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EMISSION SCENARIO DOCUMENT ON THE CHEMICALS USED IN WATER BASED WASHING OPERATIONS AT INDUSTRIAL AND INSTITUTIONAL LAUNDRIES

OECD Environment, Health and Safety Publications
Series on Emission Scenario Documents Number 29

Michihiro Oi
Tel: +33 (0)1 45 24 79 07; Fax: +33 (0)1 44 30 61 80; Email: michi.oi@oecd.org

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This publication was developed in the IOMC context. The contents do not necessarily reflect the views or stated policies of individual IOMC Participating Organizations.

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OECD Environment Directorate,
Environment, Health and Safety Division
2 rue André-Pascal
75775 Paris Cedex 16
France

Fax: (33-1) 44 30 61 80

E-mail: ehscont@oecd.org

EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns, and potential release pathways of chemicals to be used in water washing machines at industrial and institutional laundries. The document presents standard approaches for estimating the environmental releases of and occupational exposures to chemicals used in water washing machines in laundries. These approaches may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to chemicals used in these types of operations. Such 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 settings.

This ESD may be periodically updated to reflect changes in the industry, if new information becomes available, or if the ESD is 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) and U.S. Environmental Protection Agency (EPA) (EPA contact: Nhan Nguyen, nguyen.nhan@epa.gov). The OECD Task Force on Exposure Assessment will forward the comments to the lead country, which updates the document as necessary. Submitted information will also be made available to users by way of the OECD web site (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 in water-based washing operations at industrial and institutional laundries. Such 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 industry-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and Methodology

EPA developed this ESD using relevant data[1] on the industrial and institutional laundries industry, including process descriptions, operating information, chemicals used, wastes generated, waste treatment, worker activities, and exposure information. EPA supplemented the data collected with standard models[2] to develop the environmental release and occupational exposure estimating approaches presented in this ESD.

Much of the information presented in this document is based on data collected by EPA during the proposal development phase of the industrial laundries effluent limitation guidelines and pretreatment

[1] Please refer to Section 8 for a list of the specific references used in developing this ESD.

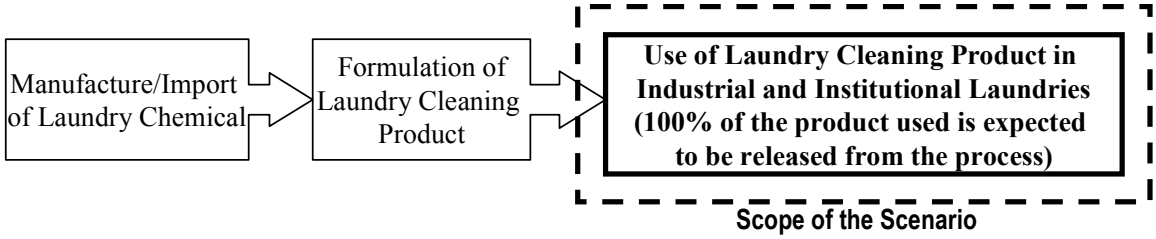
[2] EPA has developed a series of "standard" models for use in performing conservative release and exposure assessments in the absence of chemical- or industry-specific data. Several of these standard models are described in Appendix B to this ESD.

standards. The effluent guidelines data were collected from actual field surveys and are specific to the use of laundry cleaning products in water washing machines at industrial laundries. The Uniform and Textile Service Association (UTSA), a leading trade association for this industry, conducted a survey of potential occupational exposures in the industry, organized a site visit to an industrial laundry, and provided comments on the draft scenario. Additional specific sources of current information include the Kirk-Othmer Encyclopedia of Technology, the 2004 U.S. Census Bureau's County Business Patterns (CBP), the Organization for Economic Co-operation and Development (OECD), and industry-specific trade associations and publications (e.g., UTSA, *Industrial Launderer*). Additional information on the sources investigated and the references cited in this document are presented in Section 0.

The information in this document is based on U.S. data. Certain aspects of the chemicals used in water-washing laundries may differ in other regions and/or countries; therefore, alternate assumptions and parameters may be necessary in some applications of this emission scenario.

This ESD presents methods for estimating potential occupational exposures and environmental releases from the commercial use of laundry cleaning products in water washing machines at industrial and institutional laundries. The scenario does not cover chemicals used for pretreatment, dry-cleaning, or any other chemicals not directly added to a water washing machine. Laundry cleaning products are used in the washing cycle to remove stains and dirt, brighten and soften fabric, eliminate microorganisms, and finish textiles. Laundry cleaning products may include alkalis/builders, antichlors, bleaches, detergents (including surfactants), fabric softeners, sours, and starches. Materials used in laundries are generally non-volatile; however, fragrances used in some commercial laundry cleaning products are typically volatile chemicals, and are included in this scenario.

Releases and exposures from the manufacture of laundry chemicals and the formulation of the chemicals into laundry cleaning products are beyond the scope of this scenario, and therefore not addressed.[3] The following life-cycle diagram demonstrates the applicability of this scenario.



This ESD presents methods that can be used to estimate the following releases of and exposures to chemicals during the use of the laundry cleaning products in water-based washing at industrial and institutional laundries:

- Transfer operation losses to air of volatile chemicals of interest from unloading and transferring the laundry cleaning product;
- Releases of dusts generated from the transfer of powdered chemicals;

[3] Note: The formulation of fragrance chemicals into commercial and consumer cleaning products is covered under the scope of the Organisation for Economic Co-operation and Development (OECD) *Emission Scenario Document (ESD) on the Blending of Fragrance Oils into Commercial and Consumer Products* (OECD, 2007) currently being developed by EPA.

- Inhalation and dermal exposures to powdered and liquid chemicals of interest from connecting transfer lines or from scooping or pouring during transfer into washing machines;
- Transport container residual from pails, drums, or totes containing the laundry cleaning product released to water, incineration, or land;
- Open surface losses to air of volatile chemicals of interest during transport container cleaning;
- Inhalation and dermal exposures to powdered and liquid chemicals of interest during transport container cleaning;
- Release of chemicals of interest to a publicly owned treatment works (POTW) from the water discharge and to air from the evaporation of volatile chemicals of interest during the washing process; and,
- Dermal exposure from handling damp laundry and inhalation exposures to volatile chemicals of interest during laundering operations.

How this document was developed

EPA with support from Eastern Research Group, Inc. (ERG) has developed this draft Emission Scenario Document (ESD) on the chemicals used in water-based washing operations at industrial and institutional laundries. The scope of the ESD is designed to serve the needs of both EPA and OECD programs. The Chemical Engineering Branch (CEB) 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) review. While OECD ESDs traditionally focus on the potential releases of chemicals from industrial processes, this document also describes approaches for estimating the potential occupational exposures to chemicals used in water washing machines at laundries. The occupational exposure estimation methods are included so that the ESD may be used to fully support EPA's chemical review programs.

A proposal to develop this document as an OECD ESD was approved at the 15th meeting of the Task Force on Environmental Exposure Assessment (then TFEEA, to be re-organised to TFEA in 2009) in December 2007. The first draft ESD was forwarded to the TFEEA for comments in July 2008. Comments were received from the United Kingdom on the first draft and were included in the second draft submitted to the TFEA in August 2009. Comments were received from the Netherlands and were incorporated by EPA. The final draft ESD was then circulated to the TFEA in July 2010 and approved at the final commenting round by the end of January 2011.

Note: Summary of changes since the first draft

The first draft developed by EPA primarily discussed compositions of detergents used in the U.S. EPA revised it to present the possibility of alternative detergent compositions in other countries and has referenced the draft OECD Emission Scenario Document on Industrial Surfactants for additional information [OECD, 2002]. In the final draft, EPA has further refined the text of the document.

This document is published on 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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Industry Summary and Background

This section provides on overview of the classifications of laundries, including information on the number and scale of each type of laundry. This section also provides background information on data obtained by EPA's Office of Water to develop pretreatment standards for the industrial laundries industry, which is used in many of the estimations presented in this scenario.

Laundry Classifications

Laundries can be classified into two main categories in the United States: industrial and institutional. These categories are defined by location. Industrial laundries are off-premise laundries that wash soiled laundry received from a hospital, repair shop, doctor's office, etc. Institutional laundries are commonly referred to as on-premise laundries (OPL) and are laundries located within a hospital, nursing home, hotel, or other facility.

Industrial laundries fall under North American Industry Classification System (NAICS) codes 81233: Linen and Uniform Supply. This 5-digit NAICS code is further divided by the primary types of items laundered under each 6-digit NAICS code as presented in Table 1-1.

Table 0-1. Primary Items Laundered at Industrial Laundries

NAICS Code	NAICS Category	SIC Code	Primary Items Laundered
812331	Linen Supply	7218	Table and bed linens; towels; diapers; and uniforms, gowns, or coats of the type used by doctors, nurses, barbers, beauticians, and waitresses
812332	Industrial Launderers	7213 and 7219	Work uniforms and related work clothing, such as protective apparel (flame and heat resistant) and clean room apparel; dust control items, such as treated mops, rugs, mats, dust tool covers, cloths, and shop or wiping towels

Source: USCB, 2002.

Note that these NAICS and SIC codes specifically exclude coin-operated laundries and dry-cleaners, which are outside the scope of this ESD.

The items laundered at an institutional laundry will also vary based on the facility. For example, an institutional laundry at a hotel may wash bed linens, wash towels, and table linens, while an institutional laundry at a hospital may wash uniforms, gowns, bed linens, and other medical linens. Table 1-2 presents information on the number and size of industrial and institutional laundry facilities in the United States. Table 1-3 and Table 1-4 provide size distribution data for industrial laundries based on the amount of laundry processed and the number of employees, respectively. Note that the statistics in these tables may vary between countries.

Table 0-2. Scale of Laundry Facilities in the United States

Laundry Category	Facility Type	Number of Facilities (sites)	Percent With OPLs	Amount of Dry, Clean Laundry Processed (kg/site-yr)	
				Average	Range
Industrial	Linen Supply	1,018[a]	-	3,300,000[b]	190,000 – 15,000,000[b]
Industrial	Industrial Launderers	3,320[a]	-	3,000,000[b]	110,000 – 11,000,000[b]
Institutional	Hospitals	6,200[c]	18[c]	2,180,000[c]	NA
Institutional	Nursing Homes/Assisted Living	54,000[c]	86[c]	406,000[d]	NA
Institutional	Hotels	47,997[a]	~100[d]	402,000[d]	NA

NA – Not available.
a – Source: USCB, 2005.
b – Source: USEPA, 1994.
c – Source: Laundry Today, 2004.
d – Source: CUWCC, 2006.

Table 0-3. Size Distribution of Industrial Laundries by Production

Amount of Dry, Clean Laundry Processed (kg/site-yr)[a]	Estimated Number of Facilities (sites)[b]	Estimated Percent of Facilities	Total Estimated Production for this Category (kg/yr)[a]	Estimated Percent of Total Production
<454,000	167	10	34,700,000	<1
454,000 to <1,360,000	475	27	402,000,000	10
1,360,000 to <2,720,000	629	36	1,240,000,000	29
2,720,000 to <4,080,000	199	11	630,000,000	15
4,080,000 to <6,800,000	139	8	726,000,000	17
>6,800,000	138	8	1,210,000,000	28
Total	1,747	100	4,250,000,000	100

Source: USEPA, 1997.
a – Original data presented in lbs and converted to kg by dividing by 2.2046 (lbs/kg).
b – Only includes facilities within the scope of the Industrial Laundries Point Source Category (see Section 1.2); therefore, the number of facilities is less than the total number of Industrial Launderers classified under NAICS Code 812332 presented in Table 1-2.

Table 0-4. Size Distribution of Industrial Laundries by Employment

NAICS Code	NAICS Category	Total Facilities (sites)	Number of Facilities by Employment Size Class								
			1-4	5-9	10-19	20-49	50-99	100-249	250-499	500-999	≥1000
81233	Linen and Uniform Supply	4,338	1,510	580	580	636	533	458	34	7	0
812331	Linen Supply	1,018	254	142	129	161	161	151	16	4	0
812332	Industrial Launderers	3,320	1,256	438	451	475	372	307	18	3	0

Source: USCB, 2005.

EPA's Effluent Guidelines Data

Much of the data presented in this ESD for the industrial and institutional laundry industry are based on data obtained by EPA's Office of Water to develop pretreatment standards for the industrial laundries industry. The Office of Water focused on industrial laundries that launder industrial textile items[4] and specifically excluded facilities that laundered only linen items[5]. Data from facilities that did not launder industrial textile items were not presented in the 1997 *Technical Development Document for Proposed Pretreatment Standards for Existing and New Sources for the Industrial Laundries Point Source Category* (TDD) (USEPA, 1997). Because the types of items laundered most directly affect the pollutant loading discharged to wastewater, facilities laundering only linen items were excluded so EPA could obtain pollutant loading data related only to industrial textile items.

The TDD summarizes detailed operating data collected by the Office of Water for the 1993 operating year. Over 1,500 laundries submitted general information, including SIC code, in responding to the *1993 Screener Questionnaire* (USEPA, 1993). A subset of the facilities responding to the screener questionnaire reported detailed operating data in response to the *1994 Industrial Laundries Detailed Questionnaire* (DEQ) (USEPA, 1994). Screener Questionnaire data were compared and matched with DEQ data to determine the SIC codes represented in the data collection. Based on the definitions provided above for industrial and institutional laundries, the DEQ database contains information from 82 industrial launderers (sites reporting SIC code 7218 only), 45 linen suppliers (sites reporting SIC codes 7213 and/or 7219), and 46 combined laundries (sites reporting SIC code 7213 and/or 7219 and 7218). DEQ data referenced throughout this ESD are taken from these facilities responses to the DEQ. Data presented in this document for "all industrial laundries" includes industrial launderers, linen suppliers, and combined laundries.

[4] Industrial textile items include, but are not limited to: shop towels, printer towels/rags, furniture towels, rags, mops, mats, rugs, tool covers, dust-control items, gloves, buffing pads, absorbents, uniforms, filters, and clean room items. If the item has hospital, hotel, or restaurant uses, it was not included in the data (USEPA, 1997).

[5] Linen items include the following: linen supply garments, linen flatwork/full dry, health care items, continuous roll towels, family laundry, new items, executive wear, and other miscellaneous items (USEPA, 1997).

PROCESS DESCRIPTION

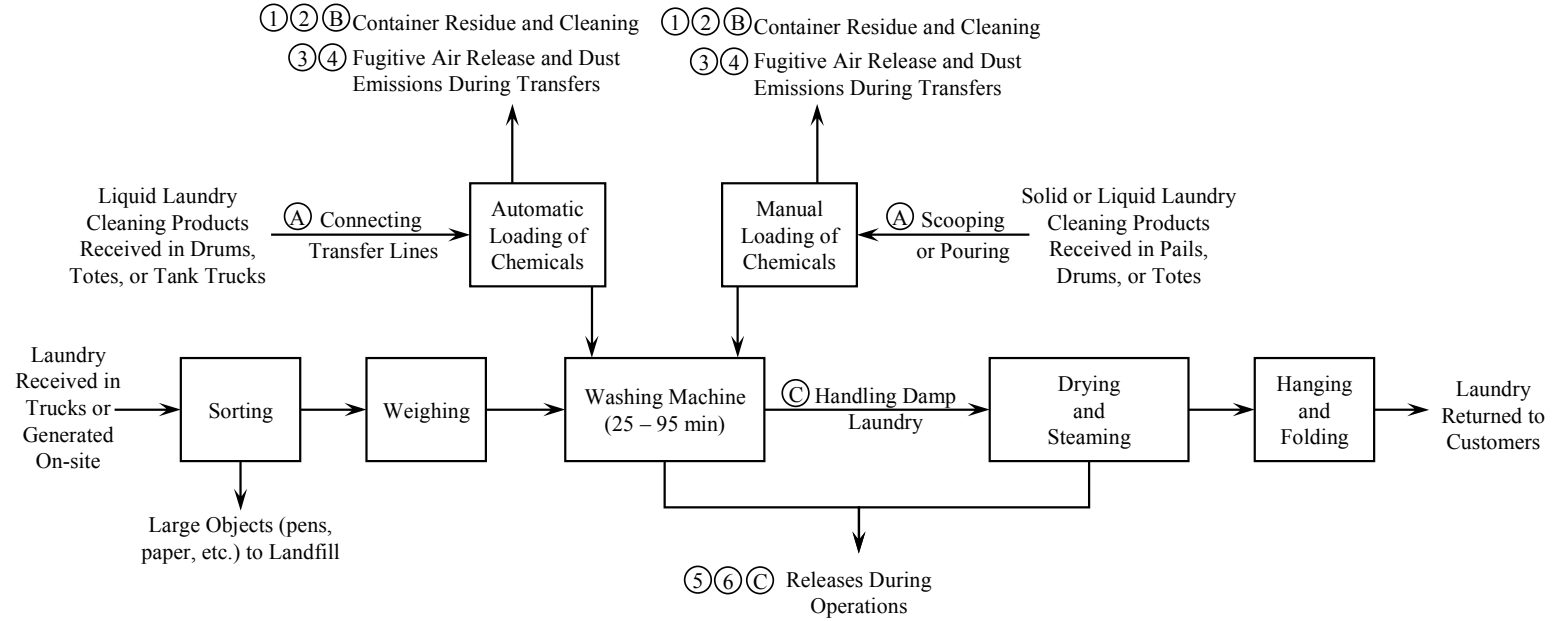
The following sections discuss the water-based washing process and laundry cleaning products used in the laundry process. Section 0 presents a detailed discussion of the water-based washing process. Section 2.2 highlights the use of different forms of wash products and formulations within the process. Section 0 discusses the chemicals that may be used in water-based washing operations, their purpose, and typical chemical composition. While some industrial and institutional laundries may also perform dry-cleaning operations, these operations are outside the scope of this scenario. Nationwide, 97 percent of all industrial laundry items are washed in water (USEPA, 1997).

Water-Based Washing Process

The following process descriptions are based on industry-specific literature and may vary on a site-by-site basis. The description is primarily based on information presented in the Industrial Laundries TDD (USEPA, 1997) and information provided by the Uniform and Textile Service Association (UTSA, 2005). Figure 0-1 presents a flow diagram of the industrial/institutional laundering operations, including potential release and exposure points for the chemical of interest. Although large and small washing operations may have different process equipment, environmental releases and occupational exposures are expected to be similar; therefore no distinction was made between the two types of processes.

Industrial laundries typically receive laundry by truck. Dirty laundry is generated on-site at institutional laundries; however, some institutional laundries may wash laundry for an affiliate (e.g., one hospital laundering items for multiple hospitals owned by the same company). The laundry is sorted by hand and transported by cart or overhead sling to a weighing station. During the sorting process, large objects including pens, paper, and similar items are removed from the laundry. After weighing the sorted laundry, stain treatment chemicals may occasionally be applied. Alternatively, stained items may be removed and run in separate "stain loads" (UTSA, 2005). Items are then bagged and taken to the washers by overhead slings or carts. The items are loaded into the washers directly from the bags. The laundry is washed using a wash formula appropriate for the item type and soil loading. Wash cycle times vary from 25 to 95 minutes with an average between 40 and 45 minutes (UTSA, 2005). However, some washing machines operate in a continuous process. The typical water-washing processes may be broken into the following cycles as presented in the Industrial Laundries TDD (USEPA, 1997):

- **Flush cycle** - Loosely attached solids and a portion of the water-soluble soils are removed during a rinsing operation.
- **Break cycle** - Items are treated with an alkali solution to swell the cellulosic fibers, allowing the soil to be more readily removed. Detergents may also be added.
- **Sudsing cycle** – Detergents are added in varying concentrations and the items are agitated until they are clean. Note that in many newer washers the break and sudsing cycles may be combined (UTSA, 2005).



Exposures:

Ⓐ Dermal and inhalation exposure from connecting transfer lines or from scooping and pouring.

Ⓑ Dermal and inhalation exposure during container cleaning (if containers cleaned on-site).

Ⓒ Dermal exposure from handling damp laundry and inhalation exposure to vaporized chemicals during operations.

Releases:

① Transport container residue released to water, incineration, or landfill.

② Open surface losses to air during transport container cleaning (if containers cleaned on-site; volatile chemicals only).

③ Transfer operation losses to air from unloading and transferring laundry cleaning product (volatile chemicals only).

④ Dust losses during unloading and transferring solids (powdered laundry products only).

⑤ Releases to air within the workers' breathing zone from operations.

⑥ Washing water discharge to POTW (non-volatile and volatile chemicals) and evaporation losses to air during washing and drying operations (volatile chemicals only).

Figure 0-1. Flow Diagram for Industrial/Institutional Laundering Operations

- **Bleaching cycle** (optional) - Detergent is replaced with a bleach solution. Bleach does not remove stains; rather, removes the color and appearance of stains. Bleach also destroys bacteria (UTSA, 2005).

- **Rinsing cycle** – Extracted soil is removed from the wash water during this step as well as the used alkali, detergent, and bleach.

- **Blueing/brightening cycle** - Additional chemicals are added to whiten/brighten the items. Brightening chemicals may be alternatively added during the break cycle when necessary (UTSA, 2005).

- **Final Rinse and Finish** - The water batch is soured or acidified to a pH of 5, preventing the yellowing of fabrics by sodium bicarbonate during pressing and drying.

After washing, overhead slings, carts, or automated shuttles transport most of the laundry to dryers. Some of the items are steamed to remove wrinkles. After drying and steaming, the items are typically folded or placed on hangers. The processed laundry is then sorted and returned to customers. While some chemicals may be added before washing (stain pretreatment) and after washing (starches before ironing and pressing or pH neutralizers before release to POTW), this scenario focuses on releases of and exposures to laundry cleaning products added to a water-washing machine.

Forms of Wash Chemicals in the Water-Based Washing Process

Industrial and institutional laundries may receive cleaning products in bags, cardboard boxes, or drums of various types and sizes as a solid powder or liquid solution (Renescu and Kerr, 1993). However, most of the cleaning products are liquid, received at industrial laundries and larger institutional laundries in drums, totes, or bulk tanker trucks (UTSA, 2005). Institutional laundries typically receive liquid cleaning products in pails or other smaller containers. Liquid products have been replacing solid products over the past few decades and now make up over 90 percent of all industrial and institutional wash chemicals utilized in the United States (CEB, 2006b). Liquids have the following advantages over solid products:

- Liquids can be automatically loaded into the washer, resulting in reduced occupational exposure and labor costs;

- Liquid metering systems precisely add cleaning products, resulting in less wasted product;

- Solids are typically pre-built products (i.e., alkali builder premixed with surfactant). Liquids are typically separate components allowing the user to adjust formulations to the needs of the load based on the soiling and type of textile; and,

- Solids create dusts increasing the potential for occupational exposure (CEB, 2006b).

Table 2-1 presents the prevalence of liquid laundry cleaning products at industrial laundries, based on a 2005 survey of 141 industrial laundries conducted by UTSA.

Table 0-1. Physical Form of Laundry Cleaning Products Utilized by Industrial Laundries

Type of Facility	Percent of Facilities
Liquid laundry cleaning products utilized exclusively	88.7
Solid laundry cleaning products utilized exclusively	8.5
Liquid and solid laundry cleaning products utilized	2.8

Source: UTSA, 2005.

