Waste Transfer for Methylene Chloride

CAS 000075092: Methylene Chloride		On-site Releases (lb)						Off-site Transfers (lb)				
NAICS	NAICS Description	# of Forms		Air Emissions		Water Discharges	Land Disposal	Land Disposal	Wastewater Treatment	Incineration	Recycled	Other
		# Form R	# Form A	Fugitive	Stack							
212393	Other Chemical and Fertilizer Mineral Mining	1	0	194	13	0	0	0	0	0	0	0
221112	Fossil Fuel Electric Power Generation	1	0	0	147,000	0	0	0	0	0	0	0
313320	Fabric Coating Mills	1	0	1,568	0	0	0	0	0	0	17,369	0
322110	Pulp Mills	1	0	9	2,720	0	0	0	0	0	0	0
324191	Petroleum Lubricating Oil and Grease Manufacturing	2	0	8	57	0	0	0	0	119,381	0	0
325110	Petrochemical Manufacturing	3	0	80	6,058	0	0	0	0	120,593	126,253	0
325120	Industrial Gas Manufacturing	2	0	22,671	3,300	0	0	0	0	2,253	0	0
325180	Other Basic Inorganic Chemical Manufacturing	4	0	8,439	3,555	99	4,388	600,065	0	2,310	0	0
325193	Ethyl Alcohol Manufacturing	1	0	1	44	0	0	0	0	0	0	389
325194	Cyclic Crude, Intermediate, and Gum and Wood Chemical Manufacturing	1	1	220	520	0	0	240	0	0	0	0
325199	All Other Basic Organic Chemical Manufacturing	29	1	27,112	122,776	55	12	2,862	12	1,335,434	249,919	1,699
325211	Plastics Material and Resin Manufacturing	5	0	281,052	16,076	95	0	18	0	38,509	29,200	0
325220	Artificial and Synthetic Fibers and Filaments Manufacturing	2	0	23,038	1,869	0	0	0	0	3,677	159,955	0
325320	Pesticide and Other Agricultural Chemical Manufacturing	2	1	17,803	16,869	0	0	0	0	7,871	135,384	0
325411	Medicinal and Botanical Manufacturing	14	0	43,695	38,684	0	0	0	41	2,771,771	3,414,288	312,711
325412	Pharmaceutical Preparation Manufacturing	31	0	51,571	70,722	2,008	51,000	18,528	10,593	4,871,458	3,266,319	803,044
325413	In-Vitro Diagnostic Substance Manufacturing	4	0	1,704	11,354	0	0	0	1,068	321,075	14,768	0
325510	Paint and Coating Manufacturing	11	1	7,685	36,180	0	0	0	2	57,834	17,909	0
325520	Adhesive Manufacturing	8	0	54,658	3,854	0	5	22,066	0	20,635	0	0
325611	Soap and Other Detergent Manufacturing	2	0	3,014	1,581	0	0	0	0	1,940	0	1,039
325612	Polish and Other Sanitation Good Manufacturing	2	1	324	1	0	0	80	0	1,367	0	0
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	20	3	216,452	24,624	89	0	10,268	5,291	192,046	10,329	750
326122	Plastics Pipe and Pipe Fitting Manufacturing	1	0	0	65,634	0	0	0	0	5,694	0	0

