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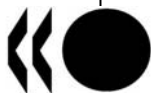
**ENVIRONMENT DIRECTORATE
JOINT MEETING OF THE CHEMICALS COMMITTEE AND
THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY**

OECD Environment, Health and Safety Publications Series on Emission Scenario Documents No. 21

**EMISSION SCENARIO DOCUMENT ON THE FORMULATION OF RADIATION CURABLE
COATINGS, INKS AND ADHESIVES**

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**EMISSION SCENARIO DOCUMENT ON THE FORMULATION
OF RADIATION CURABLE COATINGS, INKS, AND ADHESIVES**

IOMC

**INTER-ORGANISATION PROGRAMME FOR THE
SOUND MANAGEMENT OF CHEMICALS**

**A cooperative agreement among
UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD**

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris, 2009

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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 used in the radiation curable products industry, specifically during formulation of radiation curable coatings, inks, and adhesives. The document focuses primarily on ultraviolet (UV) and electron beam (EB) curable products and presents standard approaches for estimating the environmental releases of and occupational exposures to components and additives used in radiation curable products.

This ESD may be periodically updated to reflect changes in the industry and new information available, and extended to cover the industry area in countries other than the lead (the United States). Users of the document are encouraged to submit comments, corrections, updates, and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org) and U.S. Environmental Protection Agency (EPA) (EPA contact: Nhan Nguyen, nguyen.nhan@epa.gov). The comments received will be forwarded to the OECD Task Force on Environmental Exposure Assessment, which will review the comments every two years so that the lead country can update the document. Submitted information will also be made available to users within the OECD web site (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 both volatile and nonvolatile chemical components contained in radiation curable products. 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 data¹ and information on the radiation curable products industry, including process descriptions, operating information, chemicals used, wastes generated, waste treatment, worker activities, and exposure information. EPA supplemented the data collected with standard models² to develop the environmental release and occupational exposure estimating approaches presented in this ESD.

The primary sources of information cited in this ESD include RadTech International, the U.S. Census Bureau's Economic Census, and various EPA and other government sources (e.g., CEB, OECD, and regional/state pollution prevention organizations). Additional information on the sources investigated and the references cited in this document are presented in Section 8.

The information in this document is based on U.S. data. Certain aspects of the formulation process of radiation curable products may differ in other countries; therefore, alternate assumptions and parameters may be necessary in some applications of this emission scenario.

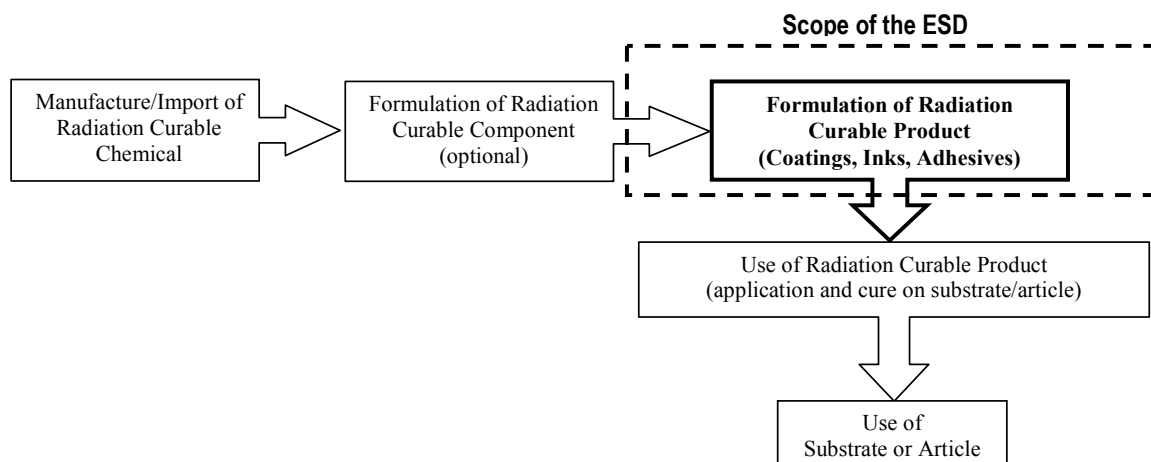
This ESD includes methods for estimating the environmental releases of and associated occupational exposures to both volatile and nonvolatile chemical components used during the liquid formulation of radiation curable products.