Liquid laundry cleaning products are almost exclusively loaded into the washing machine using a liquid injection system (UTSA, 2005). Solid laundry cleaning products are typically manually loaded into the washing machine. In almost all larger facilities and most smaller facilities, liquid products are pumped directly from their transport containers into the washing machine. Automatic liquid injection systems also reduce worker exposure during the washing process, but workers may face dermal and possible inhalation exposure to volatile chemicals when connecting chemical transfer lines or transferring the liquid chemicals from the transport container to storage tanks (Exposure A). If liquid injection systems are not used, workers manually scoop or pour solid or liquid products into the washing machine, either directly from its transport container, or from a transfer container (such as a pail for easy transport around the facility) prior to being loaded into the machine. During manual loading, workers may undergo a dermal exposure and possible inhalation exposure to volatile liquids or powder chemicals (Exposure A). During both automatic and manual transfer operations, volatile components may vaporize resulting in a fugitive air release (Release 3). Additionally, powdered chemicals may form dusts during transfers (Release 4). Table 2-2 presents the prevalence of liquid injection systems at industrial laundries, based on a 2005 survey of 141 industrial laundries conducted by UTSA.

Table 0-2. Prevalence of Liquid Injection Systems at Industrial Laundries

Application Method	Percent of Facilities
Liquid Injection System	91.5
Manual wash chemical loading	8.5

Source: UTSA, 2005.

Empty drums are typically returned directly to the wash chemical supplier or sent to a drum recycler/reconditioner. The drums are triple-rinsed before reuse (Release 1, Release 2, Exposure B) (CEB, 2006b; UTSA, 2005; Shultz, 2004). Empty transport containers are not typically rinsed at the laundry facility. Similarly, bulk tank trucks would be rinsed at the wash chemical supplier's site or a separate cleaning facility. Pails, cardboard boxes, and other smaller containers typically used by institutional laundries are typically discarded without rinsing into municipal solid waste (potential release to incineration or landfill).

Laundry wash chemicals may be added at various times during the washing process. Alkaline, builder, bleach, and detergent products are generally added near the beginning of the washing process during the break and sudsing cycles, while antichlors, sours, softeners, and starches are generally added later in the washing process, before the final rinse (Melrose Chemical, 2005; National Starch, 2004). During the washing process, volatile components may vaporize and be released to the atmosphere, while the remaining non-

volatile components are typically discharged to a POTW after the wash cycle (Release 5, Release 6). The water may first pass through on-site wastewater treatment (collection or settling basins, pH neutralization) before release to POTW; however, these control technologies are generally designed to remove dirt, oil, and other materials removed from the textile during the laundering process, not the laundry wash chemicals. Control technologies are discussed further in Section 0. After the final rinse and water removal from the washer, very small amounts of chemicals may remain on the item. When workers are transferring, drying, steaming, or pressing the item, workers may be exposed to any residual laundry chemical on the item (Exposure C). Of 141 industrial laundries surveyed, almost 28 percent reported some level of wash floor automation to transfer wet laundry from washers to dryers (UTSA, 2005).

Chemicals Used in Water-Based Washing

Laundries may use one detergent formulation product without the addition of any other chemicals to the washing machine; however, laundries typically add other laundry cleaning products along with a detergent formulation, depending on water hardness, textile type, and textile soiling. Other laundry cleaning products added may include alkalis/builders, antichlors, bleaches, softeners, sours, and starches. The following sections describe products that may be used in water-based washing operations, their purpose and typical chemical composition. Many chemicals may be used in multiple laundry cleaning products. Section 3.3 summarizes the defaults presented in this section for the type of laundry cleaning product in which chemicals are typically received. Section 0 discusses the physical chemical properties of laundry chemicals.

Detergent Formulations

A detergent is not an individual chemical, but a formulation of multiple chemical types. The major components of detergents are builders and surfactants. Detergents may also contain anti-redeposition agents, bleaches, brighteners, corrosion inhibitors, enzymes, fabric softeners, fragrances, hydrotopes, preservatives, solvents, and stabilizers (USEPA, 1999). Many of these components such as bleaches, builders, and fabric softeners may also be added to the washing machine as components of other laundry cleaning products. Industrial laundries and larger institutional laundries typically use separate formulations of surfactants and builders, while smaller institutional laundries and consumers use formulated detergents.

Table 0-3 provides information on a typical detergent formulation in the United States. Detergents formulated in different countries may have varying compositions. For example, the 2002 OECD ESD on Industrial Surfactants reported the general formulation for a completely built (solid) detergent in the United Kingdom would include approximately 87 percent builder (water softeners, alkalis and anti-redeposition agents), 12 percent surfactants, and 0.2 percent optical brightener. Additional formulations for other types of detergents may also be found in the Industrial Surfactants ESD (OECD, 2002).

Table 0-3. Typical Detergent Product Formulation

Component	Percent in Formulation (Chem. Book, 1995)[a]	Percent in Formulation (C&EN, 1996)[a]
Builders	58	59
Surfactants	36	32
Bleach, brighteners, enzymes	2.5	3
Fragrances & fabric softener	1.5	2
Others	2	4

a – Percentages as presented in USEPA, 1999.

Surfactants

Surfactants are surface-active agents that reduce the tension at the surface between the water and the fabric to be cleaned. The surfactant's main function is to suspend the soil that has been removed from the surface, but it also plays a key role in loosening soil (OECD, 2002; USEPA, 1999). Surfactants can be split into four separate classes: anionic, nonionic, cationic, and amphoteric surfactants.

- **Anionic** - Anionic surfactants are negatively charged. These surfactants resist the effects of water acidity and hardness (USEPA, 1999). Typical anionic surfactants are sulfated fatty alcohols and sulfonated amides (OECD, 2002; USEPA, 1999).

- **Nonionic** - Nonionic surfactants, which have no charge, are the most widely used today in laundry detergents (USEPA, 1999; Dunlap, 2001). They effectively remove oily soil from fabrics. Typical nonionic surfactants are ethylene oxide or propylene oxide with fatty alcohol, fatty acid condensates with ethylene oxide, amides from fatty acids and diethanolamine, and condensate of ethylene oxide with an amine or amide (OECD, 2002; USEPA, 1999).

- **Cationic** - Cationic surfactants are positively charged. These surfactants are poor detergents but good fabric softeners and antibacterial agents. They are commonly used in conjunction with nonionic surfactants. They cannot be used with anionic surfactants because opposite-charged ions will clump together and precipitate out of solution (USEPA, 1999). Most cationic surfactants are quaternary ammonium salts; however, amine and imidazoline salts also fall under this category (OECD, 2002).

- **Amphoteric** - Amphoteric surfactants have the ability to act either as an acid or base, displaying either a positive or negative charge. These surfactants are well suited as recyclable cleaners because they exhibit low foaming properties, provide good detergency and compatibility with alkaline formulations, and exhibit excellent water solubility (USEPA, 1999). Amphoteric surfactants include betaines, glycinates, aminopropionates, and imidazoline-based surfactants (OECD, 2002).

Typically, detergents received at industrial and larger institutional laundries will contain a surfactant at over 90 percent concentration (CEB, 2006b). However, formulated detergents used at smaller institutional facilities may be more similar to the data presented in Table 2-3.

Builders (Alkalis, Water Softeners, and Anti-Redeposition Agents)

Builders are chemicals added to detergent formulations or to wash loads directly to enhance the surfactant's performance and increase the overall effectiveness. Builders increase the alkalinity, soften the water, and prevent redeposition of soil on the items. Increasing the alkalinity is important as surfactants work more effectively in an alkaline medium (USEPA, 1999). Alkalis raise the pH of the wash water to ensure the effectiveness of the surfactant and help to swell cellulosic fibers, allowing the soil to be more easily removed. Detergent formulations and separately added builder products may contain between 30 percent and 85 percent alkalis (OECD, 2002). The laundry industry uses alkalis such as hydroxides, silicates, carbonates, and phosphates (USEPA, 1999; Kirk-Othmer, 2004).

Hardness ions like calcium and magnesium can decrease the effectiveness of the surfactant. They directly interact with the surfactant or interact with the negative charges on the fabric or soil, reducing the electric repulsion between them (Kirk-Othmer, 2004). Water softeners sequester these ions and prevent their interaction with the surfactant. In detergent formulations or separately added builder products, water softeners may account for between 15 percent and 55 percent of the formulation (OECD, 2002). Note that this percentage is based on the phosphate concentration, which acts as both a water softener and an anti-redeposition agent. Typical water softeners are phosphates, zeolites, sodium carbonate, sodium silicate, sodium citrate, ethylendiaminetetraacetic acid (EDTA), and nitrilotriacetic acid (NTA) (USEPA, 1999; Kirk-Othmer, 2004).

Once the soil or stain has been removed from the laundered article and suspended in water, anti-redeposition agents help suspend the soil to prevent it from re-depositing on or getting trapped within the textile. Builders with multiple charges are the most effecting anti-redeposition agents (Kirk-Othmer, 2004). In typical detergent formulations and separately added builder products, anti-redeposition agents account for less than 5 percent of the formulation (OECD, 2002). The laundry industry typically uses polycarboxylates, polyacrylates, polyethylene glycol, sodium silicate, and polyaspartic acid as anti-redeposition agents (USEPA, 1999).

Builders and alkalis are standard in most detergent formulations; however, they may also be added individually to adjust the supply water, especially if it is acidic or hard. To clean heavily soiled loads, builders may also be added individually. Industrial laundries and larger institutional laundries typically use separate builder formulations.

Other Additives in Detergent Formulations

Detergent formulations may contain several other additives. Additives commonly found in detergent formulations (and not added separately to the wash water) are briefly discussed below.

- **Antimicrobial Agents** - Inhibit microbial growth. Typical microbial agents are pine oil, quaternary ammonium compounds, sodium hypochlorite, hydrogen peroxide, triclocarban, and triclosan.

- **Optical Brighteners** - Absorb invisible ultraviolet light and re-emit it as visible light within the blue spectrum (USEPA, 1999). The blue tint counterbalances the yellow tint present in off-white fabrics, and imparts a greater whiteness from the fabric. Brighteners are generally used only on cotton articles and are best absorbed at high temperatures. Typical optical brighteners are stilbene disulfonates and coumarin derivates.

- **Enzymes** - Act as catalysts to facilitate in the destruction of soil particles and stains. These chemicals are classified as proteins. Typical enzymes are protease, amylase, lipase, and cellulose (USEPA, 1999). Because anionic and cationic surfactants lower the stability of enzymes, most enzymes are used with nonionic surfactants.

- **Corrosion Inhibitors** - Help protect the metal washing machine parts. Sodium silicate is the most commonly used corrosion inhibitor (USEPA, 1999).

- **Fragrances** - Used to mask the odors of the chemical components of the detergents. While fragrances are common in consumer laundry cleaning products, they are rarely used in industrial laundry products (UTSA, 2005).

- **Hydrotropes** - Prevent the individual constituents of liquid detergents from separating into phases. These chemicals promote uniformity within the detergent solution. Typical hydrotropes are glycols, toluene sulfonates, and cumene sulfonates (USEPA, 1999; UTSA, 2005).

- **Preservatives** – There are two types of preservatives: in-can preservatives which prevent deterioration of the laundry detergent product, and fiber preservatives which prevent oxidation, discoloration, and bacterial growth on the fabric (USEPA, 1999). The most common in-can preservatives include butylated hydroxytoluene, ethylenediaminetetraacetic acid (EDTA), bronopol, formaldehyde, and isothiazolinones. Fiber preservatives are not as common in detergent formulations , and are not discussed further in this ESD.

- **Stabilizers and Suppressors** - Work to stabilize and/or prohibit excessive sudsing. Typical stabilizers used to keep sudsing constant are alkanolamides and alkylamine oxides (USEPA, 1999). Typical suppressors such as silicone, soap, and alkyl phosphates act to prohibit excessive detergent sudsing.

Bleaches

Bleaches act to maintain the whiteness of laundered items and destroy most bacteria on the textile. Bleaches eliminate the stain's color or solubilize the stain for rinse away (USEPA, 1999). Laundries may use either oxidizing or reducing bleaches. Oxidizing bleaches remove electrons from the stain. Reducing bleaches add electrons to the stain. Oxidizing bleaches are often chlorine or oxygen-based. Oxygen bleaches are less effective than chlorine bleaches. They require higher temperatures, alkalinity, and concentration to perform adequately (USEPA, 1999). However oxygen bleaches can achieve better whitening. Oxygen bleaches include hydrogen peroxide, perborates, and peracids. The most common chlorine bleach is sodium hypochlorite. Typical reducing bleaches are sulfur dioxide, sulfites, and bisulfites (Kirk-Othmer, 2004).

While most consumer detergent formulations contain small quantities of bleach, industrial and institutional laundries typically use a separate bleach formulation for white cotton loads. The most common bleach, sodium hypochlorite, is typically received at industrial laundries at less than 12 percent concentration in water.

Antichlors, Sours, Softeners, and Starches

These products are typically added to the washing machine immediately before or during the final rinse cycle. They do not have an effect on detergency (dirt and oil removal), but are added to finish the textile item and neutralize chemicals added to clean the item. Antichlors, sours, softeners, and starches may be added individually or as part of a finishing formulation. A brief description of each is presented below.

- **Antichlors** - Remove excess bleach from laundered items by neutralizing excess chlorine (Evans Vanodine, 2003; Washing Systems, 2004). Antichlors are used only on chlorine-bleached items and are typically added during the final rinse cycle.

- **Sours (Acids)** - Lower the pH of the water during the final rinse to counteract the alkaline builders that may have been added at the beginning of the wash cycle. Sours return the pH to a proper level, preventing the item from yellowing and hardness, and to reduce skin irritation when the textile is used (Evans Vanodine, 2003; Washing Systems, 2004). Some alkalinity may remain in the wash water if the water is recycled into the wash process (UTSA, 2005). Sours also remove rust and prevent iron deposition.

- **Softeners** - Control the static electricity and soften laundered items (Evans Vanodine, 2003; Washing Systems, 2004). Laundries often use cationic surfactants as fabric softeners because they bind strongly to negatively charged surfaces. The softener molecules form a film on the fabric's surface, and lubricate the fabric to give it increased softness and flexibility.

- **Starches** – Stiffen laundered fabric to help the item hold its shape. Starches help attain a smooth crisp finishes to ironed items (National Starch, 2004). Dirt and sweat also adhere to the starch rather than the fabric, and are more easily removed the next time the item is washed. Starch can be added in the final rinse cycle or sprayed onto the item prior to ironing. Spray application of starch is outside the scope of this scenario.

Physical Properties of Laundry Chemicals

In general, laundry cleaning chemicals are water-soluble neat solids. Table 0-4 presents the physical properties of a chemical compound from each additive category. The chemicals were chosen to be representative of the category; however, physical properties may vary across the category. The physical property data are only provided for a general estimate of the properties of the category.

Table 0-4. Physical Properties of Representative Laundry Chemicals

Additive Category	Chemical (CAS)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (g/L)	Other (Density(ρ), Oct/H_2O, etc.)
Anionic Surfactant	Dodecylbenzene sulfonic acid, sodium salt (25155-30-0)	Solid[a]	348.48[a]	2.29e-15[d]	N/A	N/A	0.8[d]	log K_{OW} 1.96[d]
Nonionic Surfactant	Poly(oxy-1,2-ethanediyl),alpha-(4-nonylphenyl)-omega-hydroxy-, branched (127087-87-0)	Liquid[f]	396[f]	<0.01 at 20°C[f]	>200[f]	N/A	5[f]	**ρ** 1.029 at 20ºC pH 7.3 in 1% solution isopropyl/H_2O[f]
Cationic Surfactant	Dimethyloctadecyl benzyl ammonium chloride (122-19-0)	Solid[b]	424.15[c]	Salt; VP assumed negligible	N/A	N/A	Soluble[b]	log K_{OW} 3.23[d]
Amphoteric Surfactant	Cocamidopropyl Betaine (61789-40-0)	Liquid[e]	N/A	N/A	>100[e]	-8[e]	Soluble[e]	**ρ** 1.043[e]
Alkali	Sodium Hydroxide (1310-73-2)	Solid[b]	40.00[a]	1.82e-21[d]	1390[b]	318[b]	1000[a]	**ρ** 2.13[a] log K_{OW} -3.88
Water Softener	EDTA (60-00-4)	Solid[a]	292.25[a]	4.98e-13[d]	Decomp[a,b]	Decomp[a,b]	0.5[a]	Decomposes at 220 - 240°C[a,b]
Anti-Redeposition Agent	Sodium Metasilicate (6834-92-0)	Solid[a]	122.06[a]	5.01e-17[d]	N/A	1089[a]	1000[d]	pH 12.6 in 1% solution[b] log K_{OW} -5.65[d]
Antimicrobial Agent	Alkyl dimethyl benzyl ammonium chloride (68391-01-5)	Solid[i]	N/A	Salt; VP assumed negligible	N/A	N/A	Soluble[i]	**ρ** 1.09[i]
Optical Brightener	7-diethylamino-4-methylcoumarin (91-44-1)	Solid[b]	231.29[c]	N/A	N/A	68 - 72[b]	Soluble in aqueous acid solutions[b]	
Enzyme	Amylase (9000-92-4)	N/A	Amylase is a class of enzymes that converts starch into sugars.[a,b] Physical properties are not easily characterized.				N/A	

Additive Category	Chemical (CAS)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (g/L)	Other (Density(ρ), Oct/H_2O, etc.)
Corrosion Inhibitor	Sodium Metasilicate (6834-92-0)	Solid[a]	122.06[a]	5.01e-17[d]	N/A	1089[a]	1000[d]	pH 12.6 in 1% solution[b] log K_{OW} -5.65[d]
Fragrance	Benzyl Acetate (140-11-4)	Liquid[a]	150.18[a]	0.177[d]	213[a]	-51[a]	3.1[d]	**ρ** 1.050[a] log K_{OW} 1.96[d]
Hydrotope	Polyethylene Glycol (25322-68-3)	Liquid[h]	Polyethylene glycol is a polymer, which typically have high molecular weights, low vapor pressures, and high melting and boiling points.				Soluble[h]	**ρ** 1.1[h]
Preservative	Butylated Hydroxytoluene (128-37-0)	Solid[a]	220.35[a]	0.00516[d]	265[a]	70[a]	Insoluble[a]	**ρ** 1.048[a] log K_{OW} 5.10[d]
Stabilizer / Suppressor	N,N-Dimethyldodecylamine Oxide (1643-20-5)	Solid[d]	229.41[d]	6.23e-8[d]	N/A	132[d]	190[d]	log K_{OW} 4.67[d]
Oxidizing Bleach	Sodium Hypochlorite (7681-52-9)	Solid[a]	74.44[a]	1.03e-13[d]	N/A	18[a]	29.3[a]	log K_{OW} -3.42[d]
Reducing Bleach	Sodium Bisulfite (7631-90-5)	Solid[a]	104.06[a]	Salt; VP assumed negligible	Decomp[b]	Decomp[b]	Soluble[a]	**P** 1.48[a]
Antichlor	Sodium Thiosulfate (7772-98-7)	Solid[a]	158.11[a]	Salt; VP assumed negligible	Decomp[a]	48[a]	Soluble[a]	**ρ** 1.69 at 17°C pH 6.5 - 8 in solution[a]
Sour	Phosphoric Acid (7664-38-2)	Liquid[g]	98[g]	0.03 at 20°C[g]	158[g]	21[g]	Miscible at all proportions to H_2O[g]	**ρ** 1.69 at 25°C pH 1.5 in 0.1N aq solution[g]
Fabric Softener	Dimethyloctadecyl benzyl ammonium chloride (122-19-0)	Solid[b]	424.2[c]	Salt; VP assumed negligible	N/A	N/A	Soluble[b]	log K_{OW} 3.23[d]
Starch	Starch (9005-25-8)	Solid[a]	Starch is a high molecular weight carbohydrate polymer found naturally in plants.[a,b] Physical properties are not easily characterized.				Insoluble in cold water, gels in hot water[a,b]	

N/A – Not Available.

a – Source: Merck, 1996.
b – Source: Hawley, 1997.
c – Source: CambridgeSoft, 2004.
d – Source: SRC, 2004.
e – Source: Stephan Company, 2004.
f – Source: Dow, 2003.
g – Source: JT Baker, 2006a.
h – Source: JT Baker, 2006b.
i – Source: Stepan Company, 2006.

OVERALL APPROACH AND GENERAL FACILITY ESTIMATES

This document presents a standard approach for estimating environmental releases of and worker exposures to laundry wash chemicals used in water-based washing operations at industrial and institutional laundries. The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible; however, EPA acknowledges several areas in which additional wash chemical information would benefit the scenario. These data needs are summarized in Section 7. EPA intends that the default values cited throughout this scenario only be used when appropriate site-specific or industry-specific information is not available.

Because this scenario presents several alternative default assumptions or values for some estimation parameters, selecting different defaults will affect the final assessment results differently. For example, conservative or high-end daily use rates will result in more conservative release estimates[6]. Alternatively, average or median use rates will result in release estimates that are more "typical" of the industry. This ESD presents available data that support alternative input values.

This section of this ESD presents general facility calculations, which estimates the operating days, concentration of the chemical of interest in the laundry cleaning product, throughput of the laundry cleaning product containing the chemical of interest, number of laundries that use the chemical, and the number of containers used per facility.

Section 4 of this document presents the environmental release assessment, which uses the general facility estimates to estimate of the quantity of laundry wash chemical released from various points in the washing process and the most likely media of release for each release source.

Section 5 of this document presents the occupational exposure assessment, which uses both the general facility estimates and release estimates to estimate the number of workers potentially exposed while performing various process activities and the corresponding potential level (quantity) of both inhalation and dermal exposure.

Introduction to the General Facility Estimates

The general facility calculations are based mainly on data obtained by EPA's Office of Water during the effort to develop pretreatment standards for the industrial laundries industry. The DEQ database contains information from 82 industrial launderers, 45 linen suppliers, and 46 combined laundries (see Section 1.2). DEQ data referenced throughout this ESD are taken from these facilities' responses to the DEQ. Data presented in this document for "all industrial laundries" includes industrial launderers, linen suppliers, and combined laundries. Because the types of linens washed at institutional laundries are more similar to linen suppliers, data for linen suppliers has been scaled for institutional laundries.

Table 3-1 summarizes the general facility parameters developed in this section with their corresponding section number. In addition, Table A-4 in Appendix A presents a detailed summary of the default values used as inputs to each of the general facility estimates, accompanied by their references.

[6] Note: When evaluating environmental releases, EPA typically assumes the highest daily release is the most conservative, because it will result in the highest aquatic stream concentrations. Therefore, EPA typically uses high-end daily use rates to generate conservative environmental release estimates. Conversely, for conservative occupational exposure assessments, EPA typically utilizes lower daily use rates, which will result in a greater number of use sites, longer use duration, and a greater number of workers exposed.