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326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing	4	1	100,268	7,028	0	7,339	0	0	1,950	0	7,589
326199	All Other Plastics Product Manufacturing	4	0	18,065	15,282	0	0	4,500	0	98	0	750
327310	Cement Manufacturing	9	1	2,495	1,296	0	0	4,637	0	49,043	0	850
327992	Ground or Treated Mineral and Earth Manufacturing	1	0	550	96	0	0	0	0	1,018	817	0
331420	Copper Rolling, Drawing, Extruding, and Alloying	2	0	21,889	50,712	0	0	0	3	3,086	3,775	0
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	1	0	141	1,546	0	0	0	627	30,576	69,001	0
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)	2	0	170	22,350	0	74	0	0	79	1,149	0
332439	Other Metal Container Manufacturing	1	0	5,366	0	0	0	0	0	0	0	0
332710	Machine Shops	1	0	0	16,144	0	585	0	0	0	0	0
332721	Precision Turned Product Manufacturing	1	0	0	28,568	0	695	0	0	695	0	0
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing	1	0	17,262	1,315	0	0	0	0	0	3,320	0
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	1	0	250	58,972	0	0	0	0	0	4,266	0
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	1	0	21,305	0	0	0	0	0	0	377	0
332911	Industrial Valve Manufacturing	1	0	0	12,933	0	0	0	0	0	450	0
332993	Ammunition (except Small Arms) Manufacturing	2	0	9	846	0	0	0	0	750	25,320	0
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	1	0	0	41,480	0	0	0	0	24,090	0	0
333314	Optical Instrument and Lens Manufacturing	1	0	1,212	0	0	1,082	0	0	1,082	0	0
333316	Photographic and Photocopying Equipment Manufacturing	1	0	0	5,600	0	0	0	0	940	150,000	0
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	1	0	0	8,400	0	0	0	0	0	2,400	0
333514	Special Die and Tool, Die Set, Jig, and Fixture Manufacturing	1	0	179	24,809	0	0	0	0	34	0	0
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	1	0	241,540	12,846	0	0	0	0	14,015	0	0
334516	Analytical Laboratory Instrument Manufacturing	3	0	7,451	16,014	0	0	0	0	133,060	57,449	0
334517	Irradiation Apparatus Manufacturing	1	0	1,250	819	0	0	0	0	11,803	0	0

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336370	Motor Vehicle Metal Stamping	1	0	5	5,030	0	0	0	0	0	0	0
336415	Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts Manufacturing	1	0	5	3,200	0	0	0	0	850	0	0
339112	Surgical and Medical Instrument Manufacturing	4	0	10,145	200,184	0	0	1,720	0	44,572	0	0
339113	Surgical Appliance and Supplies Manufacturing	1	0	5	6,594	0	0	0	0	0	0	626
339910	Jewelry and Silverware Manufacturing	1	0	0	6,000	0	0	0	0	0	0	400
339920	Sporting and Athletic Goods Manufacturing	2	0	8,214	0	0	0	0	0	265	0	0
424690	Other Chemical and Allied Products Merchant Wholesalers	24	10	14,618	38,797	0	0	1,750	30	133,544	23,002	720
424710	Petroleum Bulk Stations and Terminals	0	1	0	0	0	0	0	0	0	0	0
562211	Hazardous Waste Treatment and Disposal	21	0	9,353	7,586	1	35,069	8,966	187,596	4,482,240	66,898	14,776
562213	Solid Waste Combustors and Incinerators	1	0	0	0	0	0	0	0	304	0	0
562920	Materials Recovery Facilities	2	0	15,335	45,430	0	0	0	0	21,082	938	0
928110	National Security	3	0	4,105	66,293	19	0	1,737	0	2,100	0	226
	TOTAL	251	21	1,262,485	1,279,661	2,366	100,248	677,437	205,264	14,831,123	7,850,855	1,145,568

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Table C-5. Summary of 2015 TRI On-site Releases and Off-site Waste Transfer for NMP