Table 0-1. Summary of General Facility Parameters

Parameter	Description	Section
$TIME_{working_days}$	Operating Days (days/yr)	3.2
$F_{chem_formulation}$	Weight fraction of the chemical of interest in the laundry product (kg chemical of interest/kg formulation)	3.3
$Q_{facility_day}$	Daily use rate of laundry product containing the chemical of interest (kg of product/site-day)	3.4
Q_{chem_day}	Daily use rate of chemical of interest (kg chemical of interest/site-day)	3.5
N_{sites}	Number of sites using the laundry product containing the chemical of interest (sites)	3.6
$N_{cont_site_yr}$	Annual number of containers containing chemical of interest per site (containers/site-year)	3.7

Operating Days

LaundryESP, a joint environmental stewardship program sponsored by the Uniform and Textile Service Association (UTSA) and the Textile Rental Service Association (TRSA) collected operational data from 1997 to 2002 from over 600 industrial laundries. These data are presented in Table 0-2. These data are consistent with 1994 data collected in the DEQ (facilities reporting in the DEQ averaged 261 days/yr and 11.3 hrs/day) (USEPA, 1994).

Table 0-2. Industrial Laundry Operational Data

	Days of Operation per Year		Hours of Operation per Day	
Year	Average	Range	Average	Range
1997	260	20 - 365	11.8	6 – 21
1998	261	30 - 365	12.0	6 – 22
1999	260	34 - 365	12.2	6 – 22
2000	259	72 - 365	11.9	6 – 23
2001	260	152 - 365	11.9	6 – 23
2002	260	85 - 365	11.5	6 – 22

Source: LaundryESP Operational Data (generated 9/15/05), as presented in UTSA, 2005.

Data on the days of operation at institutional laundries was not available; however, data from an OPL equipment supplier recommends purchasing equipment based on 37.5 hours of operation/week (Pierce Commercial, 2005). This would correspond to 7.5 hours/day over 5 days/week or 260 days/yr, although many facilities that operate institutional laundries (e.g., hotels, hospitals) may operate up to 365 days/yr. Because both industrial and institutional laundries average approximately 260 days of operation per year, this may be used as a default if site-specific information is not available.

$TIME_{working_days}$ = Operating days (Default = 260 days/yr; See Section 3.2)

Concentration of the Chemical of Interest in the Laundry Cleaning Product

As discussed in Section 2.3, products received at industrial laundries are typically over 90 percent one chemical (e.g., detergents may be over 90 percent surfactant with small concentrations of

stabilizers and brighteners). This allows facilities greater flexibility to create optimal mixes of chemicals for the specific requirements of each load. Smaller institutional laundries may receive "pre-built" products that combine surfactants, builders, and other wash chemicals. If site-specific or chemical-specific information is not available, Table 3-3 presents default assumptions for the product type and concentration for each chemical type for both industrial and institutional laundries. If the type of laundry the chemical of interest is used at is unknown, values for industrial laundries are recommended as default because they are greater. Please note that the concentrations are designed to represent high end concentrations based on the data presented in Section 2.3. Please refer to these data if alternate values are desired. If the chemical function is unknown, 100 percent concentration in the laundry cleaning product may be assumed.

$F_{chem_formulation}$ = Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

Table 0-3. Defaults for Product Types and Concentrations

Chemical	Industrial Laundry Default Product Type	Industrial Laundry Default Concentration	Institutional Laundry Default Product Type	Institutional Laundry Default Concentration
Alkali / Builders	Alkali / Builder	100	Detergent	50
Antimicrobial Agents	Detergent	4	Detergent	4
Anti-Redeposition Agents	Alkali / Builder	5	Detergent	3
Antichlors	Antichlor	100	Antichlor	100
Bleaches	Bleach	100	Bleach	100
Corrosion Inhibitors	Detergent	4	Detergent	4
Enzymes	Detergent	3	Detergent	3
Fabric Softeners	Fabric Softener	100	Fabric Softener	100
Fragrances	Detergent	2	Detergent	2
Hydrotypes and Viscosity Controlers	Detergent	5	Detergent	4
Optical Brighteners	Detergent	5	Detergent	3
Preservatives	Detergent	4	Detergent	4
Sours	Sour	100	Sour	100
Starches	Starch	100	Starch	100
Stabilizers and Suppressors	Detergent	5	Detergent	4
Surfactants (Default)	Detergent	100	Detergent	32
Water Softeners	Alkali / Builder	55	Detergent	33
All Other Products	Other Products	100	Other Products	100
All Other Additives	Detergent	4	Detergent	4

Source: See Section 2.3 and CEB, 2006b.

Use Rate of the Laundry Product

Annual use rates of laundry cleaning products ($Q_{facility_yr}$) at industrial laundries can be estimated from DEQ data. Respondents estimated the quantity and purpose of laundry cleaning products used in their facilities in 1993. This use rate is assumed to be the purchase rate (in-process use rate plus container residue and transfer losses). Table 0-4 and Table 3-5 present annual use information for powdered laundry products and liquid laundry products, respectively. These tables show annual use rates for industrial launderers, linen suppliers, and all industrial laundries by industry average, median, and 90th percentile derived from DEQ data. The daily use rate of the chemical of interest can be directly calculated from the annual product use rates.

No information is currently available on the average annual use rate of laundry cleaning products at institutional laundries; however, the types of items laundered at institutional laundries are expected to be similar to the types of items laundered at linen suppliers. Therefore, the use rates at linen suppliers were scaled based on the average amount of textiles laundered per year at linen suppliers versus

institutional laundries (presented in Table 1-2) to generate the estimated use rates at institutional laundries presented in Table 3-4 and Table 3-5.

When site-specific information is not available, the steps outlined in Figure 0-1 should be followed to determine which values from Table 0-4 and Table 3-5 to use in estimating calculations. Figure 0-1 includes notes providing further explanation of the outlined steps. The daily use rate of the product ($Q_{facility_day}$) containing the chemical of interest can be calculated using the following equation:

$$Q_{facility_day} = \frac{Q_{facility_yr}}{TIME_{working_days}} \quad (3\text{-}1)$$

Where:

$Q_{facility_day}$ = Daily use rate of laundry product (kg formulation/site-day)

$Q_{facility_yr}$ = Annual use rate of laundry product (Default = 27,000 kg formulation/site-yr[7]; See Figure 0-1 to determine which data points from Table 0-4 and Table 3-5 should be used)

$TIME_{working_days}$ = Operating days (Default = 260 days/yr; See Section 3.2)

[7] This default should be used only if all default assumptions in Table 3-3 and Figure 0-1 are used.

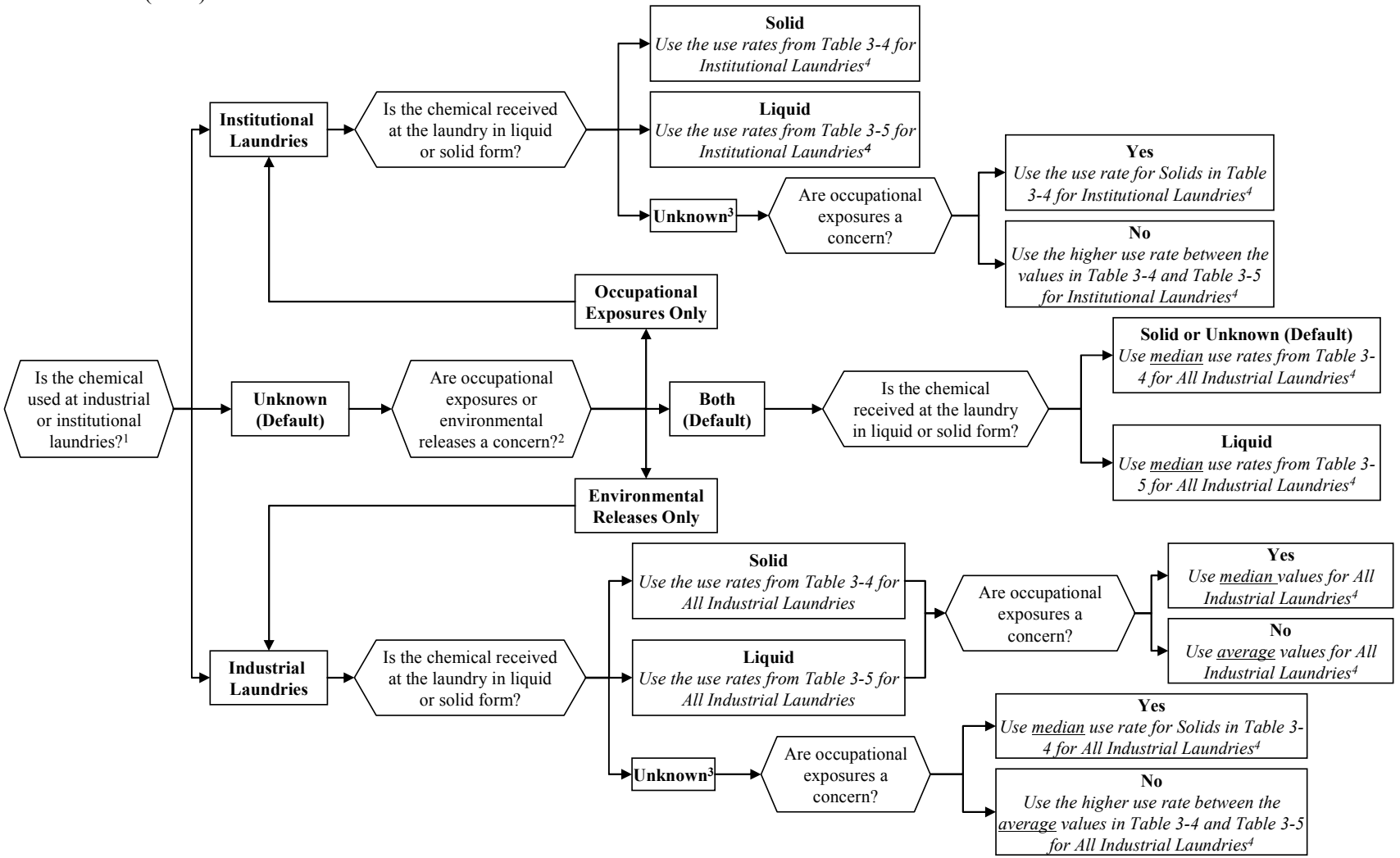


Figure 0-1. Decision Logic Diagram for Determining the Use Rate

Notes for Figure 0-1 are presented on the following page.

Notes for Figure 0-1:

1. Industrial laundries are typically significantly larger than institutional operations. Industrial laundries receive the majority of their wash chemicals at high concentrations and tailor the wash chemistry for the type of textile being laundered. As discussed in Section 2.3.1, if a surfactant or builder is received at a laundry as part of a formulated detergent, it is more likely used at smaller institutional laundries.

2. If the type of laundry (institutional or industrial) is not specified and cannot be determined, the concerns of the screening-level assessment should be considered. If occupational exposures are the only concern, *institutional laundries* may be selected because the lower use rate will result in greater number of potentially exposed workers. If environmental releases are the only concern, average use rates for *all industrial laundries* may be selected because the higher use rate will result in a greater daily release. If both exposures and releases are a concern, median use rates for *all industrial laundries* may be selected because they fall between the use rates for institutional laundries and the average use rates for all industrial laundries. The median annual use rate from Table 0-4 and Table 3-5, are also likely to be more accurate. The average values have been raised by a few outliers in the data; in many cases, less than 10 percent of the data points were above the average value as shown by the records with average values greater than the 90^{th} percentile (e.g., liquid alkaline/builder for industrial launderers in Table 3-5). These data points likely represent several facilities that are significantly larger than typical facilities.

3. If the form of chemical of interest is unknown and occupational exposures are a concern, assume that the laundry receives all chemicals in powdered form, since inhalation and dermal exposure estimates are higher for powders than liquids. Use the values in Table 0-4 as defaults. Note that this may be an overly conservative estimate since almost 90 percent of industrial laundries use liquid chemicals exclusively (see Table 2-1). If occupational exposures are not a concern, the higher value between Table 3-4 and Table 3-5 may be used to maximize the daily release.

4. The decision logic presented in this Figure is designed to guide the user in selecting which column from Table 3-4 or Table 3-5 should be utilized. To determine which row should be utilized, see Table 3-3.

Table 0-4. Annual Use Rate of Powdered Laundry Products[a,b]

Laundry Cleaning Product	Annual Use Rate of Powdered Laundry Products (kg/site-yr)									
	Linen Suppliers[c]			Industrial Launderers[c]			All Industrial Laundries[c]			Institutional Laundry[d]
	Median	Average	90th %	Median	Average	90th %	Median	Average	90th %	Average
Alkaline/Builder	15,000	14,000	22,000	1,700	18,000	57,000	4,200	15,000	33,000	1,800
Antichlor	1,500	1,500	2,600	340	440	940	500	900	2,200	190
Bleach	450	1,200	3,200	730	1,300	2,900	730	1,200	2,700	160
Detergent	28,000	35,000	57,000	28,000	45,000	95,000	27,000	40,000	81,000	4,500
Fabric Softener	590	610	1,300	590	830	2,200	570	690	1,600	79
Sour	2,300	2,700	6,300	1,000	1,600	4,000	1,800	2,100	4,600	350
Starch	8,000	13,000	23,000	590	1,300	3,500	1,900	7,100	20,000	1,700
Other Products	500	1,100	2,700	180	730	1,500	180	870	3,100	140

Table 0-5. Annual Use Rate of Liquid Laundry Products[a,b]

Laundry Cleaning Product	Annual Use Rate of Liquid Laundry Products (kg/site-yr)									
	Linen Suppliers[c]			Industrial Launderers[c]			All Industrial Laundries[c]			Institutional Laundry[d]
	Median	Average	90th %	Median	Average	90th %	Median	Average	90th %	Average
Alkaline/Builder	16,000	37,000	69,000	16,000	96,000	67,000	17,000	64,000	71,000	4,700
Antichlor	830	2,200	4,100	790	1,200	2,500	890	6,200	4,200	280
Bleach	14,000	34,000	81,000	3,000	11,000	19,000	6,400	29,000	62,000	4,400
Detergent	4,900	21,000	62,000	7,900	19,000	47,000	6,800	21,000	56,000	2,700
Fabric Softener	820	2,100	5,000	950	1,700	3,100	1,200	4,900	5,300	270
Sour	4,000	6,900	20,000	2,400	7,800	5,800	2,600	7,000	16,000	890
Starch	530	1,100	3,100	230	260	400	450	1,800	3,200	140
Other Products	1,100	2,500	6,700	950	4,800	16,000	680	4,200	9,300	320

90th % - Statistical value for which 90 percent of the data points are at or below this value.

a – Source: U.S. EPA, 1994.

b – Respondents to the DEQ could report usage in either pounds per year or gallons per year. It is assumed that products reported in pounds are powders and products reported in gallons are liquids. Gallons were converted to kilograms by assuming a density of 1 kg/L (3.785 kg/gal).

c – Note: Linen suppliers and industrial launderers are both sub-categories of industrial laundries defined by the types of items they typically launder (see Section 1.1). The DEQ database contains information from 173 total industrial laundries, including 45 linen suppliers, 82 industrial launderers and 46 combined laundries (see Section 1.2).

d – Estimated by scaling the average use rate at linen suppliers by the average annual amount of laundry processed at linen suppliers (3,300,000 kg/site-yr) versus institutional laundries (425,000 kg/site-yr; weighted average for hotels, hospitals, and nursing homes) presented in Table 1-2. Only average use rates were estimated because only average data on the quantity of laundry processed were available.

As shown in Figure 3-1, this scenario presents default approaches that provide conservative screening-level assessments. For cases where the type of laundry facility is unknown, the figure directs the user to apply the throughput values for industrial laundries. The daily use rate for industrial laundries is higher, resulting in higher facility release rates and a more conservative assessment. If additional data is available or a more detailed assessment is desired, the production volume of the chemical may be split between industrial and institutional uses. However, if the split is unknown but desired, an approach for splitting the production volume of the chemical between industrial and institutional laundries is presented below in Table 3-6, based on the respective amount of laundry processed. Using this approach, approximately 25 percent of laundry cleaning products could be assumed used at industrial sites versus 75 percent used at institutional laundries. Note that no direct data was found on the percent of laundry cleaning products used at industrial laundries versus institutional laundries. Additionally, some chemicals may be commonly used at industrial laundries, but rarely used at smaller institutional laundries.

Table 0-6. Estimated Percentage of Laundry Products Used at Industrial and Institutional Laundries

Laundry Category	Facility Type	Number of Facilities (sites)	Percent With OPLs (%)	Average Amount of Dry, Clean Laundry Processed (kg/site-yr)	Estimated Total Amount of Clean, Dry Laundry Processed at All Site (10^6kg/yr)[e]	Percent of All Laundry Processed at the Facility Type[f] (%)
Industrial	Linen Supply	1,018[a]	-	3,300,000[b]	3,359	6.2
Industrial	Industrial Launderers	3,320[a]	-	3,000,000[b]	9,960	18
All Industrial Laundries		*4,338*	-	-	*13,319*	*25*
Institutional	Hospitals	6,200[c]	18[c]	2,180,000[c]	2,433	4.5
Institutional	Nursing Homes/ Assisted Living	54,000[c]	86[c]	406,000[d]	18,855	35
Institutional	Hotels	47,977	~100[d]	402,000[d]	19,287	36
All Institutional Laundries		*95,533*[g]	-	-	*40,575*	*75*
Total of All Laundries		**99,871**	-	-	**53,894**	-

a – Source: USCB, 2005.
b – Source: USEPA, 1994.
c – Source: Laundry Today, 2004.
d – Source: CUWCC, 2006.
e – Estimated by multiplying the average amount of dry, clean laundry processed per site per year by the number of laundry facilities.
f – Estimated by dividing the estimated total amount of dry, clean laundry processed at all sites within the facility type by the total amount of laundry processed at all sites for all facility types (i.e., 53,894 $\times 10^6$kg/yr).
g – Calculated by multiplying the number of facilities by the percent with OPLs and summing the totals for each type of institutional facility.

Note that facilities may use multiple formulations of a particular laundry product. For example, a facility may use one detergent containing the chemical of interest for heavily soiled loads, and another detergent formulation not containing the chemical of interest for fine linens. Based on the DEQ database, Table 0-7 presents the average number of laundry product formulations used at industrial laundries. However, the estimation technique for the throughput of the chemical of interest presented in this scenario assumes that the chemical of interest is in every formulation of a laundry product used at the facility. While the method presented in the scenario may slightly overestimate the throughput of the chemical of interest, it is recommended for screening-level assessments. Also, laundries frequently purchase multiple

formulations from a single supplier. While the facility may use two different detergent formulations, the supplier may use the chemical of interest in both formulations.

Table 0-7. Average Number of Formulations of a Laundry Product Used at Each Facility

Laundry Product	Average Number of Formulations
Alkaline/Builder	1.19
Antichlor	1.06
Bleach	1.29
Detergent	2.54
Fabric Softener	1.13
Sour	1.11
Starch	1.15

Source: U.S. EPA, 1994.

While the data presented in Table 0-7 should not be used as default, it may be used to adjust the throughput of the chemical of interest. For example, if the chemical of interest is used at only a small number of sites (e.g., less than five), a correction factor may be used to adjust the throughput using the following equation. The adjusted throughput would then be used in all subsequent calculations.

$$Q_{facility_day_adjusted} = \frac{Q_{facility_day} \times N_{formulations_chem}}{N_{product_formulations}} \quad (3\text{-}2)$$

Where:

$Q_{facility_day_adjusted}$ = Daily use rate of laundry product containing the chemical of interest adjusted for multiple formulations used per site (kg formulation/site-day)

$Q_{facility_day}$ = Daily use rate of laundry product (kg formulation/site-day)

$N_{formulations_chem}$ = Number of laundry products containing the chemical of interest used per site (Default = 1 formulation/site)

$N_{product_formulations}$ = Average number of laundry products used per facility (Default = 1 formulation/site; alternate defaults may be selected from Table 0-7)

Use Rate of the Chemical of Interest

The daily use rate of the chemical of interest may be estimated utilizing the daily use rate of the laundry product containing the chemical of interest ($Q_{facility_day_adjusted}$) and the concentration of the chemical within the laundry product ($F_{chem_formulation}$).

$$Q_{chem_day} = Q_{facility_day_adjusted} \times F_{chem_formulation} \quad (3\text{-}3)$$

Where:

Q_{chem_day} = Daily use rate of chemical of interest (kg chemical of interest/site-day)

$Q_{facility_day_adjusted}$ = Daily use rate of laundry product containing the chemical of interest adjusted for multiple formulations used per site (kg formulation/site-day; See Section 3.4)

$F_{chem_formulation}$ = Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

Number of Sites

The daily use rate and the annual production volume of the chemical of interest can be used in the following equation to estimate the number of sites using the laundry cleaning product containing the chemical of interest. Table 1-2 presents the maximum number of sites for both laundry types not to be exceeded.

$$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_day} \times TIME_{working_days}} \quad (3\text{-}4)$$

Where:

N_{sites}[8] = Number of sites using the laundry product containing the chemical of interest (sites)

Q_{chem_yr} = Annual production volume of the chemical of interest - for laundry use (kg chemical of interest/yr)

Q_{chem_day} = Daily use rate of chemical of interest - at a laundry facility (kg chemical of interest/site-day; See Section 3.5)

$TIME_{working_days}$ = Operating days (Default = 260 days/yr; See Section 3.2)

Annual Number of Containers Used per Facility

The number of containers used annually per site can be estimated from the laundry cleaning product use rate, the container size, and the density of the formulation. Laundry cleaning products may be received at the industrial or institutional laundry in bags, cardboard boxes, or drums of various types and sizes (Renescu and Kerr, 1993) as a solid powder or liquid solution. However, most of the cleaning products are liquid, received at industrial laundries and larger institutional laundries in drums, totes, or bulk tanker trucks (UTSA, 2005). Institutional laundries typically receive liquid cleaning products in pails or other smaller containers. In the absence of site-specific information, a 55-gallon drum may be assumed for industrial laundries and a 5-gallon pail may be assumed for institutional laundries as the default transportation container size because they are the most common. If the fluid density is not known, the density of water may be assumed (1 kg/L). The annual number of containers used may be estimated using the following equation:

$$N_{cont_site_yr} = \frac{Q_{chem_yr}}{F_{chem_formulation} \times Q_{cont} \times N_{sites}} \quad (3\text{-}5)$$

[8] The value for N_{sites}, calculated using equation 3-4, should be rounded up to a whole number. Q_{chem_day} should be adjusted after N_{sites} is calculated to account for any rounding errors:

$$Q_{chem_day} = \frac{Q_{chem_yr}}{N_{sites} \times TIME_{working_days}}$$

Where:

$N_{cont_site_yr}$	=	Annual number of containers containing chemical of interest per site (containers/site-year)
Q_{chem_yr}	=	Annual production volume of the chemical of interest (kg chemical of interest/yr)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)
Q_{cont}[9]	=	Mass of the laundry cleaning product in the container (kg formulation/container)
N_{sites}	=	Number of sites using the laundry product containing the chemical of interest (sites)

Summary of the Relationship of Section 0 Parameters

The values for chemical of interest throughput (Q_{chem_day}), number of sites (N_{sites}), and production volume of the chemical of interest (Q_{chem_yr}) are all related. This scenario presents an equation to calculate the parameter for the chemical of interest throughput (Q_{chem_day}) from DEQ and UTSA data. The chemical of interest throughput and supplied production volume are then used to determine the number of sites.

If the number of sites is known, the chemical of interest throughput can be calculated directly without the use of Equation 3-3. This alternate calculation is:

$$Q_{chem_day} = \frac{Q_{chem_yr}}{N_{sites} \times TIME_{working_days}}$$

If N_{sites} is known and $TIME_{working_days}$ is unknown, it is recommended that the default assumption that the laundry operates 260 days per year (see Section 3.2) is made, and Q_{chem_day} be calculated using the equation above.

It is recommended to calculate the chemical of interest throughput based on the methodology presented in Sections 3.4 and 3.5 and compare it to the throughput based on the number of sites and operating days, as calculated above.

[9] If the mass of the laundry cleaning product in each container is not known, it can be calculated using the volume of the container and the density of the formulation:

$$Q_{cont} = V_{cont} \times RHO_{formulation}$$

Where:

V_{cont}	=	Volume of laundry product container (Default = 208 L/container for 55-gallon drum or 19 L/container for 5-gallon pail) See Table B-3 in Appendix B for alternative default container volumes.
$RHO_{formulation}$	=	Density of the formulation (Default = 1 kg/L)

ENVIRONMENTAL RELEASE ASSESSMENTS

This section presents approaches for calculating the amount of chemical of interest released for each release source during water-based washing operations at industrial and institutional laundries. The release sources are discussed in the order that they occur in the process (please refer to flow diagram in Figure 2-1). An indication of the most likely receiving media (i.e., air, water, landfill, incineration) is also provided. The primary sources of releases for nonvolatile chemicals include container residue (Release 1) and wash water discharge (Release 6). Volatile chemicals of interest may also be released to air during transfer operations (Release 3), container cleaning (Release 2), and during washing operations and wastewater discharge (Release 5, Release 6). Key default values used for the release estimates, accompanied by their respective references, are provided in Table A-4 of Appendix A.

All release equations in this section estimate daily rates for a given site. To estimate annual releases for all sites for a given source, the release rates must be multiplied by the number of days of release and by the number of sites using the laundry cleaning product containing the chemical of interest (N_{sites}) (See Equation 3-4).

For most release sources, this scenario assumes that the number of days of release is the same as the days of operation. Some of these releases are expected to go to the same medium of release on the same days; therefore, daily and annual releases to a given medium may be summed to yield total amounts released per site per day and per year, respectively.

Many of the environmental release estimates presented in this document are based on standard EPA/OPPT release models. The remaining estimate is based on the assumption that the entire volume loaded into the washer is discharged to the environment during the washing process. Note that no releases occur from equipment cleaning because all of the production volume is assumed to already be released to water or air. Table 4-1 summarizes the release estimation methods used in this scenario. Refer to Section 8 for a description of the sources reviewed and full citations for those specifically used in these calculations.

Note that the standard model default values cited are current as of the date of this document; however, EPA may update these models as additional data become available. EPA recommends using the most current version of the models in these calculations.

EPA has developed a software package (ChemSTEER) containing these models as well as all current EPA defaults. Appendix B provides additional information on ChemSTEER, including instructions for obtaining the program, as well as background information, model equations, and default values for several parameters for all standard EPA/OPPT models.

To estimate environmental releases, this scenario assumes that volatile chemicals may be released to air at certain points in the process, and that associated inhalation exposures to the chemical vapors may occur as a result of handling those chemicals. Each scenario user will have to decide the definition of what constitutes *volatile* based on the specific objectives of the assessment. For example, EPA often assumes chemicals with a vapor pressure less than 0.001 torr are nonvolatile, resulting in negligible releases to air and negligible associated inhalation exposures (CEB, 1991).

Table 0-1. Summary of Laundries Scenario Release Models

Release Source #	Description	Model Name or Description[a]	Standard EPA Model (✓)	On- or Off-Site Release
1	Container residue released to water, incineration, or landfill	*EPA/OPPT Bulk Transport Residual Model* *EPA/OPPT Drum Residual Model*(Default) *EPA/OPPT Small Container Residual Model* *EPA/OPPT Solid Residuals in Transport Containers Model*	✓	On- or off-Site
2	Fugitive releases of volatile chemicals to air during container cleaning	*EPA/OPPT Penetration Model*	✓	On-site
3	Fugitive releases of volatile chemicals to air during transfer operations	*EPA/OPPT Penetration Model*	✓	On-site
4	Dust losses of powdered chemicals during unloading to air, water, incineration, or land	*EPA/OPPT Dust Emissions from Transferring Solids Model*	✓	On-site
5	Releases to air of volatile chemicals into the workers' breathing zone during operations	*EPA/OPPT Penetration Model*	✓	On-site
6	Release to POTW (nonvolatile chemicals) and POTW and air (volatile chemicals) from the water-based washing operation	All chemicals added to the washing operation are assumed discharged to the environment		On-or off-site

OPPT – Office of Pollution Prevention and Toxics.
a – Additional detailed descriptions for each of the models presented in this section are provided in Appendix B.

Control Technologies

Table 0-2 presents the percentage of industrial laundries that have on-site control technologies for water releases, based on data from the DEQ. Note that EPA's Effluent Guideline's program for the industrial laundries point source category was limited to facilities that laundered industrial textile items (e.g., shop towels, mops, rugs, filters) and focused on the release of dirt, oil, and other materials removed from the textile during the laundering process (see Section 1.2). Most of the control technologies evaluated in the *TDD* (USEPA, 1997) are designed to remove dirt, oil, and other materials removed from the textile during the laundering process, not minimize the release of chemicals in laundry cleaning products. Therefore, the effects of on-site control technologies are not considered in this scenario when estimating potential releases of chemicals in laundry cleaning products. After any on-site pretreatment, all sites responding in the DEQ reported discharging to a Publicly-Owned Treatment Works (POTW).

At an industrial laundry that primarily laundered white linens and textiles for the medical industry visited by EPA during the development of this scenario, wastewater is sent through a lint screen to remove solids, neutralized using sulfuric acid as necessary to meet pH pretreatment standards, and discharged to a POTW.

Table 0-2. On-Site Control Technologies at Industrial Laundries

Control Technology	Percentage of Facilities Using Technology
Collection or Settling Basins	83%
Screens	72%
pH Equalization/Neutralization	47%
Air Flotation	20%
Clarification	20%
Media Filtration	5%
Sludge Dewatering	29%
Oil/Water Separation	18%
Other	17%

Source: U.S. EPA, 1994.

Container Residue (Release 1)

The amount of laundry cleaning product remaining in the transportation containers depends on the size of the transport container and the physical form of the laundry product. In the absence of industry-specific data, the following standard EPA/OPPT models may be used to estimate container residue releases. The rationale, defaults, and limitations of these models are further explained in Appendix B.

- *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 (379 liters);
- *EPA/OPPT Drum Residual Model* may be used for drums containing between 20 and 100 gallons of liquid (76 to 379 liters);
- *EPA/OPPT Small Container Residual Model* may be used for liquid containers containing less than 20 gallons (76 liters); and
- *EPA/OPPT Solid Residuals in Transport Containers Model* may be used for containers of all sizes containing solids.

Empty containers are handled differently at industrial and institutional laundries. Use the approaches presented for industrial or institutional laundries consistent with the selection of industrial or institutional laundries when estimating the facility throughput (see Section 3.4 and Figure 3-1).

Industrial Laundries (Default)

Empty drums used at industrial laundries are typically returned directly to the wash chemical supplier or sent to a drum recycler/reconditioner. The drums are triple-rinsed before reuse (CEB, 2006b, UTSA, 2005, Shultz, 2004). Empty transport containers are not typically rinsed at the laundry facility. Similarly bulk totes or tank trucks would be rinsed at the wash chemical supplier's site or a separate cleaning facility. However, pails, cardboard boxes, and other smaller containers that may be used for

laundry products received in smaller quantities may be discarded without rinsing into municipal solid waste (potential disposal to incineration or landfill).

EPA recommends assessing container residue releases from chemicals used at industrial laundries at the laundry cleaning product formulation facility. Note that even if the containers are being rinsed at a drum recycler/reconditioner rather than the laundries, the number of drum recyclers/reconditioners is expected to be closer to the number of formulation sites than to the number of use sites (i.e., the formulators typically contract out the drum reconditioning prior to reuse rather than each laundry). The following equation could be used to estimate the release to water from rinsing the containers at the laundry product formulation sites using the number of formulation days ($TIME_{formulation_days}$) and the number of the formulation sites ($N_{formulation_sites}$)[10]:

$$Elocal_{container_residue_disp} = \frac{Q_{chem_yr} \times F_{container_residue}}{TIME_{formulation_days} \times N_{formulation_sites}} \quad (4\text{-}1a)$$

This release will occur over [$TIME_{formulation_days}$] days/year from [$N_{formulation_sites}$] sites.

Where:

$Elocal_{container_residue_disp}$	=	Daily release of chemical of interest from container residue (kg chemical of interest/site-day)
Q_{chem_yr}	=	Annual production volume of the chemical of interest (kg chemical of interest/yr)
$F_{container_residue}$	=	Fraction of chemical remaining in the container as residue (Default: 0.03 kg chemical remaining/kg shipped for drums containing liquids (CEB, 2002a); See Appendix B for defaults used for other container types and for solids)
$TIME_{formulation_days}$	=	Days of operation at the formulation sites (days/yr)
$N_{formulation_sites}$	=	Number of sites formulating the chemical of interest into laundry cleaning products (sites)

If the containers are rinsed on-site, the methodology presented for institutional laundries below could be utilized to estimate releases from container residue.

Institutional Laundries

While empty drums used at industrial laundries and larger institutional laundries are typically returned directly to the wash chemical supplier or sent to a drum recycler/reconditioner, institutional laundries typically receive laundry chemicals in pails, cardboard boxes, and other smaller containers (CEB, 2006b, UTSA, 2005, Shultz, 2004). These containers are typically discarded without rinsing into municipal solid waste (potential incineration or landfill).

The annual number of containers used ($N_{cont_site_yr}$) is estimated based on the use rate of the laundry cleaning product and the container size (see Section 3.7). As discussed in Section 3.7, 5-gallon (19 L) pails for institutional laundries and density of 1 kg/L (density of water) may be assumed if chemical-specific information is not available. If the $N_{cont_site_yr}$ value is fewer than the days of operation

[10] Default values for $TIME_{formulation_days}$ and $N_{formulation_sites}$ are outside the scope of this scenario; however, the 1996 *Generic Scenario for Surfactants in Industrial/Commercial* (CEB, 1996) provides methodologies to estimate these parameters.

($TIME_{working_days}$), the days of release equal $N_{cont_site_yr}$ (as calculated in Equation 3-5) and the daily release to incineration or land is calculated based on the following equation:

$$Elocal_{container_residue_disp} = Q_{cont} \times F_{chem_formulation} \times F_{container_residue} \times N_{cont_site_day} \quad (4\text{-}1b)$$

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

Where:

$Elocal_{container_residue_disp}$	=	Daily release of chemical of interest from container residue (kg chemical of interest/site-day)
Q_{cont}	=	Mass of the laundry cleaning product in the container (kg formulation/container) (Default: use the same value used to estimate $N_{cont_site_yr}$ in Section 3.7)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)
$F_{container_residue}$	=	Fraction of chemical remaining in the container as residue (Default: 0.006 kg chemical remaining/kg shipped for small containers containing liquids (CEB, 2002a); See Appendix B for defaults used for other container types and for solids)
$N_{cont_site_day}$[11]	=	Number of containers unloaded per site, per day (Default: 1 container/site-day)

If $N_{cont_site_yr}$ is greater than $TIME_{working_days}$, more than one container is unloaded per day (i.e., $N_{cont_site_day} > 1$). The days of release should equal the days of operation, and the average daily release can be estimated based on the following equation:

$$Elocal_{container_residue_disp} = Q_{chem_day} \times F_{container_residue} \quad (4\text{-}1c)$$

This release will occur over [$TIME_{working_days}$] days/year from [N_{sites}] sites.

Where:

$Elocal_{container_residue_disp}$	=	Daily release of chemical of interest from container residue (kg chemical of interest/site-day)
Q_{chem_day}	=	Daily use rate of chemical of interest (kg chemical of interest/site-day; See Section 3.5)
$F_{container_residue}$	=	Fraction of chemical remaining in the container as residue (Default: 0.006 kg chemical remaining/kg shipped for small containers containing liquids (CEB, 2002a); See Appendix B for defaults used for other container types and for solids)

Note: this equation may also be used if a container size is not assumed in Equations 3-5 and 4-1a, and $N_{cont_site_yr}$ is unknown.

[11] The daily number of containers unloaded per site may be estimated as (consistent with Section 3.7):

$$N_{cont_site_day} = \frac{N_{cont_site_yr}}{TIME_{working_days}}$$

($N_{cont_site_day}$ should be rounded up to the nearest integer.)

Where:

$N_{cont_site\ yr}$	=	Annual number of containers containing chemical of interest per site (containers/site-year) (See Equation 3-5)
$TIME_{working_days}$	=	Operating days (Default = 260 days/yr; See Section 3.2)

Open Surface Losses to Air During Container Cleaning (Release 2)

Most chemicals used in laundries are not volatile. For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, chemicals may volatilize while empty containers are being rinsed and cleaned ($Elocal_{air_cleaning}$). However, as discussed for Release 1, containers used at industrial laundries are typically rinsed off-site, and containers used at institutional laundries are typically disposed without rinsing. This release is presented for completeness if on-site rinsing occurs and as an example for how the release could be estimated at the laundry cleaning product formulation facility. If containers are not cleaned (default for institutional laundries), this release would be negligible.

The EPA/OPPT standard model for estimating releases to air from containers cleaned inside (*EPA/OPPT Penetration Model* as of the date of this scenario) should be used if chemical-specific information is not available.

Table 0-3 lists the model inputs and default values. The models and all current EPA/OPPT defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate open surface losses to air during container cleaning. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 0-3. *EPA/OPPT Penetration Model* Parameter Default Values During Container Cleaning

Input Parameter	Default Values
Diameter of Opening	CEB default 2 in. (5.08 cm) for all containers less than 5,000 gallons (CEB, 2002b) (See Appendix B for alternative default diameters)
Frequency of Use	On-site rinsing: Equal to the lesser of $N_{cont_site_yr}$ or $TIME_{working_days}$, consistent with Section 4.2 Off-site rinsing: $TIME_{formulation\ days}$ consistent with Section 4.2
Molecular Weight	Specific chemical parameter
Number of Sites	On-site rinsing: N_{sites} calculated in Section 0, Equation 3-4 Off-site rinsing: $N_{formulation\ days}$ consistent with Section 4.2
Operating Hours for the Activity	Number of containers cleaned per site, per day[12] divided by the unload rate (CEB, 2002b) (Default: 20 containers/hr for volumes between 20 and 1,000 gallons (CEB, 1991); Alternative default unload rates are found in Appendix B)
Vapor Pressure	Specific chemical parameter
Air Speed	CEB default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	Standard CEB default = 1

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

Transfer Operation Losses to Air from Loading Laundry Cleaning Product into Washers (Release 3)

Most chemicals used in laundries are not volatile. For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, releases to air may occur as a worker manually pours the laundry cleaning product into the washer (default scenario). Where automatic liquid injection systems are used, air releases are expected only when transfer lines are being connected to the transport containers. To estimate the release from either manual or automatic loading ($Elocal_{air_transfers}$), the *EPA/OPPT Penetration Model* may be used. While the *EPA/OAQPS AP-42 Loading Model* is the standard EPA/OPPT estimation model for transfer operations, it assumes containers are quickly and completely unloaded into a container of equal size, and estimates the release to air based on vapor displacement of saturated air. However,

[12] For on-site rinsing, the number of containers cleaned per site, per day is equal to $N_{cont_site_day}$, consistent with Release 1. For off-site rinsing, the following equation may be used to estimate the number of containers cleaned per formulation site, per day:

$$N_{cont_site_day} = \frac{N_{cont_site_yr} \times N_{sites}}{N_{formulation_sites} \times TIME_{formulation_days}}$$

($N_{cont_site_day}$ should be rounded up to the nearest integer.)

Where:

$N_{cont_site\ yr}$ = Annual number of containers containing chemical of interest per site (containers/site-year) (See Equation 3-5)
N_{sites} = Number of sites using the laundry product containing the chemical of interest (sites)
$TIME_{formulation_days}$ = Days of operation at the formulation sites (days/yr)
$N_{formulation_sites}$ = Number of sites formulating the chemical of interest into laundry cleaning products (sites)

laundry cleaning product transport containers will slowly be unloaded into washers over the course of several days or weeks. The *EPA/OPPT Penetration Model* estimates the volatilization of a chemical from a static pool of liquid; use of this model will provide a better estimate of the releases to air from this transfer operation.

Table 0-4 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.

Table 0-4. *EPA/OPPT Penetration Model* Parameter Default Values During Transfers of Liquids

Input Parameter	Default Values
Diameter of Opening	CEB default 2 in. (5.08 cm) for all containers less than 5,000 gallons (CEB, 2002b)
Frequency of Use	Manual loading (default): Operating days (default = 260 days/yr; See Section 3.2) Automatic loading: Equal to the lesser of $N_{cont_site_yr}$ or $TIME_{working_days}$ (See Section 4.2)
Molecular Weight	Specific chemical parameter
Number of Sites	Calculated in Section 0, Equation 3-4
Operating Hours for the Activity	Manual loading (default): Operation hours/day (default = 12 hr/day; see Table 3-2) Automatic loading: Number of containers per site, per day ($N_{cont_site_day}$, consistent with Release 1) divided by the unload rate (CEB, 2002b) (Default: 20 containers/hr for volumes between 20 and 1,000 gallons (CEB, 1991); Alternative default unload rates are found in Appendix B)
Vapor Pressure	Specific chemical parameter
Air Speed	CEB default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	Standard CEB default = 1

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

The CEB default for operating hours for this activity is equal to the number of containers used per site per day divided by a constant fill rate. Default fill rates are found in Appendix B. This is a reasonable assumption for automatic liquid injection systems, because releases are expected only when transfer lines are being connected. For manual loading, laundry cleaning products are unloaded from transport containers and loaded into washers throughout the working day. Table 3-2 presents the operating hours per day for industrial laundries. From these data, a default of 12 hours of operation per day may be assumed for industrial laundries. Additionally, as discussed in Section 3.2, institutional laundries are expected to operate approximately 7.5 hours per day. While transfer operations are not continuous throughout the day, as a conservative estimate assume this release occurs over 12 hours/site-day, if the laundry type is unknown. This would be appropriate where the lid is not placed back on the container after each transfer.

Dust Generation from Transfer Operations Released to Air, Water, Incineration, or Landfill (Release 4)

For chemicals received at industrial or institutional laundries in liquid laundry cleaning products, this release is negligible.

For powdered laundry products, dust generation is expected from transferring operations. Industry-specific data was not found on control technologies used to collect and dispose dust generated from unloading or transferring solid powders. The *EPA/OPPT Dust Emissions from Transferring Solids Model* may be used to estimate dust releases generated during the transfer of solid laundry cleaning products. This model assumes that up to 0.5 percent of the transferred quantity may be released to the environment. The rationale, defaults, and limitations of these models are further explained in Appendix B.

Control technologies to capture dust emissions (e.g., baghouse filter) are not anticipated at industrial or institutional laundries; however, if the powdered laundry product is being poured into a washer full of water, the water will likely reduce the dust generation. In some cases, uncontrolled/uncollected particulate may be small enough to travel several miles from the facility, resulting in environmental and human exposures to the chemical of interest beyond the boundaries of the site. Some amount of the dust particles may alternately settle on the floor or equipment within the workspace and are disposed of during facility cleaning (water if the floors are rinsed or land or incineration if the floors are swept). Therefore, if additional site specific information is not available, this release is conservatively assumed released to air, water, incineration, or land (CEB, 2007).

The following equation may be utilized to estimate potential releases from dust generation during transfer operations. If control technologies for capturing dust emissions are utilized, please utilize the alternate equations presented in Appendix B.

$$Elocal_{dust_fugitive} = Q_{chem_day} \times F_{dust_generation} \qquad (4\text{-}2)$$

Where:

$Elocal_{dust_fugitive}$ = Daily amount not captured by control technology from transfers or unloading (kg/site-day)

Q_{chem_day} = Daily use rate of chemical of interest (kg chemical of interest/site-day; See Section 3.5)

$F_{dust_generation}$ = Fraction of chemical lost during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled) (CEB, 2007)

This approach is designed for screening-level estimates where appropriate industry-specific or chemical specific information is not available. If the site provided a loss fraction from dust releases, then the site-specific number should be used.

Release to Air into the Worker's Breathing Zone from the Water-Washing Process (Release 5)

Most chemicals used in laundries are not volatile. For nonvolatile chemicals (e.g., the vapor pressure is <0.001 torr), releases to air are expected to be negligible.

During the water-based washing operation all wash chemicals are expected to eventually be released into the environment (see Section 4.7). While non-volatile chemicals are anticipated to be released entirely to water, volatile chemicals may evaporate and be released to air during the washing and drying process. While most of these volatile releases will be vented outside the facility from the washer or dryer, a portion of volatile chemicals may be released into the workers breathing zone. Please note that this release is not an estimate of the entire portion of the chemical of interest that may be released to air (see Section 4.7); rather, just an estimate of the portion that may be released into the worker's breathing zone. These releases are separated for better estimating inhalation exposure (Exposure C, See Section 5.5).

The *EPA/OPPT Penetration Model* may be used to estimate volatile release from a pool of liquid. During a site visit to an industrial laundry, EPA observed 1½ foot × 3 feet "lifters" located next to the large continuous-batch washer (CBW). These "lifters" are open vessels that process hot water from one stage of the washer to the next. While there may be multiple "lifters" on a large washer, one "lifter" may be assumed to estimate release vapors directly into the workers' breathing zone. Using this assumption to estimate the pool surface area, the *EPA/OPPT Penetration Model* may be used to estimate the portion that may be released into the worker's breathing zone.

While other releases to air of volatile chemicals presented in this scenario (Releases 2 and 3) are from emissions from mostly pure liquids (i.e., chemical at approximately 100% concentration) at room temperature, the chemical is at dilute concentrations in hot wash water for this release. Both the temperature of the wash water and concentration of the chemical of interest in the wash water will affect the volatility of the chemical. EPA recommends utilizing the vapor pressure of the chemical at 130ºF (55ºC) when estimating this release, based on the wash temperature of the washer observed during a site visit to an industrial laundry (CEB, 2006b).

Target concentrations in the wash water for most chemicals are approximately 100-150 ppm (CEB, 2006b); however, they may be as high as 800 ppm for some surfactants (UTSA, 2005). As a conservative estimate, a concentration of the chemical of interest in the wash water of 0.1 percent (1,000 ppm) may be assumed. Utilizing Raoult's Law, the vapor pressure of chemical within a mixture may be estimated by multiplying the mole faction of the chemical within the mixture by the pure component vapor pressure. Therefore, a vapor pressure correction factor, $F_{correction_factor}$, equal to the mole fraction of the chemical within the wash water can be estimated assuming water is the only other chemical species in the wash water[13]:

$$F_{correction_factor} = \frac{F_{chem_water} \times MW_{chem}}{\left(F_{chem_water} \times MW_{chem}\right) + \left(\left(1 - F_{chem_water}\right) \times MW_{water}\right)} \quad (4\text{-}3)$$

Where:

$F_{correction_factor}$ = Vapor pressure correction factor (moles of chemical/mole of wash water)

F_{chem_water} = Weight fraction of the chemical of interest in the wash water (Default = 0.001 kg chemical of interest/kg of wash water)

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

MW_{water} = Molecular weight of water (18 g of water/mole of water)

Note that EPA does not typically evaluate environmental releases and associated inhalation exposures to chemicals with adjusted vapor pressures (i.e., $F_{correction_factor}$ × the pure component vapor pressure) less than 0.001 torr (CEB, 1995). However, for this scenario, EPA recommends estimating potential environmental release and subsequent occupational exposure for chemicals with a pure component vapor pressure greater than 0.001 torr even if the adjusted vapor pressure is less than 0.001 torr. The 0.001 torr cutoff is based on exposure during standard worker activities in the chemical industry (e.g., unloading, drumming) (CEB, 1995), and may not be appropriate for the potential volatilization from a churning vessel of hot water (CEB, 1995).