CAS 000872504: NMP		On-site Releases (lb)						Off-site Transfers (lb)				
NAICS	NAICS Description	# of Forms		Air Emissions		Water Discharges	Land Disposal	Land Disposal	Wastewater Treatment	Incineration	Recycled	Other
		# Form R	# Form A	Fugitive	Stack							
313110	Fiber, Yarn, and Thread Mills	1	0	3	48,470	0	0	0	29	0	0	0
313320	Fabric Coating Mills	5	0	5,267	5,435	0	0	0	0	123,661	84,788	1,251
316210	Footwear Manufacturing	2	0	0	0	0	0	0	0	0	48,436	0
322220	Paper Bag and Coated and Treated Paper Manufacturing	2	0	0	15,170	0	0	11	138	229	0	0
322299	All Other Converted Paper Product Manufacturing	2	0	41,579	13,523	0	0	0	464	0	0	655
323111	Commercial Printing (except Screen and Books)	5	0	961	18,757	0	0	0	0	112,884	0	0
323120	Support Activities for Printing	1	0	1,056	0	0	0	0	34,153	0	0	0
324110	Petroleum Refineries	4	0	5,970	1,180	27	0	0	0	0	0	0
324191	Petroleum Lubricating Oil and Grease Manufacturing	1	2	4	9	0	0	0	0	398	0	0
325110	Petrochemical Manufacturing	7	0	110	341	0	22,089	0	0	130,290	0	0
325130	Synthetic Dye and Pigment Manufacturing	4	0	5	82	0	0	5	20,037	118,351	0	3,075
325180	Other Basic Inorganic Chemical Manufacturing	2	1	1	1	0	0	0	0	4,891	0	0
325199	All Other Basic Organic Chemical Manufacturing	17	3	26,373	3,804	0	651,092	19,303	0	1,255,599	2,295,657	37
325211	Plastics Material and Resin Manufacturing	18	3	16,894	42,097	8,989	1,183,388	1,890,290	82,995	707,056	2,864,494	14,795
325212	Synthetic Rubber Manufacturing	1	0	17	0	0	0	0	0	0	0	0
325220	Artificial and Synthetic Fibers and Filaments Manufacturing	2	0	1,773	42,795	4,602	0	0	0	844,912	181,895	0
325311	Nitrogenous Fertilizer Manufacturing	1	0	4	4	0	0	5	0	0	0	0
325314	Fertilizer (Mixing Only) Manufacturing	2	4	80	6	0	0	0	0	1,297	0	0
325320	Pesticide and Other Agricultural Chemical Manufacturing	8	11	251	674	0	0	554,387	5	2,715	0	17
325411	Medicinal and Botanical Manufacturing	3	0	103	46	0	0	0	250	386,572	250	80,670
325412	Pharmaceutical Preparation Manufacturing	5	0	7,230	15	0	0	777	1,173	18,002	0	0
325414	Biological Product (except Diagnostic) Manufacturing	1	0	0	0	0	0	0	0	0	0	0
325510	Paint and Coating Manufacturing	24	5	4,069	10,995	22	0	25,568	1,116	224,889	63,830	7,471
325520	Adhesive Manufacturing	4	1	72	732	0	0	0	0	22,383	5,473	53
325611	Soap and Other Detergent Manufacturing	2	1	11	7	0	0	0	509	0	0	534
325612	Polish and Other Sanitation Good Manufacturing	1	1	3	0	0	0	0	1,476	0	0	0

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325613	Surface Active Agent Manufacturing	1	1	894	0	0	0	0	0	0	0	0
325910	Printing Ink Manufacturing	2	0	308	2,294	0	0	330	0	331	0	0
325991	Custom Compounding of Purchased Resins	1	0	0	929	0	0	0	0	187,920	328,893	0
325992	Photographic Film, Paper, Plate, and Chemical Manufacturing	5	0	1,400	4,676	0	0	0	6,900	285,728	120,000	1,163
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing	11	4	170	425	0	0	335,840	17,729	13,622	7,885	1,974
326112	Plastics Packaging Film and Sheet (including Laminated) Manufacturing	3	0	1,871	366	0	0	0	1,623	10,566	703,826	0
326113	Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing	6	0	1,175	11,762	0	11	0	240,644	18,347	57,200	20
326130	Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing	3	0	253,000	1,837	0	0	0	117,800	1,900	465,629	0
326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing	3	0	5	757	0	0	0	0	33,064	13,890	0
326199	All Other Plastics Product Manufacturing	7	1	7,949	12,549	0	0	0	275,189	25,960	95,902	0
326291	Rubber Product Manufacturing for Mechanical Use	1	0	120	0	0	0	47,464	0	0	0	0
326299	All Other Rubber Product Manufacturing	1	0	0	14,184	0	0	0	0	0	6,777	0
327310	Cement Manufacturing	5	1	166	239	0	0	0	0	3,332	0	3
327992	Ground or Treated Mineral and Earth Manufacturing	1	0	6	1	0	0	0	0	11	9	0
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	1	0	6,948	4,098	0	0	0	0	0	0	0
331318	Other Aluminum Rolling, Drawing, and Extruding	1	0	6,125	4,488	0	0	0	0	8,518	7,563	55
331420	Copper Rolling, Drawing, Extruding, and Alloying	7	0	6,720	9,840	1	0	0	0	42,800	10,513	814
331511	Iron Foundries	1	1	31,901	0	0	0	0	0	0	0	0
331524	Aluminum Foundries (except Die-Casting)	1	0	92	830	0	0	27,000	0	0	2,600	0
332431	Metal Can Manufacturing	2	0	2,281	19,677	0	0	0	0	29,138	0	451
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	1	0	0	670	0	0	0	0	3,674	0	21
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	4	0	9,383	9,412	0	0	0	21,047	20,812	0	1,924
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	3	0	2,125	110	0	0	0	100,974	6,670	0	1,152
334112	Computer Storage Device Manufacturing	2	0	250	8,495	0	0	0	3,269	0	861,191	0
334412	Bare Printed Circuit Board Manufacturing	2	0	5	8,156	0	0	0	1,679	250	5,040	0