[13] Note: Vapor pressure correction factors are not estimated for Releases 2 and 3 because the chemical of interest is at a significantly higher concentration in the laundry cleaning product and the molecular weights of the other chemical components are unknown. EPA typically assumes that chemical-containing mixture exhibits the vapor pressure of the chemical of interest, as conservative (i.e., $F_{correction_factor} = 1$).

Table 4-5 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 operations. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 0-5. *EPA/OPPT Penetration Model* Parameter Default Values During Operations

Input Parameter	Default Values
Diameter of Opening	73 cm (a circle with a 73 cm diameter has the same surface area as a 1.5ft x 3ft rectangle)
Frequency of Use	Operating days (default = 260 days/yr; See Section 3.2)
Molecular Weight	Specific chemical parameter
Number of Sites	Calculated in Section 0, Equation 3-4
Operating Hours for the Activity	Operation hours/day (default = 12 hr/day; see Table 3-2)
Vapor Pressure	Specific chemical parameter; note that the vapor pressure of the chemical at 55ºC should be utilized.
Air Speed	CEB default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	$F_{correction_factor}$ (calculated in Equation 4-3)

Note: The model also assumes standard temperature and pressure along with ideal gas interactions. While the vapor pressure of the chemical may be adjusted because the wash water is at an elevated temperature, the temperature parameter required by the model is the ambient air temperature (assumed 298 K). See Appendix B for additional information.

Release from the Water-Washing Process (Release 6)

Industrial laundries use an estimated 72,000 gallons of water/site-day, based on an average of 2.74 gallons of water used to produce one pound of dry, clean laundry (USEPA, 1997) and the average amount of laundry processed per site shown in Table 1-2. Laundry is typically rinsed to remove the majority of the wash chemicals, since some may cause skin irritation. Only minimal quantities of wash chemicals may remain on the laundered item after washing. Note that many wash chemicals will likely undergo various reactions during the washing process (e.g., antichlor neutralizes bleach, sour neutralizes alkali builder). While many facilities may have on-site wastewater treatment, most of these treatment technologies are designed to remove dirt, oil, and other materials that were lifted from the textile during laundering. Section 0 discusses the treatment technologies in more detail. All of the facilities responding in the DEQ reported discharging to a POTW.

Non-Volatile Chemical of Interest:

To calculate the daily release to POTW of non-volatile components, as a conservative estimate, assume the entire production volume of the chemical of interest except the container residue and dust emissions (powdered products only) is discharged directly to a POTW from the washing process.

$$Elocal_{washing} = Q_{chem_day} \times (1 - F_{container_residue} - F_{dust_generation}) \quad (4\text{-}4)$$

This release will occur over [$TIME_{working_days}$] days/year from [N_{sites}] sites.

Where:

$Elocal_{washing}$	=	Daily release of chemical of interest to POTW from the washing process (kg chemical of interest/site-day)
Q_{chem_day}	=	Daily use rate of chemical of interest (kg chemical of interest/site-day)
$F_{container_residue}$	=	Fraction of chemical remaining in the container as residue (Default = 0.03 kg chemical remaining/kg shipped for drums containing liquids; consistent with value used for Release 1)
$F_{dust_generation}$	=	Fraction of chemical lost during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)

Volatile Chemical of Interest:

Volatile components may be released to a POTW in wastewater after the washing cycle. They may also evaporate and be released to air during the washing process, especially if a hot water washing cycle is used. Any residual volatile components that are not removed during the washing process will evaporate during the transfer, steaming, pressing, or drying of the laundered textile. For volatile components, assume the entire production volume of the chemical of interest, except for container residue, dust emissions (powdered products only), and releases to air during transfers and container cleaning, is released to POTW or vented to air. Note that Release 5 is only designed to estimate the amount of chemical of interest that may volatilize into the worker's breathing zone, not the total quantity of chemical that may be released to air. The following equation can be used to calculate the daily release to POTW or air of volatile components from the water-washing process:

$$Elocal_{washing} = Q_{chem_day} \times (1 - F_{container_residue} - F_{dust_generation}) - Elocal_{air_cleaning} - Elocal_{air_transfers} - Elocal_{air_breathing} \quad (4\text{-}5)$$

This release will occur over [$TIME_{working_days}$] days/year from [N_{sites}] sites.

Where:

$Elocal_{washing}$	=	Daily release of chemical of interest to POTW or air from the washing process (kg chemical of interest/site-day)
Q_{chem_day}	=	Daily use rate of chemical of interest (kg chemical of interest/site-day)
$F_{container_residue}$	=	Fraction of chemical remaining in the container as residue (Default = 0.03 kg chemical remaining/kg shipped for drums containing liquids; consistent with value used for Release 1)
$F_{dust_generation}$	=	Fraction of chemical lost during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$Elocal_{air_cleaning}$[14]	=	Daily release to air of volatile chemicals during container cleaning (kg chemical of interest/site-day; See Section 4.3)
$Elocal_{air_transfers}$	=	Daily release to air of volatile chemicals during transfers (kg chemical of interest/site-day; See Section 4.4)
$Elocal_{air_breathing}$	=	Daily release to air of volatile chemicals into the workers' breathing zone (kg chemical of interest/site-day; See Section 4.6)

[14] Note: This parameter should only be included if releases from on-site container cleaning are assessed.

The quantity of volatile chemicals released to water versus released to air is unknown and may be dependent on several factors such as wash-water temperature, agitation, washer venting, and the vapor pressure of the chemical of interest. Fragrances may be released to air at a higher fraction than other volatile components in laundry cleaning products. Fragrances are generally designed for the consumer or worker to help mask less pleasant chemical odors. They are more likely to remain on clothing after the washing process. However, they are generally not designed to stay on the textile after drying, and will volatilize during the drying cycle (Tolliver, 2004).

Mass Balance

The following equation provides a balance for the use of laundry cleaning products at industrial and institutional laundry sites.

$$Q_{chem_yr} = (Q_{chem_day} \times (F_{container_residue} + F_{dust_generation}) + Elocal_{air_transfers} + Elocal_{air_cleaning} + Elocal_{washing} + Elocal_{breathing}) \times N_{sites} \times TIME_{working_days} \quad (4\text{-}6) \quad (4\text{-}5)$$

Where:

Q_{chem_yr}	=	Annual production volume of the chemical of interest (kg chemical of interest/yr)
Q_{chem_day}	=	Daily use rate of chemical of interest (kg chemical of interest/site-day)
$F_{container_residue}$	=	Fraction of chemical remaining in the container as residue (Default = 0.03 kg remaining/kg shipped for drums; consistent with value used for Release 1)
$F_{dust_generation}$	=	Fraction of chemical lost during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$Elocal_{air_cleaning}$ [15]	=	Daily release to air of volatile chemicals during container cleaning (kg chemical of interest/site-day; See Section 4.3)
$Elocal_{air_transfers}$	=	Daily release to air of volatile chemicals during transfers (kg chemical of interest/site-day; See Section 4.4)
$Elocal_{air_breathing}$	=	Daily release to air of volatile chemicals into the workers' breathing zone (kg chemical of interest/site-day; See Section 4.6)
$Elocal_{washing}$	=	Daily release of chemical of interest to POTW or air from the washing process (kg chemical of interest/site-day; See Section 4.7)
N_{sites}	=	Number of sites using the laundry product containing the chemical of interest (sites)
$TIME_{working_days}$	=	Operating days (Default = 260 days/yr; See Section 3.2)

[15] Note: This parameter should only be included if releases from on-site container cleaning are assessed.

Summary of Relationship Between Release Estimates of Section 0

Chemical of interest release estimates (Releases 1 through 6) are all related. If less than one container is used per site per day (typically true), the release from container residue will not occur over the number of operating days, while other releases will occur over the number of operating days. Equations 4-4, 4-5, and 4-6 rely on the alternate method for calculating the release from container residue shown in Equation 4-1c, because the water discharge release, fugitive air release, and mass balance are based on daily releases occurring over the number of operating days. Due to rounding errors when determining the number of containers per site per year, $Elocal_{container_residue_disp}$ may not be equal to the terms used in Equation 4-6 (e.g., calculating the release based on five full containers per site per year, when only four and a half will be used). However, this rounding error is automatically corrected when using standard EPA/OPPT container residual models in ChemSTEER.

OCCUPATIONAL EXPOSURE ASSESSMENTS

The following section presents estimation methods for worker exposures to the chemical of interest. Figure 2-1 illustrates the occupational activities that have the greatest potential for worker exposure to the chemical.

Industry-specific occupational exposure monitoring data was not found in the references reviewed for the development of this scenario (refer to Section 8 for a description of the sources reviewed and full citations for those specifically used in these calculations). The occupational exposure estimates presented in this document are based on standard EPA/OPPT exposure models. Table 5-1 summarizes the exposure estimation methods used in this scenario.

Note that the standard model default values cited are current as of the date of this scenario; however, EPA may update these models as additional data become available and recommends that the most current version of the models be used in these calculations.

EPA has developed a software package (ChemSTEER) containing these models as well as all current EPA defaults. Because of the complexity of the inhalation exposure to vapor models, ChemSTEER is recommended for estimating these exposures. Appendix B provides additional information on ChemSTEER, including information on obtaining the program, as well as background information, model equations, and default values for several parameters for all standard EPA/OPPT models.

This scenario assumes that volatile chemicals may be released to air at certain points in the process, and that associated inhalation exposures to the chemical vapors may occur as a result of handling those chemicals. Each scenario user will have to decide the definition of what constitutes *volatile* based on the specific objectives of the assessment. For example, EPA often assumes chemicals with a vapor pressure less than 0.001 torr are nonvolatile, resulting in negligible releases to air and negligible associated inhalation exposures (CEB, 1991).

Table 0-1. Summary of Laundries Scenario Exposure Models

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description	Standard EPA Model (✓)
A	Exposure to solid or liquid laundry cleaning products during transfer operations	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Inhalation of solid chemical particles	Specific model used is based on daily amount of product handled: • For amounts > 54 kg/day: *OSHA PNOR PEL-Limiting Model* • For amounts ≤ 54 kg/day: *EPA/OPPT Small Volume Solids Handling Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquid Model*	✓
		Dermal exposure to solid chemical	*EPA/OPPT 2-Hand Dermal Contact with Solids Model*	✓
B	Exposure to solid or liquid laundry cleaning products during container cleaning	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Inhalation of solid chemical particles	Specific model used is based on daily amount of product handled: • *For amounts > 54 kg/day: OSHA PNOR PEL-Limiting Model* • *For amounts ≤ 54 kg/day: EPA/OPPT Small Volume Solids Handling Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Contact with Liquid Model*	✓
		Dermal exposure to solid chemical	*EPA/OPPT 2-Hand Dermal Contact with Solids Model*	✓
C	Exposure from handling damp laundry and other operational exposures	Inhalation of volatile liquid chemical vapors	*EPA/OPPT Mass Balance Model*	✓
		Dermal exposure to liquid chemical	*EPA/OPPT 2-Hand Dermal Immersion in Liquid Model*	✓

Personal Protective Equipment (PPE)

EPA visited an industrial laundry on February 14, 2006 for the development of this scenario. At the site, workers wore gloves and a faceshield while moving drums and connecting chemical transfer lines. PPE was not worn during other operations at the facility (CEB, 2006b). A guide for occupational safety at industrial laundries recommends the following PPE:

- Skin and eye protection when handling corrosive substances;
- Respirator protection when handling substances which produce dusts or vapors that can be inhaled; and
- Skin protection if worker's hands are constantly immersed in water or wash solutions containing detergents and other chemicals. (DIR, 1994)

However, these situations are not typical for most activities at industrial and institutional laundries. Information on the use of PPE at institutional laundries was not available.

Number of Workers

While industrial laundries employ an average 87 employees, only a small percentage of employees are potentially exposed to wash chemicals (UTSA, 2005). Wash floor operators are responsible for changing drums, connecting transfer lines, operating the washers, and have the highest potential for exposure. Sometimes maintenance and production management employees may also come in contact with wash chemicals, due to their inherent job responsibilities (UTSA, 2005). Table 5-2 presents data from 141 facilities on the number of workers potentially exposed to wash chemicals. Other job functions at industrial laundries that are not likely to be exposed include laundry sorting, picking up dirty laundry from and delivering clean laundry to customers, laundry folding/handling, laundry finishing, and administrative activities.

Table 0-2. Number of Exposed Workers at Industrial Laundries

Employee Category	Average Number of Employees	Percent of Total
Wash Floor	4.6	5.3%
Wash Floor, Maintenance, and Production Management	8.4	9.7%
Total Plant Employees	86.6	

Source: UTSA, 2005.

For smaller institutional laundries, approximately 2 to 5 workers per site may be exposed to wash chemicals based on site-visits to hotel laundry facilities (Osborne, 2005). However, up to 9 workers per site should be assumed if the type of laundry is unknown (see Table 5.2). Note that the same workers exposed to the chemical of interest during washer loading (Exposure A) are also likely to be exposed to any residual chemical during steaming, drying, or transfer operations (Exposure C).

Assume one additional worker per site (CEB default for container cleaning, as of the date of this scenario) may be exposed to the chemical of interest during container cleaning (Exposure B) if containers are cleaned on-site. As discussed in Section 4.2, containers used at industrial laundries are typically rinsed off-site, and containers used at institutional laundries are typically disposed without rinsing. This exposure is presented for completeness if on-site rinsing occurs and as an example for how the exposure could be estimated at the laundry cleaning product formulation facility. If containers are not cleaned (default for institutional laundries), this exposure would not occur.

Exposure from Loading Laundry Cleaning Products into Washers (Exposure A)

Laundry cleaning products may be added automatically or manually to the washing machine. Automatic liquid injection systems limit worker exposure during the washing process, but workers may still be exposed when connecting transfer lines or transferring the liquid chemicals from the transport container to storage tanks. If automatic liquid injection systems are not used, workers manually scoop or pour solid or liquid detergent chemicals into the washing machine (default scenario). If site-specific information is not available, assume that the laundry cleaning product is manually loaded as a conservative exposure estimate. Note that this may be an overly conservative estimate since almost 90 percent of industrial laundries use liquid chemicals exclusively (see Table 2-1). In the case of automatic loading, the number of days of exposure is equal to the number of containers used per year if the number

of containers is less than the days of operation. Assume up to 9 workers per site are exposed to the cleaning product during this activity, if site-specific information is not available.

Inhalation Exposure:

Liquids:

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

The vapor generation rate calculated in Release 3 and the EPA standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*) may be used to estimate the associated worker inhalation exposure to the chemical of interest during transfer operations. The model and all current EPA/OPPT 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/OPPT default values for several model parameters.

Table 0-3 lists the model inputs and default values. Note that while the release and vapor generation for manual loading may occur over 12 hours per day (consistent with Section 4.4 calculation), EPA recommends a maximum exposure duration of eight hours per day for an individual worker. Similarly, while facilities may operate an average of 260 days/year, EPA recommends a maximum of 250 days of exposure per year. This estimate is equivalent to 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 0-3. *EPA/OPPT Mass Balance Model* Parameter Default Values During Transfers

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (CEB, 1991)
Exposure Days	Consistent with the Frequency of Release determined in Section 4.4, up to 250 days per year
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 0)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.4, up to 8 hours per day
Mixing Factor	CEB defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Specific chemical parameter
Number of Sites	Calculated in Section 0, Equation 3-4
Ventilation Rate	CEB 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 (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Specific chemical parameter
Vapor Pressure Correction Factor	Standard CEB default = 1

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

Solids:

The transfer of non-volatile powdered laundry cleaning products from containers to washing machines generates particulates. The degree of inhalation exposure to particulates depends on the concentration of the chemical of interest in the laundry cleaning product ($F_{chem_formulation}$), the potential concentration of the laundry cleaning product in the worker's breathing zone ($C_{particulate}$), and the total amount of laundry cleaning product the worker transfers or handles to per day ($Q_{facility_day}$). Note that the trigger for using Equation 5-1 versus 5-2 is based on the amount of solid laundry cleaning product the worker transfers or handles per day ($Q_{facility_day}$; See Equation 3-1), not the amount of chemical of interest used per day (Q_{chem_day}). A further explanation, including the background and model defaults, of the two standard CEB models used to estimate inhalation exposure to solid powder is presented in Appendix B.

If the quantity of solid powder laundry cleaning product containing the chemical of interest handled per day ($Q_{facility_day}$) is *greater than* 54 kg of formulation/site-day the *OSHA Total PNOR PEL-Limiting Model* may be used:

$$EXP_{inhalation} = C_{particulate} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_formulation} \quad (5\text{-}1)$$

This exposure will occur over [$TIME_{working_days}$, up to 250][16] days/year.

Where:

$EXP_{inhalation}$ = Inhalation exposure from the chemical of interest per day (mg chemical of interest/day)

$C_{particulate}$ = Concentration of particulate in the workers breathing zone (Default = 15 mg/m^3; based on OSHA PEL (8-hr TWA*) for nuisance dusts, not otherwise regulated 29 CFR 1910.1000)

[16] Solids are assumed manually loaded into the washer; therefore, this exposure would occur throughout the year and not just when new containers are received and connected to transfer lines.

$RATE_{breathing}$	=	Typical worker breathing rate (Default = 1.25 m^3/hr) (CEB, 1991)
$TIME_{exposure}$	=	Duration of exposure (Default = 8 hr/day, Note: because the default value for $C_{particulate}$ is an 8-hr TWA*; the 8-hr/day value must be used)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

*TWA = Time-weighted average.

If the quantity of solid powder laundry cleaning product containing the chemical of interest handled per day ($Q_{facility_day}$) is *less than or equal to* 54 kg of formulation/site-day the *EPA/OPPT Small Volume Solids Handling Inhalation Model* may be used:

$$EXP_{inhalation} = Q_{facility_day} \times F_{chem_formulation} \times F_{exposure} \quad (5\text{-}2)$$

This exposure will occur over [$TIME_{working_days}$, up to 250][17] days/year.

Where:

$EXP_{inhalation}$	=	Inhalation exposure from the chemical of interest per day (mg chemical of interest/day)
$Q_{facility_day}$	=	Daily use rate of laundry product (kg formulation/site-day; See Equation 3-1)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)
$F_{exposure}$	=	Weight fraction of the total particulate laundry cleaning product in the workers breathing zone (Default: 0.0477 (typical) to 0.161 (worst) mg formulation exposure/kg formulation handled) (CEB, 1992)

Dermal Exposure:

Dermal exposure is expected for both automatic and manual loading. Automatic liquid injection systems limit worker exposure during the washing process, but workers may still be exposed when connecting transfer lines or transferring the liquid chemicals from the transport container to storage tanks. If automatic liquid injection systems are not used, workers manually scoop or pour solid or liquid detergent chemicals into the washing machine. No dermal monitoring data on the transfer of laundry cleaning products were found. In the absence of data, the EPA/OPPT standard models for estimating dermal exposures from industrial activities can be used. Similar models can be used to estimate exposure to detergent chemicals for both automatic and manual loading. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these activities, and the *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* may be used to estimate dermal exposure to the chemical of interest in a solid powder formulation. The rationale, defaults, and limitations of these models are further explained in Appendix B.

Liquids:

[17] Solids are assumed manually loaded into the washer; therefore, this exposure would occur throughout the year and not just when new containers are received and connected to transfer lines.

The following equation may be used to estimate the potential worker exposure to the chemical of interest in a liquid laundry cleaning product for this activity:

$$EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_formulation} \quad (5\text{-}3)$$

This exposure will occur over [the lesser of $N_{cont_site_yr}$ or $TIME_{working_days}$ (consistent with Section 4.4), up to 250] days per year

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical of interest/day)
Q_{liquid_skin}	=	Quantity of liquid laundry cleaning product remaining on skin (Defaults = 2.1 mg formulation/cm^2-incident (high-end) and 0.7 mg formulation/cm^2-incident (low-end) for routine or incidental contact)(CEB, 2000)
$AREA_{surface}$	=	Surface area of contact (Default = 840 cm^2, 2 hands) (CEB, 2000)
$N_{exp_incident}$[18]	=	Number of exposure incidents per day (Default =1 incident/day)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

Solids:

The following equation may be used to estimate the potential worker exposure to the chemical of interest in a solid laundry cleaning product for this activity:

$$EXP_{dermal} = \text{up to } 3{,}100 \text{ mg formulation/incident} \times N_{exp_incident} \times F_{chem_comp} \quad (5\text{-}4)$$

This exposure will occur over [$TIME_{working_days}$, up to 250][19] days/year.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical of interest/day)
$N_{exp_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day) (see footnote to Equation 5-3)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

[18]Only one contact per day ($N_{exp_incident}$ = 1 event/worker-day) is assumed because Q_{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.

[19] Solids are assumed manually loaded into the washer; therefore, this exposure would occur throughout the year and not just when new containers are received and connected to transfer lines.

Exposure During Transport Container Cleaning (Exposure B)

Workers may be exposed to the chemical of interest during container cleaning. As discussed in Section 4.2, containers used at industrial laundries are typically rinsed off-site, and containers used at institutional laundries are typically disposed without rinsing. This exposure is presented for completeness if on-site rinsing occurs and as an example for how the exposure could be estimated at the laundry cleaning product formulation facility. If containers are not cleaned (default for institutional laundries), this exposure would be negligible. The exposures presented for this activity are similar to those presented for Exposure A. One worker per site may be assumed exposed to the laundry product during this activity, if site-specific information is not available.

Inhalation Exposure:

Liquids:

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

Using the vapor generation rate calculated in Release 2, the *EPA/OPPT Mass Balance Model may* be used to calculate worker inhalation exposure due to volatilization during cleaning operations. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure.

Table 0-4 lists the model inputs and default values. Note that while facilities may operate an average of 260 days/year, EPA recommends a maximum of 250 days of exposure per year (see Section 5.3). The model and all current EPA/OPPT 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/OPPT default values for several model parameters.