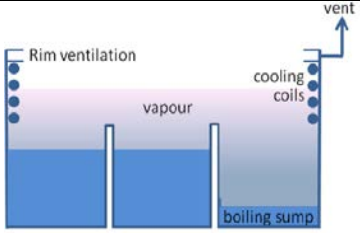
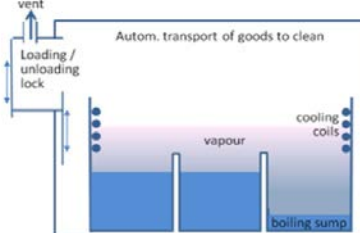
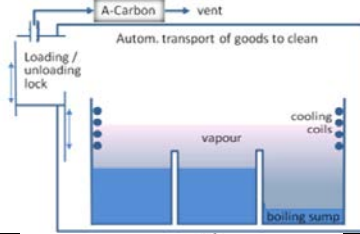
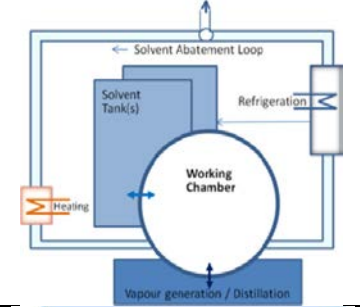
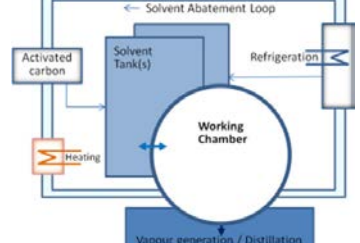
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334413	Semiconductor and Related Device Manufacturing	42	0	9,166	146,045	451	537	4,623	800,070	2,075,205	3,039,546	48,989
334419	Other Electronic Component Manufacturing	4	0	5,637	50,158	0	0	0	48,256	2	937,387	0
334516	Analytical Laboratory Instrument Manufacturing	1	0	0	993	0	0	0	0	5,033	12,969	0
335911	Storage Battery Manufacturing	4	0	322	611	0	0	42,966	19,883	11,132	1,219,068	0
335929	Other Communication and Energy Wire Manufacturing	1	0	772	2,744	0	0	0	0	40,207	0	0
335991	Carbon and Graphite Product Manufacturing	1	0	48,598	0	0	0	0	0	97,578	512,294	0
336111	Automobile Manufacturing	9	0	8,255	145,560	0	0	5	175	8,675	4,419	328
336112	Light Truck and Utility Vehicle Manufacturing	6	0	954	114,800	0	0	0	0	4,163	1,280	31
336213	Motor Home Manufacturing	1	0	11,617	0	0	0	0	0	0	0	0
336310	Motor Vehicle Gasoline Engine and Engine Parts Manufacturing	1	0	0	0	0	0	0	0	0	0	0
336360	Motor Vehicle Seating and Interior Trim Manufacturing	5	0	2,685	53,048	0	0	15,451	0	26,556	57,600	0
336370	Motor Vehicle Metal Stamping	1	0	0	0	0	0	0	0	0	0	0
336390	Other Motor Vehicle Parts Manufacturing	2	0	0	963	0	0	639	0	508	0	0
336411	Aircraft Manufacturing	1	0	1,231	11,022	0	0	0	0	0	0	0
336419	Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing	1	0	284	3,073	0	0	0	0	0	16,570	0
339112	Surgical and Medical Instrument Manufacturing	2	0	1,611	25,063	0	0	9,930	0	3,181	0	0
339940	Office Supplies (except Paper) Manufacturing	0	1	0	0	0	0	0	0	0	0	0
339999	All Other Miscellaneous Manufacturing	4	0	123	950	0	0	0	722,398	79,870	15,064	0
424690	Other Chemical and Allied Products Merchant Wholesalers	11	24	1,016	273	0	0	0	0	6,027	260	2,421
424710	Petroleum Bulk Stations and Terminals	0	1	0	0	0	0	0	0	0	0	0
562211	Hazardous Waste Treatment and Disposal	21	0	4,629	5,546	0	1,766,284	465,905	32,346	5,305,997	2,464	344,865
562920	Materials Recovery Facilities	3	0	0	1,612	0	0	0	0	43,520	1,303,941	0
928110	National Security	3	0	473	2,452	0	0	42,019	0	9,823	0	19,973
	TOTAL	324	66	542,101	884,851	14,092	3,623,401	3,482,518	2,552,326	12,364,248	15,354,602	532,742