Table 0-4. *EPA/OPPT Mass Balance Model* Parameter Default Values During Container Cleaning

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (CEB, 1991)
Exposure Days	Consistent with the Frequency of Release determined in Section 4.3, up to 250 days per year
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 0)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.3, up to 8 hours per day
Mixing Factor	CEB defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Specific chemical parameter
Number of Sites	Consistent with the number of sites used for Release 2 (See Table 4-3)
Ventilation Rate	CEB 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 (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Specific chemical parameter
Vapor Pressure Correction Factor	Standard CEB default = 1

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

Solids:

The cleaning of solid powders from transport containers may generate dust particulate. The degree of inhalation exposure to particulates depends on the concentration of the chemical of interest in the formulation ($F_{chem_formulation}$), the potential concentration of the laundry chemical in the worker's breathing zone ($C_{particulate}$), and the total amount of laundry cleaning product residual removed from the containers ($Q_{formulation_residue}$). The following equation may be used to estimate the amount of laundry cleaning product residual handled by a worker during container cleaning:

$$Q_{formulation_residue} = \frac{Elocal_{container_residue_disp}}{F_{chem_formulation}} \quad (5\text{-}5)$$

Where:

$Q_{formulation_residue}$ = Quantity of laundry product handled during container cleaning (kg formulation/site-day)

$Elocal_{container_residue_disp}$ = Daily release of chemical of interest from container residue (kg chemical of interest/site-day; see Section 4.2)

$F_{chem_formulation}$ = Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

Note that the trigger for using Equation 5-6 versus 5-7 is based on the amount of laundry cleaning product the worker handles per day ($Q_{formulation_residue}$), not the amount of chemical of interest used per day ($Elocal_{container_residue_disp}$). A further explanation, including the background and model defaults, of the two standard EPA/OPPT models used to estimate inhalation exposure to solid powder is presented in Appendix B.

If the quantity of solid powder laundry cleaning product containing the chemical of interest handled per day ($Q_{formulation_residue}$) is *greater than* 54 kg of formulation/site-day the *OSHA Total PNOR PEL-Limiting Model* may be used

$$EXP_{inhalation} = C_{particulate} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_formulation} \quad (5\text{-}6)$$

This exposure will occur over [the lesser of $N_{cont_site_yr}$ or $TIME_{working_days}$ (consistent with Section 4.2), up to 250] days per year

Where:

$EXP_{inhalation}$	=	Inhalation exposure from the chemical of interest per day (mg chemical of interest/day)
$C_{particulate}$	=	Concentration of particulate in the workers breathing zone (Default = 15 mg/m^3; based on OSHA PEL (8-hr TWA*) for nuisance dusts, not otherwise regulated 29 CFR 1910.1000)
$RATE_{breathing}$	=	Typical worker breathing rate (Default = 1.25 m^3/hr) (CEB, 1991)
$TIME_{exposure}$	=	Duration of exposure (Default = 8 hr/day, Note: because the default value for $C_{particulate}$ is an 8-hr TWA*; the 8-hr/day value must be used)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

*TWA = Time-weighted average.

If the quantity of solid powder laundry cleaning product containing the chemical of interest handled per day ($Q_{formulation_residue}$) is *less than or equal to* 54 kg of formulation/site-day use the EPA/OPPT Small Volume Solids Handling Inhalation Model:

$$EXP_{inhalation} = Q_{formulation_residue} \times F_{chem_formulation} \times F_{exposure} \quad (5\text{-}7)$$

This exposure will occur over [the lesser of $N_{cont_site_yr}$ or $TIME_{working_days}$ (consistent with Section 4.2), up to 250] days per year

Where:

$EXP_{inhalation}$	=	Inhalation exposure from the chemical of interest per day (mg chemical of interest/day)
$Q_{formulation_residue}$	=	Quantity of laundry product handled during container cleaning (kg formulation/site-day; see Equation 5-5)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)
$F_{exposure}$	=	Weight fraction of the total particulate laundry cleaning product in the workers breathing zone (Default: 0.0477 (typical) to 0.161 (worst) mg formulation exposure/kg formulation handled)(CEB, 1992)

Dermal Exposure:

Dermal exposure is expected during the cleaning of transport containers. No dermal monitoring data on the cleaning of laundry cleaning products transport containers were found. In the absence of data, the EPA/OPPT standard models for estimating dermal exposures from industrial activities can be used. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* should be used to estimate dermal exposure

to the chemical of interest in a liquid formulation during these activities, and the EPA*/OPPT Direct 2-Hand Dermal Contact with Solids Model* should be used to estimate dermal exposure to the chemical of interest in a solid powder formulation. The rationale, defaults, and limitations of these models are further explained in Appendix B.

Liquids:

The following equation may be used to estimate the potential worker exposure to the chemical of interest in a liquid laundry cleaning product for this activity:

$$EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_formulation} \quad (5\text{-}8)$$

This exposure will occur over [the lesser of $N_{cont_site_yr}$ or $TIME_{working_days}$ (consistent with Section 4.2), up to 250] days per year

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical of interest/day)
Q_{liquid_skin}	=	Quantity of liquid laundry cleaning product remaining on skin (Defaults = 2.1 mg formulation/cm^2-incident (high-end) and 0.7 mg formulation/cm^2-incident (low-end) for routine or incidental contact)(CEB, 2000)
$AREA_{surface}$	=	Surface area of contact (Default = 840 cm^2, 2 hands) (CEB, 2000)
$N_{exp_incident}$	=	Number of exposure incidents per day (Default =1 incident/day) (see footnote to Equation 5-3)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

Solids:

The following equation may be used to estimate the potential worker exposure to the chemical of interest in a solid laundry cleaning product for this activity:

$$EXP_{dermal} = \text{up to } 3{,}100 \text{ mg formulation/incident} \times N_{exp_incident} \times F_{chem_comp} \quad (5\text{-}9)$$

This exposure will occur over [the lesser of $N_{cont_site_yr}$ or $TIME_{working_days}$ (consistent with Section 4.2), up to 250] days per year

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical of interest/day)
$N_{exp_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day) (see footnote to Equation 5-3)
$F_{chem_formulation}$	=	Weight fraction of the chemical of interest in the laundry product (Default = 1 kg chemical of interest/kg formulation; See Table 3-3)

Exposure During Operations (Exposure C)

While the majority of the chemical of interest will be rinsed off the laundered item, small quantities may remain on the item after the washing process. Workers may be exposed to any residual chemical of interest during the transfer of the laundered item to a dryer or during steaming or pressing.

Also during operations, volatile chemicals of interest may be released into the workers' breathing zone as discussed in Section 4.6. The quantity of volatile chemicals released to water versus released to air is unknown and may be dependent on several factors such as wash-water temperature, agitation, washer venting, and the vapor pressure of the chemical of interest. While most of the evaporated volatile chemical of interest from the washing and drying processes will be vented to the atmosphere, the chemical may enter in the workers' breathing zone from vents in the washer or when workers open the washer or dryer, transfer the laundered items, or steam or press the item.

Assume the same up to 9 workers per site exposed during the loading of laundry cleaning products into the washer are exposed to the chemical of interest during this activity, if site-specific information is not available.

Inhalation Exposure:

Inhalation exposure is assumed negligible for nonvolatile chemicals (see Section 4.6). Using the vapor generation rate calculated in Release 5, the *EPA/OPPT Mass Balance Model may* be used to calculate worker inhalation exposure due to volatilization during the water-based washing operation. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure.

Table 0-5 lists the model inputs and default values. Note that while facilities may operate an average of 260 days per year and 12 hours per day, EPA recommends a maximum of 250 days of exposure per year and 8 hours of exposure per day (see Section 5.3). The model and all current EPA/OPPT defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during operation. Appendix B explains the background and derivation of the model and provides EPA/OPPT default values for several model parameters.

Table 0-5. *EPA/OPPT Mass Balance Model* Parameter Default Values During Laundering Operations[a]

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (CEB, 1991)
Exposure Days	Consistent with the Frequency of Release determined in Section 4.6, up to 250 days per year
Vapor Generation Rate	Calculated by the *EPA/OPPT Penetration Model* (Section 4.6)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.6, up to 8 hours per day
Mixing Factor	CEB defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Specific chemical parameter
Number of Sites	Calculated in Section 0, Equation 3-4
Ventilation Rate	CEB 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 (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Specific chemical parameter
Vapor Pressure Correction Factor	Standard CEB default = 1[b]

a – Note: The model also assumes standard temperature and pressure along with ideal gas interactions. While the vapor pressure of the chemical may be adjusted because the wash water is at an elevated temperature, the temperature parameter required by this model is the ambient air temperature (assumed 298 K). See Appendix B for additional information.
b – Note: While a vapor pressure correction factor is calculated for Release 4, a vapor pressure correction factor is not needed for this model, because the vapor pressure is only used in this model to estimate the saturation point of the chemical of interest in the ambient air. See Appendix B for additional information.

Dermal Exposure:

Dermal exposure may occur during the handling of wet laundry. No dermal monitoring data on the handling of wet laundry were found. In the absence of data, the EPA/OPPT standard models for estimating dermal exposures from industrial activities can be used. The *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model* may be used to estimate dermal exposure to the chemical of interest during these activities. The rationale, defaults, and limitations of this model are further explained in Appendix B.

Test data provided by UTSA indicates the concentration of a nonionic surfactant on cotton fabric after the washing process is less than 0.05 percent (UTSA, 2005). As a conservative estimate, assume a concentration of the chemical of interest on the wet laundry of 0.05 percent. Use the following equation to estimate the potential dermal exposure during this activity:

$$EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_laundry} \quad (5\text{-}10)$$

This exposure will occur over [$TIME_{working_days}$, up to 250] days/year.

Where:

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

Q_{liquid_skin} = Quantity of liquid remaining on skin (Defaults = Routine immersion from handling wet surfaces: 10.3 mg formulation/cm^2-incident (high-end) and 1.3 mg formulation/cm^2-incident (low-end)) (CEB, 2000)

$AREA_{surface}$	=	Surface area of contact (Default = 840 cm^2, 2 hands) (CEB, 2000)
$N_{exp_incident}$	=	Number of exposure incidents per day (Default =1 incident/day) (see Equation 5-3)
$F_{chem_laundry}$	=	Weight fraction of the chemical of interest on the wet laundry (Default = 0.0005 kg chemical of interest/kg wet laundry) (UTSA, 2005)

Note that this dermal exposure is expected to be minimal in comparison to the dermal exposure during unloading; however, it is included for completeness. The exposure may also be negligible if overhead slings transport the laundry from the washers to the dryers and no worker contact occurs. Of 141 industrial laundries surveyed, approximately 28 percent reported some level of wash floor automation to transfer wet laundry from washers to dryers (UTSA, 2005).

SAMPLE CALCULATIONS

This section presents an example using the equations introduced in Sections 3, 4, and 5 of this document. Table A-4 in Appendix A summarizes the parameters, default values if applicable, and the sources used throughout the scenario. The hypothetical operating scenario presented in this section demonstrates how the equations in Sections 3, 4, and 5 might be used to estimate releases of and exposures to a chemical within a laundry cleaning product. The default values used in these calculations are presented in Sections 3, 4, and 5 and are appropriate only in the absence of site-specific information.

The following values are chemical-specific and should be provided by the manufacturer of the laundry chemical.

- The chemical of interest is a surfactant;
- The chemical of interest has a molecular weight ($MW_{chem.}$) of 200 g/mol and a vapor pressure ($VP_{chem.}$) of 0.05 torr at 25^{o}C and 0.1 at 55 ^{o}C (Note these physical properties are not expected for surfactants; however, are assumed for demonstrative purposes);
- The chemical is received at the laundry in liquid form;
- The chemical of interest production volume (Q_{chem_yr}) is 250,000 kg/year; and
- Both environmental releases and occupational exposures are a concern.

General Facility Estimates

Operating Days

$$TIME_{working_days} = 260 \text{ days/yr}$$

Concentration of the Chemical of Interest in the Laundry Cleaning Product

The chemical of interest is a surfactant; therefore, as presented in Table 3-3, assume the chemical is received at the laundry in a detergent. Based on the decision logic diagram (Figure 3-1) assume the chemical is used at industrial laundries. Therefore:

$$F_{chem_formulation} = 1 \text{ kg chemical/kg formulation}$$

Daily Throughput of the Chemical of Interest

Following the decision logic diagram (Figure 0-1):

- It is unknown if the chemical is used at industrial or institutional laundries; therefore, assessment concerns are considered.
- Since both occupational exposures and environmental releases are concerns, median use rate data for *all industrial laundries* are used. Additionally, the concentration of the chemical of interest in the formulation should be selected for industrial laundries in Table 3-3.

- Since the chemical is received in liquid form use the median annual use rate for detergents at all industrial laundries from Table 3-5 (6,800 kg/yr).

$$Q_{facility_day} = \frac{Q_{facility_yr}}{TIME_{working_days}} = \frac{6{,}800 \text{ kg/site - yr}}{260 \text{ days/yr}}$$

$$Q_{facility_day} = 26.2 \text{ kg formulation/site – day}$$

Using the concentration of the chemical of interest in the formulation, the daily throughput of the chemical of interest can be calculated using the following equation:

$$Q_{chem_day} = Q_{facility_day} \times F_{chem_formulation} = 26.2 \text{ kg form/site-day} \times 1 \text{ kg chem./kg form}$$

$$Q_{chem_day} = 26.2 \text{ kg of chem./site-day}$$

Number of Sites

$$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_day} \times TIME_{working_days}} = \frac{250{,}000 \text{ kg/yr}}{26 \text{ kg/site - day} \times 260 \text{ days/yr}}$$

$$N_{sites} = 37 \text{ sites}$$

N_{sites} was rounded up; therefore, Q_{chem_day} is recalculated using the following equation:.

$$Q_{chem_day} = \frac{Q_{chem_yr}}{N_{sites} \times TIME_{working_days}} = \frac{250{,}000 \text{ kg/yr}}{37 \text{ sites} \times 260 \text{ days/yr}}$$

$$Q_{chem_day} = 26.0 \text{ kg/site-day}$$

Annual Number of Containers per Facility

$$N_{cont_site_yr} = \frac{Q_{chem_yr}}{F_{chem_form\ ulation} \times Q_{cont} \times N_{sites}} = \frac{250{,}000 \text{ kg/yr}}{1 \text{ kg chem./kg form.} \times 208 \text{ kg form. / container} \times 37 \text{ sites}}$$

$$N_{container} = 32 \text{ containers/site-yr}$$

Environmental Releases

Container Residue (Release 1)

Containers are assumed rinsed on-site for demonstrative purposes. The number of containers is less than the days of operation; therefore, use Equation 4-1. $F_{container_residue} = 0.03$ because the chemical is assumed to be received in drums.

$$Elocal_{container_residue_disp} = Q_{cont} \times F_{chem_formulation} \times F_{container_residue} \times N_{cont_site_day}$$

$$Elocal_{container_residue_disp} = 208 \text{ kg form./container} \times 1 \text{ kg chem./kg form.} \times$$
$$0.03 \text{ kg released/kg received} \times 1 \text{ cont/site – day}$$

$$Elocal_{container_residue_disp} = 6.2 \text{ kg/site – day}$$

…over 32 days/year from 37 sites

Open Surface Losses to Air During Container Cleaning (Release 2)

Containers are assumed rinsed on-site for demonstrative purposes. If containers were not rinsed on-site, this release would be negligible. Since the chemical of interest is volatile, it will be emitted from the process while the emptied containers are cleaned. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

[Eqn. B-1]

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

Table 0-1. Summary of ChemSTEER Inputs for Release 2

Parameter	Units	ChemSTEER Input
MW_{chem}	g/mol	200
$F_{correction\ factor}$	Dimensionless	1
VP_{chem}	Torr	0.05
$RATE_{air\ speed}$	ft/min	100
$AREA_{opening}$	cm^2	20.3
$TEMP_{ambient}$	K	298
$D_{opening}$	cm	5.08
$P_{ambient}$	Atm	1

Therefore:

$$Q_{vapor_generation} = 1.04 \times 10^{-5}\ g/s$$

Using $Q_{vapor_generation}$ calculated in Equation B-1 and the other standard default values presented in Table 4-3 for container cleaning, the model then estimates the daily release to air using the following equation:

$$Elocal_{air_cleaning} = Q_{vapor_generation} \times TIME_{activity_hours} \times \frac{3600\ sec/hour}{1000\ g/kg} \qquad \text{[Eqn. B-2]}$$

$$Elocal_{air_cleaning} = 1.04 \times 10^{-5}\ g\ chem./sec \times \left(\frac{1\ containers/site\text{-}day}{20\ containers/hr} \right) \times \frac{3600\ sec/hour}{1000\ g/kg}$$

$$Elocal_{air_cleaning} = 1.9 \times 10^{-6}\ kg\ chem.\ emitted/site\text{-}day$$

…over 32 days/year from 37 sites.

Transfer Operation Losses to Air from Loading Laundry Cleaning Products in Washers (Release 3)

Manual transfers are assumed as default. Since the chemical of interest is volatile, it will be emitted during transfers. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

[Eqn. B-1]

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

Table 0-2. Summary of ChemSTEER Inputs for Release 3

Parameter	Units	ChemSTEER Input
MW_{chem}	g/mol	200
$F_{correction\ factor}$	Dimensionless	1
VP_{chem}	Torr	0.05
$RATE_{air\ speed}$	ft/min	100
$AREA_{opening}$	cm^2	20.3
$TEMP_{ambient}$	K	298
$D_{opening}$	cm	5.08
$P_{ambient}$	Atm	1

Therefore:

$$Q_{vapor_generation} = 1.04 \times 10^{-5}\ g/s$$

Using $Q_{vapor_generation}$ calculated in Equation B-1 and the other standard default values presented in Table 4-4 for transfers, the model then estimates the daily release to air using the following equation:

$$Elocal_{air_transfers} = Q_{vapor_generation} \times TIME_{activity_hours} \times \frac{3600\ sec/hour}{1000\ g/kg} \qquad \text{[Eqn. B-2]}$$

$$Elocal_{air_transfers} = 1.04 \times 10^{-5}\ g\ chem./sec \times 12\ hours/day \times \frac{3600\ sec/hour}{1000\ g/kg}$$

$$Elocal_{air_transfers} = 4.5 \times 10^{-4}\ kg\ chem.\ emitted/site - day$$

…over 260 days/year from 37 sites.

Dust Generation from Transfer Operations Released to Air, Water, Incineration, or Landfill (Release 4)

The chemical is received in liquid form; therefore, dust generation is not expected.

Release to Air into Worker's Breathing Zone from Water-Washing Process (Release 5)

To estimate the release of the volatile chemical of interest into the workers' breathing zone, first estimate the vapor pressure correction factor ($F_{correction_factor}$) using Equation 4-3.

$$F_{correction_factor} = \frac{F_{chem_water} \times MW_{chem}}{\left(F_{chem_water} \times MW_{chem}\right) + \left(\left(1 - F_{chem_water}\right) \times MW_{water}\right)}$$

$$F_{correction_factor} = \frac{0.001\ kg\ chem/kg\ water \times 200\ g/mole}{(0.001\ kg\ chem/kg\ water \times 200\ g/mole) + ((1 - 0.001\ kg\ chem/kg\ water) \times 18\ g/mole)}$$

$$F_{correction_factor} = 0.011$$

Use the vapor pressure correction factor and the *EPA/OPPT Penetration Model* to estimate the rate at which the chemical is emitted during this activity. Note that the vapor pressure for the chemical at 55ºC should be utilized.

[Eqn. B-1]

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

Table 0-3. Summary of ChemSTEER Inputs for Release 5

Parameter	Units	ChemSTEER Input
MW_{chem}	g/mol	200
$F_{correction\ factor}$	Dimensionless	0.011
VP_{chem}	Torr	0.1
$RATE_{air\ speed}$	ft/min	100
$AREA_{opening}$	cm^2	20.3
$TEMP_{ambient}$	K	298
$D_{opening}$	cm	73
$P_{ambient}$	Atm	1

Therefore:

$$Q_{vapor_generation} = 1.24 \times 10^{-5}\ g/s$$

Using $Q_{vapor_generation}$ calculated in Equation B-1 and the other standard default values presented in Table 4-5 for releases into the workers' breathing zone, the model then estimates the daily release to air using the following equation:

$$Elocal_{air_breathing} = Q_{vapor_generation} \times TIME_{activity_hours} \times \frac{3600\ sec/hour}{1000\ g/kg} \qquad \text{[Eqn. B-2]}$$

$$Elocal_{air_breathing} = 1.24 \times 10^{-5}\ g\ chem./sec \times 12\ hours/day \times \frac{3600\ sec/hour}{1000\ g/kg}$$

$$Elocal_{air_breathing} = 5.4 \times 10^{-4}\ kg\ chem.\ emitted/site\text{-}day$$

…over 260 days/year from 37 sites.

Release from Water-Washing Process (Release 6)

Since the chemical is volatile use Equation 4-5.

$$Elocal_{washing} = Q_{chem_day} \times (1 - F_{container_residue} - F_{dust_generation}) - Elocal_{air_cleaning} - Elocal_{air_transfers} - Elocal_{air_breathing}$$

$$Elocal_{washing} = 26.0\ kg\ chem/site\text{-}day \times (1 - 0.03 - 0) - 1.9 \times 10^{-6}\ kg\ chem/site\text{-}day \times \left(\frac{32\ days/yr}{260\ days/yr}\right) - 4.5 \times 10^{-4}\ kg\ chem/site\text{-}day - 5.4 \times 10^{-4}\ kg\ chem/site\text{-}day$$

$$Elocal_{washing} = 25.2\ kg\ chem/site\text{-}day$$

…over 260 days/year from 37 sites

(Note: $Elocal_{air_cleaning}$ was scaled since the release only occurs over a portion of the operating days)

Mass Balance

$$Q_{chem_yr} = (Q_{chem_day} \times (F_{container_residue} + F_{dust_generation}) + Elocal_{air_transfers} + Elocal_{air_cleaning} + Elocal_{washing} + Elocal_{breathing}) \times N_{sites} \times TIME_{working_days}$$

$$Q_{chem_yr} = (26.0 \text{ kg/site-day} \times (0.03 + 0) + 4.5 \times 10^{-4} \text{ kg chem/site-day} + 1.9 \times 10^{-6} \text{ kg chem/site-day} \times (\frac{32 \text{ days/yr}}{260 \text{ days/yr}}) + 25.2 \text{ kg/site-day} + 5.4 \times 10^{-4} \text{ kg /site-day}) \times 37 \text{ sites} \times 260 \text{ days/yr}$$

$$Q_{chem_yr} = 250{,}000 \text{ kg/yr}$$

Occupational Exposures

Total Number of Exposed Workers

$$N_{workers} = \text{up to 9 workers/site (see Section 5.2)}$$

Note: An additional 1 worker/site may be exposed during on or off-site transport container cleaning (Exposure B)

Exposure from Loading Laundry Cleaning Products into Washers (Exposure A)

The chemical of interest is a volatile component of a liquid laundry product.

Inhalation Exposure:

Using the vapor generation rate calculated in Release 3 and the CEB standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*), ChemSTEER calculates the worker exposure using the following equations:

Table 0-4. Summary of ChemSTEER Inputs for Exposure A

Parameter	Units	ChemSTEER Input
F_{mixing_factor}	Dimensionless	Typical = 0.5 Worst Case = 0.1
$TEMP_{ambient}$	K	298
MW_{chem}	g/mol	200
$RATE_{ventilation}$	ft^3/min	Typical = 3000 Worst Case = 500
$Q_{vapor\ generation}$	g/s	1.04×10^{-5}
$RATE_{breathing}$	m^3/hour	1.25
V_{molar}	L/mol	24.45
$TIME_{exposure}$	hours/day	8

$$C_{chem_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing_factor}} \quad \text{[Eqn. B-7]}$$

$C_{chem_volumetric}$ = 0.0018 ppm for typical and 0.053 ppm for worst case

Next, the volumetric concentration is converted to a mass concentration (C_{chem_mass}) by the following equation:

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

C_{chem_mass} = 0.014 mg/m^3 for typical and 0.43 mg/m^3 for worst case

Finally, the mass concentration of the chemical and the standard default values presented in Table 5-3 for the container unloading activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

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

$$EXP_{inhalation} = (0.014 \text{ to } 0.43)\,\text{mg/m}^3 \times 1.25\,\text{m}^3\text{/hr} \times 8\,\text{hr/day}$$

$$EXP_{inhalation} = 0.14 - 4.3\,\text{mg chem./worker} - \text{day}$$

…over 250 days/year.

Dermal Exposure:

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

$$= \left[\frac{0.7 \text{ to } 2.1\,\text{mg form.}}{\text{cm}^2 \text{ - incident}} \right] \times 840\,\text{cm}^2 \times \frac{1\,\text{incident}}{\text{day}} \times \frac{1\,\text{mg chem.}}{\text{mg form.}}$$

$$EXP_{dermal} = \frac{590 - 1{,}800\,\text{mg chem.}}{\text{day}}$$

…over 250 days/year

Exposure During Transport Container Cleaning (Exposure B)

Containers are assumed rinsed on-site for demonstrative purposes. If containers were not rinsed on-site, this exposure would not be expected at the industrial or institutional laundry. The number of container used per site is less than 250 containers/site-year ($N_{containers}$ = 32 containers/site-year); therefore, exposure would occur over 32 days/yr if containers are rinsed on-site.

Inhalation Exposure:

Using the vapor generation rate calculated in Release 2 and the CEB standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*), ChemSTEER calculates the worker exposure using the following equations:

Table 0-5. Summary of ChemSTEER Inputs for Exposure B

Parameter	Units	ChemSTEER Input
F_{mixing_factor}	Dimensionless	Typical = 0.5 Worst Case = 0.1
$TEMP_{ambient}$	K	298
MW_{chem}	g/mol	200
$RATE_{ventilation}$	ft^3/min	Typical = 3000 Worst Case = 500
$Q_{vapor\ generation}$	g/s	1.04×10^{-5}
$RATE_{breathing}$	m^3/hour	1.25
V_{molar}	L/mol	24.45
$TIME_{exposure}$	hours/day	0.05

$$C_{chem_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing_factor}} \quad \text{[Eqn. B-7]}$$

$C_{chem_volumetric}$ = 0.0018 ppm for typical and 0.053 ppm for worst case

Next, the volumetric concentration is converted to a mass concentration (C_{chem_mass}) by the following equation:

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

C_{chem_mass} = 0.014 mg/m^3 for typical and 0.43 mg/m^3 for worst case

Finally, the mass concentration of the chemical and the standard default values presented in Table 5-4 for the container cleaning activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

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

$$EXP_{inhalation} = (0.014 \text{ to } 0.43)\,\text{mg/m}^3 \times 1.25\,\text{m}^3\text{/hr} \times 0.05\,\text{hr/day}$$

$$EXP_{inhalation} = 0.0009 \text{ to } 0.027\ \text{mg chem./worker} - \text{day}$$

…over 32 days/year.

Dermal Exposure:

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

$$= \left[\frac{0.7 \text{ to } 2.1\,\text{mg form.}}{\text{cm}^2 \text{ - incident}} \right] \times 840\,\text{cm}^2 \times \frac{1\,\text{incident}}{\text{day}} \times \frac{1\,\text{mg chem.}}{\text{mg form.}}$$

$$EXP_{dermal} = \frac{590 - 1{,}800 \text{ mg chem.}}{\text{day}}$$

…over 32 days/year

Exposure During Operations (Exposure C)

Inhalation Exposure:

Using the vapor generation rate calculated in Release 5 and the CEB standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*), ChemSTEER calculates the worker exposure using the following equations:

Table 0-4. Summary of ChemSTEER Inputs for Exposure C

Parameter	Units	ChemSTEER Input
F_{mixing_factor}	Dimensionless	Typical = 0.5 Worst Case = 0.1
$TEMP_{ambient}$	K	298
MW_{chem}	g/mol	200
$RATE_{ventilation}$	ft^3/min	Typical = 3000 Worst Case = 500
$Q_{vapor\ generation}$	g/s	1.24×10^{-5}
$RATE_{breathing}$	m^3/hour	1.25
V_{molar}	L/mol	24.45
$TIME_{exposure}$	hours/day	8

$$C_{chem_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing_factor}} \quad \text{[Eqn. B-7]}$$

$C_{chem_volumetric}$ = 0.0021 ppm for typical and 0.063 ppm for worst case

Next, the volumetric concentration is converted to a mass concentration (C_{chem_mass}) by the following equation:

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

C_{chem_mass} = 0.017 mg/m^3 for typical and 0.51 mg/m^3 for worst case

Finally, the mass concentration of the chemical and the standard default values presented in Table 5-5 for the container unloading activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

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

$$EXP_{inhalation} = (0.0086 \text{ to } 0.26)\,mg/m^3 \times 1.25\,m^3/hr \times 8\,hr/day$$
$$EXP_{inhalation} = 0.17 - 5.1\,mg\ chem./worker - day$$
…over 250 days/year.

Dermal Exposure:

$$EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_laundry}$$
$$EXP_{dermal} = 10.3\ mg/cm^2 - incident \times 840\ cm^2 \times 1\ incident/day \times 0.0005$$
$$EXP_{dermal} = 4.3\ mg/day$$
…over 250 days/year.

DATA GAPS/UNCERTAINTIES AND FUTURE WORK

This ESD is primarily based on extensive information collected by EPA during the proposal development phase of the industrial laundries effluent limitation guidelines and pretreatment standards. The effluent guidelines data were collected from actual field surveys and are specific to the use of laundry cleaning products in water washing machines at industrial laundries. UTSA conducted a survey of potential occupational exposures in the industry, organized a site visit to an industrial laundry, reviewed the document, and provided extensive input. These sources allow this document to provide a thorough overview of the industry and the chemicals used in washing operations and provide a sound basis for the general facility estimates and the number of workers potentially exposed.

However, EPA wishes to make this ESD as detailed and up-to-date as possible, such that the risk-screening assessments reflect current industrial practices. Reviewers should feel free to provide additional information and data that could further enhance and improve the methods described in this scenario, as well as to recommend additional resources that may be useful to the development of this scenario.

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

- This scenario relies on EPA/OPPT standard models to estimate occupational exposures. Industry-specific inhalation or dermal monitoring data would enhance the estimates presented in this scenario.

- No breakdown on the quantity of laundry cleaning products used at industrial laundries versus institutional laundries was identified. Additional data would allow for more detailed assessments.

- The method for estimating the number of exposed workers at institutional laundries is based on site visit experience of ERG staff members. Industry-specific information for a greater number of sites would strengthen the estimate for institutional laundries.

REFERENCES

The specific information researched in the development of this document include process description, operating information, chemicals used, wastes generated, worker activities, and exposure information. Specific sources investigated in the development of this document include documents and data from the following sources:

- U.S. Environmental Protection Agency (EPA);
- U.S. Occupational Safety and Health Administration (OSHA);
- U.S. National Institute for Occupational Safety and Health (NIOSH);
- U.S. Census Bureau;
- Organisation for Economic Co-operation and Development (OECD);
- Environment Canada;
- North Carolina Division of Pollution Prevention and Environmental Assistance;
- Kirk-Othmer Encyclopedia of Technology;
- Various trade association websites (e.g., Uniform and Textile Service Association (UTSA) – www.utsa.com, Textile Rental Services Association (TRSA) – www.trsa.org)); and,
- Industry specific journals and technical literature (e.g., Laundry Today – www.laundrytoday.com, Industrial Launderer - http://ilmagonline.com/).

While each of these sources was reviewed for information, not all provided information specific to the laundering process. The references specifically cited in this scenario are provided below.

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Appendix A

ESTIMATION EQUATION SUMMARY AND DEFAULT VALUE DOCUMENTATION

Summary of Release and Exposure Estimation Equations

Table A-1 summarizes the equations introduced in Section 0, which are used to calculate the general facility parameters. Tables A-2 and A-3 summarize the equations used in evaluating releases of and exposures to wash chemicals used in water-based washing operations at industrial and institutional laundries. Table A-4 summarizes the parameters for each equation, the default value if applicable and the source. The default values for standard EPA/OPPT models are presented in Appendix B.

Table A-1. General Facility Parameter Calculation Summary

General Facility Estimates	
Days of Operation per Year:	
$TIME_{working\ days} = 260$ days/year (default)	(See Section 3.2)
Concentration of the Chemical of Interest in the Laundry Cleaning Product:	
$F_{chem\ formulation} = 1$ kg chemical/kg formulation (default)	(See Table 3-3)
Daily Use Rate of Formulation per Facility:	
$$Q_{facility_day} = \frac{Q_{facility_yr}}{TIME_{working_days}}$$	(3-1)
If site-specific information indicates facilities use multiple different formulations of a particular laundry product, Equation 3-2 may be used to adjust the throughput. The adjusted throughput would then be used in all subsequent calculations.	
$$Q_{facility_day_adjusted} = \frac{Q_{facility_day} \times N_{formulations_chem}}{N_{product_formulations}}$$	(3-2)
Daily Use Rate of Chemical of Interest per Facility:	
$$Q_{chem_day} = Q_{facility_day_adjusted} \times F_{chem_formulation}$$	(3-3)
Number of Sites:	
$$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_day} \times TIME_{working_days}}$$	(3-4)
Annual Number of Containers per Facility:	
$$N_{cont_site_yr} = \frac{Q_{chem_yr}}{F_{chem_formulation} \times Q_{cont} \times N_{sites}}$$	(3-5)

Table A-2. Environmental Release Calculation Summary

Environmental Release Calculations		
Source	**Media of Release**	**Calculations**
Release 1 Container Residue	Water, Incineration, or Landfill	*Industrial Laundries (default):* Release should be assessed at laundry product formulators sites. The following equation could be used (see Section 4.2): $\text{Elocal}_{\text{container_residue_disp}} = \frac{\text{Q}_{\text{chem_yr}} \times \text{F}_{\text{container_residue}}}{\text{TIME}_{\text{formulation_days}} \times \text{N}_{\text{formulation_sites}}}$ (4-1a) *Institutional Laundries (or on-site cleaning):* Estimate if number of containers is fewerthan days of operation (see Section 4.2): $\text{Elocal}_{\text{container_residue_disp}} = \text{Q}_{\text{cont}} \times \text{F}_{\text{chem_formulation}} \times \text{F}_{\text{container_residue}} \times \text{N}_{\text{cont_site_day}}$ (4-1b) Estimate if number of containers is greater than days of operation: $\text{Elocal}_{\text{container_residue_disp}} = \text{Q}_{\text{chem_day}} \times \text{F}_{\text{container_residue}}$ (4-1c)
Release 2 Fugitive Air Release During Container Cleaning	Air	Should only be assessed if containers are cleaned (see Section 4.3). Non-volatile chemicals: $\text{Elocal}_{\text{air_transfers}}$ = negligible Volatile chemicals: *EPA/OPPT Penetration Model* (see Section 4.3).
Release 3 Fugitive Air Release During Transfers	Air	Non-volatile chemicals: $\text{Elocal}_{\text{air_transfers}}$ = negligible Volatile chemicals: *EPA/OPPT Penetration Model* (see Section 4.4).
Release 4 Dust Generation from Transfer Operations	Air, Water, Incineration, Land	Chemicals received in liquid form: $\text{Elocal}_{\text{dust_fugitive}}$ = negligible Chemicals received in powdered form: $\text{Elocal}_{\text{dust_fugitive}} = \text{Q}_{\text{chem_day}} \times \text{F}_{\text{dust_generation}}$ (4-2)
Release 5 Air Release into the Workers' Breathing Zone During Operations	Air	Non-volatile chemicals: $\text{Elocal}_{\text{air_transfers}}$ = negligible Volatile chemicals: *EPA/OPPT Penetration Model* (see Section 4.6).
Release 6 Release from Water-Washing Process	Non-volatiles: POTW Volatiles: POTW or Air	Non-volatile chemicals: $\text{Elocal}_{\text{washing}} = \text{Q}_{\text{chem_day}} \times (1 - \text{F}_{\text{container_residue}} - \text{F}_{\text{dust_generation}})$ (4-4) Volatile chemicals: $\text{Elocal}_{\text{washing}} = \text{Q}_{\text{chem_day}} \times (1 - \text{F}_{\text{container_residue}} - \text{F}_{\text{dust_generation}}) - \text{Elocal}_{\text{air_cleaning}} - \text{Elocal}_{\text{air_transfers}} - \text{Elocal}_{\text{air_breathing}}$ (4-5)

Environmental Release Calculations		
Source	**Media of Release**	**Calculations**
Mass Balance: $Q_{chem_yr} = (Q_{chem_day} \times (F_{container_residue} + F_{dust_generation}) + Elocal_{air_transfers} + Elocal_{air_cleaning} + Elocal_{washing} + Elocal_{breathing}) \times N_{sites} \times TIME_{working\ days}$ (4-6)		

Table A-3. Occupational Exposure Calculation Summary

Occupational Exposure Estimates
Number of Exposed Workers per Site (Section 5.2): Industrial Laundries (Default): up to 9 workers/site Institutional Laundries: 2-5 workers/site Note: An additional 1 worker/site may be exposed during on- or off-site transport container cleaning (Exposure B)
Exposure from Loading Laundry Cleaning Products into Washer (Exposure A) Default Number of Exposed Workers: up to 9 workers/site Inhalation: *Liquids:* If non-volatile (VP <0.001 torr): $EXP_{inhalation}$ = Negligible If volatile (VP >0.001 torr): Calculate $EXP_{inhalation}$ using the EPA/OPPT Mass Balance Model in ChemSTEER, using the vapor generation rate from Release 3. See Table 0-3 for model inputs and defaults. *Solids:* If $Q_{facility_day}$ >54 kg of formulation/site-day: $EXP_{inhalation} = C_{particulate} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_formulation}$ (5-1) If $Q_{facility_day}$ <54 kg of formulation/site-day: $EXP_{inhalation} = Q_{facility\ day} \times F_{chem\ formulation} \times F_{exposure}$ (5-2) Dermal: *Liquids:* $EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_formulation}$ (5-3) *Solids:* EXP_{dermal} = up to 3,100 mg-incident/day $\times N_{exp\ incident} \times F_{chem\ formulation}$ (5-4)

Occupational Exposure Estimates

Exposure During Transport Container Cleaning (Exposure B)

Default Number of Exposed Workers: 1 workers/site

Inhalation:

Liquids:

If non-volatile (VP <0.001 torr):

$$EXP_{inhalation} = \text{Negligible}$$

If volatile (VP >0.001 torr):

Calculate $EXP_{inhalation}$ using the EPA/OPPT Mass Balance Model in ChemSTEER, using the vapor generation rate from Release 3. See Table 0-4 for model inputs and defaults.

Solids:

$$Q_{formulation_residue} = \frac{Elocal_{container_residue_disp}}{F_{chem_formulation}} \quad (5\text{-}5)$$

If $Q_{formulation_residue}$ >54 kg of formulation/site-day:

$$EXP_{inhalation} = C_{particulate} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_formulation} \quad (5\text{-}6)$$

If $Q_{formulation_residue}$ <54 kg of formulation/site-day:

$$EXP_{inhalation} = Q_{formulation_residue} \times F_{chem_formulation} \times F_{exposure} \quad (5\text{-}7)$$

Dermal:

Liquids:

$$EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_formulation} \quad (5\text{-}8)$$

Solids:

$$EXP_{dermal} = \text{up to } 3{,}100 \text{ mg-incident/day} \times N_{exp\ incident} \times F_{chem\ formulation} \quad (5\text{-}9)$$

Occupational Exposure Estimates
Exposure During Operations (Exposure C) Default Number of Exposed Workers: up to 9 workers/site Note: These are the same workers exposed during the loading of laundry cleaning products into washers (Exposure A). Inhalation: If non-volatile (VP <0.001 torr): $EXP_{inhalation}$ = Negligible If volatile (VP >0.001 torr): Calculate $EXP_{inhalation}$ using the EPA/OPPT Mass Balance Model in ChemSTEER, using the vapor generation rate from Release 4. See Table 5-5 for model inputs and defaults. Dermal: $EXP_{dermal} = Q_{liquid\ skin} \times AREA_{surface} \times N_{exp\ incident} \times F_{chem\ laundry}$ (5-10)

Table A-4. Parameter Declaration and Documentation Summary

Variable	Variable Description	Default Value	Data Source
$AREA_{surface}$	Surface area of contact (cm^2)	840 (2 hands)	(CEB, 200)
$C_{particulate}$	Concentration of particulate in the workers breathing zone (mg/m^3)	15	29 CFR 1910.1000
$F_{chem_formulation}$	Weight fraction of the chemical of interest in the laundry product (kg chemical of interest/kg formulation)	See Table 3-3; Default = 1 kg chemical of interest/kg formulation	(USEPA, 1999; CEB, 2006b; OECD, 2002)
$F_{chem_laundry}$	Weight faction of the chemical of interest on wet laundry (kg chemical of interest/kg of wet laundry)	0.0005	(UTSA, 2005)
F_{chem_water}	Weight faction of the chemical on interest in the wash water (kg chemical of interest/kg of wash water)	0.001	(UTSA, 2005 and CEB, 2006)
$F_{container_residue}$	Fraction of chemical remaining in the container as residue (kg container residue/kg in container)	0.03 (for drums containing liquids)	(CEB, 2002a)
$F_{dust_generation}$	Fraction of chemical lost during transfer/unloading of solid powders (kg released/kg handled)	0.005	(CEB, 2007)
$F_{exposure}$	Weight fraction of the total solid in the workers breathing zone (mg particulate/kg weighed)	0.0477 (typical) 0.161 (worst case)	(CEB, 1992)
$N_{exp_incident}$	Number of exposure incidents per day (incidents/day)	1	CEB assumption
$N_{formulations_chem}$	Number of laundry products containing the chemical of interest used per site (formulation/site)	1	CEB assumption
$N_{product_formulations}$	Average number of laundry products used per facility (formulation/site)	1 See Table 3-7 for alternate defaults	(USEPA, 1994)
$Q_{facility_yr}$	Annual use rate of laundry product (kg formulation/site-yr)	See Figure 0-1 to determine which data points from Table 0-4 and Table 3-5 should be used; Default = 27,000 kg formulation/site-yr	(USEPA, 1994)
Q_{liquid_skin}	Quantity of liquid remaining on skin (mg/cm^2-incident)	Routine or incidental contact: 2.1 (high-end) 0.7 mg/cm^2 (low-end) Routine immersion: 10.3 (high-end) 1.3 (low-end)	(CEB, 2000)
$RATE_{breathing}$	Typical worker breathing rate (m^3/hr)	1.25	(CEB, 1991)

Variable	Variable Description	Default Value	Data Source
$RHO_{formulation}$	Density of the formulation (kg formulation/L)	1	CEB assumption
$TIME_{exposure}$	Duration of exposure (hr/day)	8	the default value for $C_{particulate}$ is an 8-hr TWA
$TIME_{working_days}$	Operating days (days/yr)	See Table 0-2; Default = 260 days/yr	(UTSA, 2005)
$V_{container}$	Volume of laundry product container (L/container)	208 L/container (for 55-gallon drum)	CEB assumption

Appendix B

BACKGROUND INFORMATION AND EQUATIONS/DEFAULTS FOR THE STANDARD EPA 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 five sections:

- Section B.2: Chemical Vapor Releases & Associated Inhalation Exposures;
- Section B.3: Container Residue Release Models (non-air);
- Section B.4: Process Equipment Residue Release Models (non-air);
- Section B.5: Dust Emissions from Transferring Solids Model;
- Section B.6: Chemical Particle Inhalation Exposure Models; and
- Section B.7: 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:

http://www.epa.gov/oppt/exposure/pubs/chemsteer.htm

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 ($Q_{vapor_generation}$; 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 $Q_{vapor_generation}$, 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 ($Q_{vapor_generation}$; g/sec) and the resulting daily volatile air release rate ($Elocal_{air}$; 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*[20]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).

[20]Similar 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:

[B-1]

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

Where:

$Q_{vapor_generation}$	=	Average vapor generation rate (g of chemical/sec)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$F_{correction_factor}$	=	Vapor pressure correction factor (EPA default =1)[21]
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{air_speed}$	=	Air speed (EPA default = 100 feet/min; value must be $\leq$ 100 feet/min for this model)
$AREA_{opening}$	=	Surface area of the static pool or opening (cm^2; $B \times D_{opening}^2 / 4$)
$TEMP_{ambient}$	=	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 ($Q_{vapor_generation}$) calculated in Equation B-1, the model then estimates the daily release to air for the activity using the following equation:

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

Where:

$Elocal_{air}$	=	Daily release of the chemical vapor to air from the activity (kg/site-day)
$Q_{vapor_generation}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-1)

[21]The default vapor pressure correction factor, $F_{correction_factor}$, 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 = $F_{correction_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times$ VP_{chem}), thus the $F_{correction_factor}$ 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.

$TIME_{activity_hours}$ = Operating hours for the release activity per day (hours/site-day; See Table B-1 for appropriate EPA default values)

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*[22] 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).

[22]Similar air releases from surfaces located at *indoor* locations (air speeds ≤ 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:

[B-3]

$$Q_{vapor_generation} = \frac{(1.93\times10^{-7}) \times MW_{chem}^{0.78} \times F_{correction_factor} \times VP_{chem} \times \left(1/29 + 1/MW_{chem}\right)^{0.33} \times RATE_{air_speed}^{0.78} \times AREA_{opening}}{TEMP_{ambient}^{0.4} \times D_{opening}^{0.11} \times \left(TEMP_{ambient}^{0.5} - 5.87\right)^{2/3}}$$

Where:

$Q_{vapor_generation}$	=	Average vapor generation rate (g of chemical of interest/sec)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$F_{correction_factor}$	=	Vapor pressure correction factor (EPA default =1)[23]
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{air_speed}$	=	Air speed (EPA default = 440 feet/min; value must be > 100 feet/min for this model)
$AREA_{opening}$	=	Surface area of the static pool or opening (cm^2; $B \times D_{opening}^2 / 4$)
$TEMP_{ambient}$	=	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 ($Q_{vapor_generation}$) calculated in Equation B-3, the model then estimates the daily release to air for the activity using the following equation:

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

Where:

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

[23]The default vapor pressure correction factor, $F_{correction_factor}$, 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 = $F_{correction_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction_factor}$ 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:

[B-5]

$$Q_{vapor_generation} = \frac{F_{saturation_factor} \times MW_{chem} \times \left(V_{cont_empty} \times \frac{3785.4\,cm^3}{gal} \right) \times \left(\frac{RATE_{fill}}{3600\,sec/hour} \right) \times F_{correction_factor} \times \left(\frac{VP_{chem}}{760\,torr/atm} \right)}{R \times TEMP_{ambient}}$$

Where:

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

$F_{correction_factor}$ = Vapor pressure correction factor (EPA default =1)[24]
VP_{chem} = Vapor pressure of the chemical of interest (torr)
R = Universal Gas Constant (82.05 atm-cm^3/mol-K)
$TEMP_{ambient}$ = Ambient temperature (EPA default = 298 K)

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

$$Elocal_{air} = Q_{vapor_generation} \times TIME_{activity_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [B\text{-}6]$$

Where:

$Elocal_{air}$ = Daily release of the chemical vapor to air from the activity (kg/site-day)
$Q_{vapor_generation}$ = Average vapor generation rate (g of chemical/sec; see Equation B-5)
$TIME_{activity_hours}$ = 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.