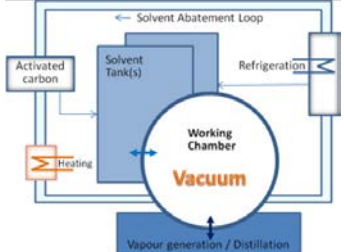
APPENDIX D: ECSA CLASSIFICATION FOR SURFACE CLEANING MACHINES

The following provides ECSA classifications of surface cleaning machines, including vapor degreasers. The table describes the different machine types / generations, and the associated controls. ECSA recommends the use of Type III or higher machine for surface cleaning to minimize emissions and solvent use.

Table D-1. ECSA Classification of Surface Cleaning Machines

Current ECSA Nomenclature	Schematic Drawing	Key Characteristic
Type I Open Top		<ul style="list-style-type: none"> • Open top • Rim ventilation • Cooling with water or refrigerated cooling (2°C) <p>Typical air emission: 1-16kg/hr (avg. 4.7 kg/hr)</p>
Type IIa Enclosed (vented directly to atmosphere)		<ul style="list-style-type: none"> • Encased (all sides closed) • Vented air lock for loading/unloading of goods • Refrigerated cooling • Automatic transport of goods <p>Typical air emission: 2.0 kg/hr</p>
Type IIb Enclosed & abatement (vented through external A-Carbon filter)		<ul style="list-style-type: none"> • As Type IIa but with additional external A-carbon filter for solvent abatement from exhaust air <p>Typical air emission: 1.0 kg/hr</p>
Type III Closed with internal air cleaning prior to opening		<ul style="list-style-type: none"> • Closed single chamber or use of a collection chamber (air-lock to seal against solvent bathe(s)) • Solvent abatement loop with refrigeration (<-20°C) to clean air prior to opening (<2g/m²) <p>Typical air emission: 155 g/hr</p>
Type IV Closed with closed loop air drying without vent		<ul style="list-style-type: none"> • No exhaust air (fully closed air loops) • Equipm. Internal A-carbon in addition to refrigeration • Better drying also of goods with difficult shapes <p>Typical air emission: 1-100 g/hr, average ~38 g/hr</p>

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<p>Type V Closed without vent and operation under vacuum</p>		<ul style="list-style-type: none">• As type IV but with vacuum technology, keeping the working chamber and distillation under reduced pressure during operation• Improved drying• Reduced emissions• Reduced waste• Increased solvent life time (because of lower temperature)
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Source: (ECSA 2013)

APPENDIX E: APPROACH FOR ESTIMATING NUMBER OF WORKERS

This appendix summarizes the methods that EPA/OPPT used to estimate number of workers who are potentially exposed to chemicals used in degreasing applications. The method consists of the following steps:

1. Identify the North American Industry Classification System (NAICS) codes for the industry sectors associated with these uses.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics (OES) data (2015).
3. Refine the OES estimates where they are not sufficiently granular by using the U.S. Census' Statistics of US Businesses (SUSB) (2012) data on total employment by 6-digit NAICS.
4. Combine the data generated in Steps 1 through 3 to produce an estimate of the number of establishments and employees that may come into contact with the degreasing chemical in each industry/occupation combination, and sum these to arrive at a total estimate of the number of employees with exposure.

Step 1: Identify Affected NAICS Codes

As a first step, EPA/OPPT identified NAICS industry codes associated with the uses in the scope. EPA/OPPT referenced EPA's Trichloroethylene (TCE) risk assessment, in which EPA/OPPT has identified a list of all possible NAICS industry sectors that may have degreasing operations (U.S. EPA 2014). It should be noted that degreasing encompasses a large number of industry sectors, and not all facilities in the identified NAICS code will have a degreasing operation.

Table F-1 lists the 6-digit NAICS code associated with degreasing applications. In addition, the table lists the corresponding BLS NAICS code at the 4-digit or 5-digit level. Note BLS employment data for certain sectors are only available at the 4-digit or 5-digit NAICS level (see Step 3 for refinement of BLS data).