[24]The default vapor pressure correction factor, $F_{correction_factor}$, 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 = $F_{correction_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction_factor}$ 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.

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

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 ($Q_{vapor_generation}$).

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 ($Q_{vapor_generation}$). 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:

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

Where:

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

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

Where:

$C_{chem_volumetric}$ = Volumetric concentration of the chemical of interest in air (ppm)
$F_{correction_factor}$ = Vapor pressure correction factor (EPA default =1)[25]
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:

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

Where:

C_{chem_mass} = Mass concentration of the chemical vapor in air (mg/m^3)
$C_{chem_volumetric}$ = 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 25ºC 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:

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

Where:

$EXP_{inhalation}$ = Inhalation exposure to the chemical vapor per day (mg chemical/worker-day)
C_{chem_mass} = Mass concentration of the chemical vapor in air (mg/m^3; see Equation B-9]
$RATE_{breathing}$ = Typical worker breathing rate (EPA default = 1.25 m^3/hr)

[25]The default vapor pressure correction factor, $F_{correction_factor}$, 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 = $F_{correction_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction_factor}$ 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.

$TIME_{exposure}$	=	Duration of exposure for the activity (hours/worker-day; see Table B-2 for appropriate EPA default values ($\leq$ 8 hours/worker-day))

References:

Fehrenbacher, M.C. and Hummel, A.A[26]. "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.

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

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	20				
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
Sampling Activities:						
Sampling Liquids (Indoors)	Not applicable		100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	1

Activity Type (Location)	$V_{cont\ emptv}$ (gallons)	$RATE_{fill}$ (containers/hour)	$RATE_{air\ speed}$ (feet/min)	$RATE_{ventilation}$ [a]	$F_{mixing\ factor}$	$TIME_{exposure}$ (hours/day)
Other Activities:						
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate models with the *Mass Balance Inhalation Model* 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:

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

Where:

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

$F_{container_residue}$ = Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table B-3 for appropriate EPA default values)

$Q_{total_daily_container}$ = Total (daily) quantity of the chemical contained in the shipping containers prior to emptying (kg of chemical/site-day; see Table B-4 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-3 and Table B-4. 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 ($TIME_{days_container_residue}$, days/site-year) must be appropriately "paired" with the total daily quantity of chemical contained in the containers ($Q_{total_daily_container}$) used in calculating the daily release. Thus, Table B-4 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	*EPA/OPPT Small Container Residual Model*	Central Tendency: 0.003 High End: 0.006
	Small Container	5 Range: 5 to <20		
	Drum	55 Range: 20 to <100	*EPA/OPPT Drum Residual Model*	Central Tendency: 0.025 High End[b]: 0.03 (for pumping liquid out of the drum) Alternative defaults: Central Tendency: 0.003 High End: 0.006 (for pouring liquid out of the drum)
	Tote	550 Range: 100 to <1,000	*EPA/OPPT Bulk Transport Residual Model*	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	*EPA/OPPT Solid Residuals in Transport Containers Model*	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 $Q_{total_daily_container}$ and $TIME_{days_container_residue}$ Values for Use in the Container Residual Models

Number of Containers Emptied per Day	$Q_{total\ daily\ container}$ (kg/site-day)	$TIME_{days\ container\ residue}$ (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. PROCESS EQUIPMENT RESIDUE RELEASE MODELS (NON-AIR)

Model Description and Rationale:

EPA has developed two standard models for estimating the quantity of residual chemical remaining in emptied process equipment that is released to non-air media (e.g., water, incineration, or landfill) when the equipment is periodically cleaned and rinsed. The residue models assume a certain portion or fraction of the chemical remains in the emptied vessels, transfer lines, and/or other equipment and is later rinsed from the equipment during cleaning operations and discharged with the waste cleaning materials to an environmental medium.

The default parameters of the model are defined based upon whether the residues are being cleaned from a *single* vessel or from *multiple* pieces of equipment. These defaults are based upon data collected during an EPA-sponsored study of residuals in process equipment from which materials have pumped or gravity-drained.

Model Equation:

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

$$Elocal_{equip_cleaning} = F_{equip_residue} \times Q_{total_chem_capacity} \quad [B\text{-}12]$$

Where:

$Elocal_{equip_cleaning}$ = Daily release of the chemical residue to water, incineration, or landfill from cleaning of empty process equipment (kg/site-day)

$F_{equip_residue}$ = Fraction of the amount of the total chemical in the process equipment remaining in the emptied vessels, transfer lines, and/or other pieces (dimensionless; see Table B-5 for appropriate EPA default values)

$Q_{equip_chem_capacity}$ = Total capacity of the process equipment to contain the chemical in question, prior to emptying (kg of chemical/site-day; see Table B-6 for appropriate EPA default values)

Each model, however, utilizes unique default values within that equation based upon whether the residues are cleaned from a single vessel or from multiple equipment pieces. These default values are summarized in Table B-5 and Table B-6. The following models are the standard EPA models for estimating process equipment residues:

- *EPA/OPPT Single Process Vessel Residual Model; and*
- *EPA/OPPT Multiple Process Vessel Residual Model.*

The default frequency with which the equipment residues are released ($TIME_{days_equip_residue}$, days/site-year) must be appropriately "paired" with the total capacity of the equipment to contain the chemical of interest ($Q_{equip_chem_capacity}$) used in calculating the daily release. Thus, Table B-6 also contains the appropriate EPA default values for $TIME_{days_equip_residue}$.

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-5. Standard EPA Default Values for Use in the Process Equipment Residual Release Models

Model Title	$F_{equip\ residue}$[a]
EPA/OPPT Single Process Vessel Residual Model	Conservative: 0.01 (for pumping process materials from the vessel) *Alternative defaults: Central Tendency: 0.0007 High End to Bounding: 0.002 (alternative defaults for gravity-draining materials from the vessel)
EPA/OPPT Multiple Process Vessel Residual Model	Conservative: 0.02

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).

Table B-6. Standard EPA Methodology for Calculating Default $Q_{equip_chem_capacity}$ and $TIME_{days_equip_residue}$ Values for Use in the Process Equipment Residual Models

Process Type	Number of Batches per Day	$Q_{equip\ chem.\ capacity}$ (kg/site-day)	$TIME_{days\ equip\ residue}$ (days/year)
Batch	1 or more	(Mass quantity of chemical in each batch (kg/batch)) × (Number of batches run per day)	Total number of operating days for the facility/operation
	Less than 1	Mass quantity of chemical in each batch (kg/batch)	Total number of batches run per site-year
Continuous	Not applicable	Daily quantity of the chemical processed in the equipment (kg/site-day)	Total number of operating days for the facility/operation

Note: Please refer to the ESD for any overriding default assumptions to those summarized above. Equipment cleaning may be performed periodically throughout the year, as opposed to the default daily or batch-wise cleaning frequencies shown above. For example, facilities may run dedicated equipment for several weeks, months, etc within a single campaign before performing equipment-cleaning activities, such that residuals remaining in the emptied are released less frequently than the standard default $TIME_{days_equip_residue}$ summarized above in Table B-6. Care should be given in defining the appropriate $Q_{total_daily_container}$ and $TIME_{days_container_residue}$ to be used in either of the standard EPA process equipment residue models.

B.5. DUST EMISSIONS FROM TRANSFERRING SOLIDS MODEL

EPA has developed the *EPA/OPPT Dust Emissions from Transferring Solids Model* to estimate the releases from dust generation during the unloading/transferring of solid powders. While there are multiple potential industrial sources of dust (e.g., grinding, crushing), the scope of this model is limited to transferring/unloading of solids. Specifically, this can be defined as activities where packaging/transport materials are opened and contents are emptied either into a feed system and conveyed or directly added into a process tank (e.g., reactor, mixing tank).

Model Description and Rationale:

The EPA/OPPT Dust Emissions from Transferring Solids Model estimates that 0.5% of the solid powder transferred may be released from dust generation. This model is based on 13 sources, including site visit reports, Oganisation for Economic Co-operation and Development (OECD) Emission Scenario Documents (ESD), EPA's AP-42 Emission Factors, and Premanufacture Notice submissions (EPA's new chemicals review program). Each source contained estimates of the quantity of solid powder that may be lost during transfers for a specific industry. The different sources contained dust loss data or loss fraction estimates from a variety of industries including paint and varnish formulation, plastic manufacturing, printing ink formulation, rubber manufacturing, and chemical manufacturing. These estimates ranged from negligible to 3% of the transferred volume. The mean of the upper bound from each data set was 0.5%.

Additionally, dust generation test data were reviewed. A study by Plinke, et al. investigated key parameters for developing a theoretical approach for estimating dust losses based on moisture content, particle size, drop height, and material flow (Plinke, 1995). Dust generation rates during unloading and transfers were measured for four materials. The highest measured dust generation rate was 0.5%. These data further justified the adoption of a 0.5% loss fraction as a conservative estimate.

For the media of release of the dust generated, most facilities utilize some type of control device(s) to collect fugitive emissions. Many facilities collect fugitive dust emissions from these operations in filters and dispose of the filters in landfills or by incineration. Wet scrubbers may also be utilized by industry. However, in some cases, uncontrolled/uncollected particulates may be small enough to travel several miles from the facility, resulting in environmental and human exposures to the chemical of interest beyond the boundaries of the site. Fugitive dust emissions may also settle to facility floors and are disposed of when floors are cleaned (water if the floors are rinsed or land or incineration if the floors are swept). Therefore, as a conservative assumption the model assumes an uncontrolled release to air, water, incineration, or landfill.

If facility-specific information states a control technology is employed, the release may be partitioned to the appropriate media. If the control technology efficiency information is not available, the *CEB Engineering Manual* may be utilized for control technology efficiencies. Table B-7 provides estimated efficiencies for common control technologies.

Table B-7. Default Control Technology Efficiencies

Control Technology	Default Control Technology Capture Efficiency (%)	Notes/Source	Default Media of Release for Controlled Release
None (default)	0	No control technology should be assumed as conservative.	N/A
Filter (such as a baghouse)	99	For particles > 1 um. CEB Engineering Manual.	Incineration or Land
Cyclone/Mechanical Collectors	80	For particles > 15 um CEB Engineering Manual.	Incineration or Land
Scrubber	Varies 95 may be assumed	Consult Table 7-1 of the CEB Engineering Manual.	Water

Model Equation:

Based on these data, the model estimates the portion of the release that is not captured or the uncontrolled release using the following equation. As a default this material is assumed released to air, water, incineration, or land.

$$Elocal_{dust_fugitive} = Q_{transferred} \times F_{dust_generation} \times (1 - F_{dust_control}) \qquad [B\text{-}13]$$

Where:

$Elocal_{dust_fugitive}$ = Daily amount not captured by control technology from transfers or unloading (kg/site-day)

$Q_{transferred}$ = Quantity of chemical transferred per day (kg chemical/site-day)

$F_{dust_generation}$ = Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)

$F_{dust_control}$ = Control technology capture efficiency (kg captured/kg processed) (Default: If the control technology is unknown, assume capture efficiency = 0 kg captured/kg processed, see Table B-7).

The following equation estimates the portion of dust release captured by the control technology. The default media of release for this material should be selected based on the information presented in Table B-7.

$$Elocal_{dust_captured} = Q_{transferred} \times F_{dust_generation} \times F_{dust_control} \qquad [B\text{-}14]$$

Where:

$Elocal_{dust_captured}$ = Daily amount captured by control technology from transfers or unloading (kg/site-day)

$Q_{transferred}$ = Quantity of chemical transferred per day (kg chemical/site-day)

$F_{dust_generation}$ = Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)

$F_{dust_control}$ = Control technology capture efficiency (kg captured/kg processed) (Default: If the control technology is unknown, assume capture efficiency = 0 kg captured/kg processed, see Table B-7).

References:

U.S. EPA. Chemical Engineering Branch. "Generic Model to Estimate Dust Releases from Transfer/Unloading Operations of Solid Powders". July 2007.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (page 4-11). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

Plinke, Marc A.E., et al. "Dust Generation from Handling Powders in Industry." *American Industrial Hygiene Association Journal*. Vol. 56: 251-257, March 1995.

B.6. CHEMICAL PARTICLE INHALATION EXPOSURE MODELS

The following EPA standard models may be used to estimate worker inhalation exposures to particles containing the chemical of interest:

- *EPA/OPPT Small Volume Solids Handling Inhalation Model*; and
- *OSHA Total Particulates Not Otherwise Regulated (PNOR) Permissible Exposure Limit (PEL)-Limiting Model.*

Each of these models is an alternative default for calculating worker inhalation exposures during the following particulate-handling activities, based upon the relative daily amount of particulate material being handled:

- Unloading and cleaning solid residuals from transport containers/vessels;
- Loading solids into transport containers/vessels; and
- Cleaning solid residuals from process equipment.

For amounts up to (and including) 54 kg/worker-shift, the *EPA/OPPT Small Volume Solids Handling Inhalation Model* is used, as it more accurately predicts worker exposures to particulates within this range than the *OSHA Total PNOR PEL-Limiting Model*. The *Small Volume Solids Handing Inhalation Model* is based on exposure monitoring data obtained for workers handling up to 54 kg of powdered material. Beyond this data-supported limit, EPA assumes that exposures within occupational work areas are maintained below the regulation-based exposure limit for "particulates, not otherwise regulated".

The *EPA/OPPT Small Volume Solids Handling Model* is also the exclusive model used for any solids sampling activity. Each of these models is described in detail in the following sections.

B.6.1 EPA/OPPT Small Volume Solids Handling Inhalation Model

Model Description and Rationale:

The *EPA/OPPT Small Volume Solids Handling Inhalation Model* utilizes worst case and typical exposure factors to estimate the amount of chemical inhaled by a worker during handling of *small*

volumes[27] (i.e., ≤54 kg/worker-shift) of solid/powdered materials containing the chemical of interest. The handling of these small volumes is presumed to include scooping, weighing, and pouring of the solid materials.

The worst case and typical exposure factor data were derived from a study of dye weighing and adapted for use in situations where workers are presumed to handle small volumes of solids in a manner similar to the handling in the study. The maximum amount of dye handled in the study was 54 kg/worker-shift, so the *Small Volume Solids Handling Inhalation Model* is presumed to be valid for quantities up to and including this amount. In the absence of more specific exposure data for the particular activity, EPA uses these data to estimate inhalation exposures to solids transferred at a rate up to and including 54 kg/worker-shift. This model assumes that the exposure concentration is the same as the concentration of the chemical of interest in the airborne particulate mixture.

Note that the amount handled per worker per shift is typically unknown, because while the throughput may be known, the number of workers and the breakdown of their activities are typically unknown. For example, while two workers may together handle 100 kg of material/day, one worker may handle 90 kg of material/day and the other may only handle 10 kg of material/day. Therefore, as a conservative estimate EPA assumes that the total throughput ($Q_{facility_day}$; kg/site-day) is equal to the amount handled per worker ($Q_{shift_handled}$; kg/worker-shift), if site-specific information is not available.

Model Equation:

The model calculates the inhalation exposure to the airborne particulate chemical using the following equation:

$$EXP_{inhalation} = (Q_{shift_handled} \times N_{shifts}) \times F_{chem} \times F_{exposure} \quad [B\text{-}15]$$

Where:

$EXP_{inhalation}$ = Inhalation exposure to the particulate chemical per day (mg chemical/worker-day)

$Q_{shift_handled}$ = Quantity of the solid/particulate material containing the chemical of interest that is handled by workers each shift (kg/worker-shift; see Table B-8 for appropriate EPA default values; must be ≤ 54 kg/worker-shift for this model to be valid)

N_{shifts}[28] = Number of shifts worked by each worker per day (EPA default = 1 shift/day)

F_{chem} = Weight fraction of the chemical of interest in the particulate material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)

$F_{exposure}$ = Exposure factor; amount of total particulate handled that is expected to be inhaled (EPA defaults: 0.0477 mg/kg (typical) and 0.161 mg/kg (worst case))

[27]Worker inhalation exposures to particulates handled in amounts *greater than 54 kg/worker-shift* are calculated using the *OSHA Total PNOR PEL-Limiting Model* (see the description provided in this section of Appendix B).

[28]Note that this value is the number of shifts worked by *each worker* per day. This value would only be greater than one if a worker worked for over eight hours in a given day.

Table B-8. Standard EPA Default Values for $Q_{daily_handled}$ in the *EPA/OPPT Small Volume Solids Handling Inhalation Model*

Activity Type	Default $Q_{shift\ handled}$[29] (kg/worker-day)
Loading and Unloading Containers	Quantity of material in each container (kg/container) × Number of containers/worker-shift
Container Cleaning	Quantity of residue in each container (kg/container) × Number of container/worker-shift
Process-Related Activity (equipment cleaning, sampling):	
Continuous process:	Daily throughput of material / Number of shifts per day
Batch process (<1 batch per day):	Quantity of material per batch
Batch process (>1 batch per day):	Quantity of material per batch × Number of batches per shift

References:

U.S. EPA. Chemical Engineering Branch. Generic Scenario: *Textile Dyeing*. October 15, 1992.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (page 4-11). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

U.S. EPA Economics, Exposure and Technology Division[30]. *Textile Dye Weighing Monitoring Study*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington D.C., EPA 560/5-90-009. April 1990.

B.6.2 OSHA Total PNOR PEL-Limiting Model

Model Description and Rationale:

The *OSHA Total Particulates Not Otherwise Regulated (PNOR) Permissible Exposure Limit (PEL)-Limiting Model* estimates the amount of chemical inhaled by a worker during handling of solid/powdered materials containing the chemical of interest. The estimate assumes that the worker is exposed at a level no greater than the OSHA PEL for *Particulate, Not Otherwise Regulated*, total particulate. Operations are generally expected to comply with OSHA's federal regulation regarding total particulate exposures. This model assumes that the exposure concentration is the same as the concentration of the chemical of interest in the airborne particulate mixture.

[29]The appropriate quantity of material handled by each worker on each day may vary from these standard CEB defaults, per the particular scenario. Be sure to consult the discussion presented in the ESD activity description in determining the most appropriate default value for $Q_{daily_handled}$.

[30]Note: This reference is currently available for viewing in the ChemSTEER Help System.

The *OSHA Total PNOR PEL-Limiting Model* is used in cases where workers are handling quantities of solid/powdered materials *in excess of 54 kg/worker-shift*[31]. As stated in Section B.6.1, the *Small Volume Solids Handling Model*, based on monitoring data, provides a more realistic estimate of worker inhalation exposures to smaller quantities particulate material. The data used by the *Small Volume Solids Handling Model* are supported up to and including 54 kg solid material handled per worker-shift. Beyond this amount, EPA assumes the occupational exposures are maintained below the regulatory exposure limit contained in the *OSHA Total PNOR PEL-Limiting Model*, although the exposures provided by this model are considered to be worst-case, upper-bounding estimates.

Refer to Table B-8 for the standard EPA assumptions used in determining the appropriate quantity of particulate material handled to determine the applicability of this model to a given activity.

NOTE: The OSHA Total PNOR PEL (used as the basis for the model calculations) is an 8-hour time-weighted average (TWA); therefore, *worker exposures must be assumed to occur over an 8-hour period* for the *OSHA Total PNOR PEL-Limiting Model* estimate to be valid basis for the calculated inhalation exposure estimate.

Model Equations:

The model first calculates the mass concentration of the airborne particulate chemical using the following equation:

$$C_{chem_mass} = C_{total_mass} \times F_{chem} \quad [B\text{-}16]$$

Where:

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

C_{total_mass} = Mass concentration of total particulate (containing the chemical) in air (EPA default = 15 mg/m^3, based on the OSHA Total PNOR PEL, 8-hr TWA)

F_{chem} = Weight fraction of the chemical of interest in the particulate material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)

Similar to Equation B-10 in the *EPA/OPPT Mass Balance Inhalation Model*, the *OSHA Total PNOR PEL-Limiting Model* then uses the mass airborne concentration of the chemical (C_{mass_chem}) in Equation B-16, to calculate the inhalation exposure to the particulate chemical using the following equation:

$$EXP_{inhalation} = C_{chem_mass} \times RATE_{breathing} \times TIME_{exposure} \quad [B\text{-}17]$$

Where:

$EXP_{inhalation}$ = Inhalation exposure to the airborne particulate chemical per day (mg chemical/worker-day)

C_{chem_mass} = Mass concentration of the particulate chemical in air (mg/m^3; see Equation B-17)

$RATE_{breathing}$ = Typical worker breathing rate (EPA default = 1.25 m^3/hr)

[31] Worker inhalation exposures to particulates handled in amounts *up to and including 54 kg/worker-shift* are calculated using the *EPA/OPPT Small Volume Handling Inhalation Model* (see the description provided in this section of Appendix B).

$TIME_{exposure}$ = Duration of exposure for the activity (EPA default = 8 hours/worker-day[32])

References:

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equations 4-1 and 4-11). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.7. 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:

$$EXP_{dermal} = AREA_{surface} \times Q_{remain_skin} \times F_{chem} \times N_{event} \quad [B\text{-}18]$$

Where:

EXP_{dermal} = Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)

$AREA_{surface}$ = Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm^2; see Table B-9 for appropriate EPA default values)

Q_{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-9 for appropriate EPA default values)

[32]Since the OSHA Total PNOR PEL is an 8-hr TWA, the exposure duration must be assumed as 8 hours/worker-day for the model defaults to apply.

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}[33]	=	Frequency of events for the activity (EPA default = 1 event/worker-day)

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-10 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.

[33]Only one contact per day (N_{event} = 1 event/worker-day) is assumed because Q_{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.

Table B-9. 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 $AREA_{surface} \times Q_{remain\ skin}$ (mg/event)
Physical Form: Liquids				
EPA/OPPT 1-Hand Dermal Contact with Liquid Model	• Liquid sampling activities • Ladling liquid/bench-scale liquid transfer	420 (1 hand mean)	Low: 0.7 High: 2.1	Low: 290 High: 880
EPA/OPPT 2-Hand Dermal Contact with Liquid Model	• Maintenance • Manual cleaning of equipment and containers • Filling drum with liquid • Connecting transfer line	840 (2 hand mean)	Low: 0.7 High: 2.1	Low: 590 High: 1,800
EPA/OPPT 2-Hand Dermal Immersion in Liquid Model	• Handling wet surfaces • Spray painting	840 (2 hand mean)	Low: 1.3 High: 10.3	Low: 1,100 High: 8,650
Physical Form: Solids				
EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model	• Handling bags of solid materials (closed or empty)	No defaults	No defaults	< 1,100[c]
EPA/OPPT 2-Hand Dermal Contact with Solids Model	• 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 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citations of this sources) and are the mean values for men taken from the EPA Exposure Factors Handbook, 1997.

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-10. 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.