Table F-1. NAICS Codes for Degreasing Uses

NAICS	BLS NAICS	Industry
314999	314900	All Other Miscellaneous Textile Product Mills
321113	321100	Sawmills
323111	323100	Commercial Printing (except Screen and Books)
325180	325100	Other Basic Inorganic Chemical Manufacturing
325998	325900	All Other Miscellaneous Chemical Product and Preparation Manufacturing
326299	326200	All Other Rubber Product Manufacturing
331110	331100	Iron and Steel Mills and Ferroalloy Manufacturing
331210	331200	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
331410	331400	Nonferrous Metal (except Aluminum) Smelting and Refining
331420	331400	Copper Rolling, Drawing, Extruding, and Alloying
332111	332100	Iron and Steel Forging
332112	332100	Nonferrous Forging
332119	332100	Metal Crown, Closure, and Other Metal Stamping (except Automotive)

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NAICS	BLS NAICS	Industry
332117	332100	Powder Metallurgy Part Manufacturing
332215	332200	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing
332216	332200	Saw Blade and Handtool Manufacturing
332311	332300	Prefabricated Metal Building and Component Manufacturing
332313	332300	Plate Work Manufacturing
332431	332400	Metal Can Manufacturing
332510	332500	Hardware Manufacturing
332618	332600	Other Fabricated Wire Product Manufacturing
332721	332720	Precision Turned Product Manufacturing
332722	332720	Bolt, Nut, Screw, Rivet, and Washer Manufacturing
332811	332800	Metal Heat Treating
332812	332800	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers
332813	332800	Electroplating, Plating, Polishing, Anodizing, and Coloring
332912	332900	Fluid Power Valve and Hose Fitting Manufacturing
332913	332900	Plumbing Fixture Fitting and Trim Manufacturing
332919	332900	Other Metal Valve and Pipe Fitting Manufacturing
332994	332900	Small Arms, Ordnance, and Ordnance Accessories Manufacturing
332996	332900	Fabricated Pipe and Pipe Fitting Manufacturing
332999	332900	All Other Miscellaneous Fabricated Metal Product Manufacturing
333132	333100	Oil and Gas Field Machinery and Equipment Manufacturing
333249	333200	Other Industrial Machinery Manufacturing
333318	333300	Other Commercial and Service Industry Machinery Manufacturing
333410	333400	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing
333415	333400	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333921	333900	Elevator and Moving Stairway Manufacturing
333994	333900	Industrial Process Furnace and Oven Manufacturing
333999	333900	All Other Miscellaneous General Purpose Machinery Manufacturing
334220	334200	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing
334413	334400	Semiconductor and Related Device Manufacturing
334416	334400	Capacitor, Resistor, Coil, Transformer, and Other Inductor Manufacturing
334417	334400	Electronic Connector Manufacturing
334419	334400	Other Electronic Component Manufacturing
334513	334500	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables
334515	334500	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
335120	335100	Lighting Fixture Manufacturing
335121	335100	Residential Electric Lighting Fixture Manufacturing
335210	335200	Small Electrical Appliance Manufacturing
335310	335300	Electrical Equipment Manufacturing
335312	335300	Motor and Generator Manufacturing
335313	335300	Switchgear and Switchboard Apparatus Manufacturing
335911	335900	Storage Battery Manufacturing
335921	335900	Fiber Optic Cable Manufacturing

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NAICS	BLS NAICS	Industry
335929	335900	Other Communication and Energy Wire Manufacturing
335999	335900	All Other Miscellaneous Electrical Equipment and Component Manufacturing
336320	336300	Motor Vehicle Electrical and Electronic Equipment Manufacturing
336340	336300	Motor Vehicle Brake System Manufacturing
336410	336400	Aerospace Product and Parts Manufacturing
336411	336400	Aircraft Manufacturing
336413	336400	Other Aircraft Parts and Auxiliary Equipment Manufacturing
336414	336400	Guided Missile and Space Vehicle Manufacturing
336510	336500	Railroad Rolling Stock Manufacturing
337125	337120	Household Furniture (except Wood and Metal) Manufacturing
337127	337120	Institutional Furniture Manufacturing
339114	339100	Dental Equipment and Supplies Manufacturing
339990	339900	All Other Miscellaneous Manufacturing
339992	339900	Musical Instrument Manufacturing
339995	339900	Burial Casket Manufacturing
339999	339900	All Other Miscellaneous Manufacturing
488111	488100	Air Traffic Control
493110	493100	General Warehousing and Storage
811310	811300	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance

Step 2: Estimating Total Employment by Industry and Occupation

BLS's OES data (2015) 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/OPPT reviewed the occupation description and identified those occupations (SOC codes) where workers may potentially come into contact with the degreasing chemical. Table F-2 shows several example SOC codes. EPA/OPPT classified the SOC codes into "workers (W)" (near-field exposure) and "Bystander (B)" (far-field exposure), where possible.

Table F-2. SOC Codes with Possible Exposure to Degreasing Chemicals

Application	SOC	Occupation	Designation
Vapor Degreasing	17-2000	Engineers	B
	17-3000	Drafters, Engineering Technicians, and Mapping Technicians	B
	19-4000	Life, Physical, and Social Science Technicians	B
	49-1000	Supervisors of Installation, Maintenance, and Repair Workers	B
	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

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Application	SOC	Occupation	Designation
	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	B
	51-2000	Assemblers and Fabricators	W
	51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	W

After identifying relevant NAICS and SOC codes, EPA/OPPT used BLS data to determine total employment by industry and by occupation based on the NAICS and SOC combinations. For example, there are 13,560 employees associated with 4-digit NAICS 333200 (*Industrial Machinery Manufacturing*) and SOC 51-2000 (*Assemblers and Fabricators*).

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 a gross overestimate, because not all workers employed in that industry sector will be exposed. However, note 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/OPPT's methodology was to further refine the employment estimates by using total employment data in the U.S. Census' SUSB (2012). 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 exposure are included. For instance, OES data are available for the 4-digit NAICS 3332 *Industrial Machinery Manufacturing*, of which only the 6-digit NAICS 333249 *Other Industrial Machinery Manufacturing* is of interest. The Census data allow us to calculate employment in the specific 6-digit NAICS of interest as a percentage of employment in the BLS 4-digit NAICS.

Table F-3 and Table F-4 provide example calculations. NAICS 333249 makes up 48 percent of total employment under NAICS 3332. 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.

For example, the number of workers under NAICS 333249 is calculated as:

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37,250 (Employment in NAICS/SOC) x 48% (Granularity Adjustment Percentage) = 17,870 workers and bystanders under 6-digit NAICS 333249.

Table F-3. Sample Granularity Calculation

NAICS	Industry	Total Employment	Percent of Total Employment
4-Digit Parent NAICS			
3332	Industrial Machinery Manufacturing	97,475	100%
6-Digit NAICS Relevant to Vapor Degreasing			
333249	Other Industrial Machinery Manufacturing	46,762	48%

Source: U.S. Census Bureau (2012)

Table F-4. Estimated Number of Workers and Bystanders under NAICS 333249

NAICS	SOC CODE	SOC Description	Employment by SOC at 4-digit NAICS level	% of Total Employment	Estimated Employment by SOC at 6-digit NAICS level
333200	17-2000	Engineers	11,780	48.0%	5,651
	17-3000	Drafters, Engineering Technicians, and Mapping Technicians	3,810	48.0%	1,828
	19-4000	Life, Physical, and Social Science Technicians	60	48.0%	29
	49-1000	Supervisors of Installation, Maintenance, and Repair Workers	520	48.0%	249
	49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	480	48.0%	230
	49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	30	48.0%	14
	49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	2,280	48.0%	1,094
	49-9070	Maintenance and Repair Workers, General	1,210	48.0%	580
	49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	80	48.0%	38
	51-1000	Supervisors of Production Workers	3,410		1,636
	51-2000	Assemblers and Fabricators	13,560	48.0%	6,505
	51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	30	48.0%	14
Total			37,250		17,870

Sources: U.S. Census Bureau (2012) and U.S. BLS (2015).

Step 4: Final Worker Estimates

For the final estimates, EPA/OPPT calculated the total number of potentially exposed employees by summing the number of workers and bystanders in each affected industry/occupation combination, using the formula previously described in Step 3.

*Employment in NAICS/SOC (Step 2) × Granularity Adjustment Percentage (Step 3) =
Potentially Exposed Employees*

The number of workers and bystanders can then be divided by the number of establishments to calculate the average number of workers and bystander per site. There are a total of 713,732 workers and 436,783 bystanders at 109,966 establishments potentially exposed to vapor degreasing chemicals. On average, this translates to approximately 6 workers and 4 bystanders per site.