Radiation curable products include coatings, inks, and adhesives. The products are generally composed of a base resin (e.g, oligomers or a blend of oligomers and monomers) formulated with other functional components. Other formulation components include reactive monomers, pigments, fillers, defoamers, adhesion promoters, flattening agents, wetting agents, slip aids, and stabilizers. This ESD may be applied to any of these components, including the base resin.

The ESD covers the blending of the components into radiation curable liquid formulations. Since solid and powder formulations represent a small portion of all radiation curable products formulated, this document does not cover the formulation of radiation curable solids or powders. The ESD also does not cover the manufacture of the chemical components used in radiation curable formulations or the application of the formulations onto a substrate. An illustration of the scope of this ESD within the context of the life cycle of the chemical of interest is provided below.

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.



Note that the formulation and application of radiation curable products are treated separately. This ESD focuses on the liquid formulation of radiation curable products. The application of radiation curable products via spray, roll, and curtain coating processes is discussed in the *Emission Scenario Document on the Application of Radiation Curable Coatings, Inks, and Adhesives* (OECD, 2008).

To estimate environmental releases for the formulation process, this ESD assumes that volatile chemicals may be released to air at certain points in the process and associated inhalation exposures to the chemical vapors may occur as a result of handling those chemicals. Each ESD user will have to define *volatile* based on the specific objectives of the assessment. For example, EPA often assumes chemicals are nonvolatile if the vapor pressure is less than 0.001 torr. Nonvolatile chemicals result in negligible releases to air from volatilization and negligible associated inhalation exposures (CEB, 1991).

The methods for estimating the following facility operating parameters and the releases and exposures to chemicals used to formulate radiation curable products are discussed in this ESD:

- Number of sites in the United States formulating radiation curable products containing the chemical of interest, and the duration of these activities;
- Releases of volatile chemicals during transfer from the container into the process (storage or mixing vessel);
- Releases of solid chemicals during transfer from the container into the process (storage or mixing vessel) from dusting;
- Releases from transport container residue (via container cleaning or direct disposal of empty containers);

- Releases of volatile chemicals vented from the equipment during the formulation process;
- Releases during product quality sampling;
- Releases from equipment cleaning;
- Releases from the disposal of filter waste;
- Releases of volatile chemicals during packaging;
- Number of workers that may come into contact with the components of the radiation curable formulation;
- Inhalation and dermal exposures during container unloading;
- Inhalation and dermal exposures during container cleaning and disposal;
- Inhalation and dermal exposures during product quality sampling activities;
- Inhalation and dermal exposures during equipment cleaning;
- Inhalation and dermal exposure during filter waste removal; and
- Inhalation and dermal exposures during packaging.

The estimation methods in this ESD apply to any volatile or nonvolatile radiation curable material component, regardless of its function within the radiation curable formulation.

How this document was developed

The U.S. Environmental Protection Agency (EPA), with support from Eastern Research Group, Inc. (ERG), has developed this Emission Scenario Document (ESD) on the formulation of radiation curable products. 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) reviews. While OECD ESDs traditionally focus on the potential releases of chemicals from industrial processes, this document also describes approaches for estimating potential occupational exposures to radiation curable chemicals. The occupational exposure methods are included so that the ESD may be used to fully support EPA's chemical review programs.

This document is the first part of a set of two ESDs covering the formulation and application of products in the radiation curable products industry. Information on potential environmental releases of and occupational exposures to radiation curable products during application can be found in the *Emission Scenario Document on the Application of Radiation Curable Coatings, Inks, and Adhesives* (OECD, 2008).

This ESD supersedes two of EPA's Chemical Engineering Branch (CEB) generic scenarios on the formulation of UV- and EB-Curable Coatings (CEB, 1994). These earlier documents have been consolidated into one scenario document and have been revised and expanded to meet EPA's revised quality standards for generic scenarios (CEB, 2006).

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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1 INDUSTRY SUMMARY AND BACKGROUND

The following subsections describe the radiation curable products industry and the market for radiation curable coatings, inks, and adhesives in the U.S.

1.1 Introduction to Radiation Curing Products

Radiation curable products include coatings, inks, and adhesives. The products are generally composed of a base resin (i.e., oligomers) formulated with other functional components. Oligomers impart most of the basic properties of the formulation and are typically moderately low molecular weight polymers. Reactive monomers are primarily used in formulation as reactive diluents and crosslinking agents to modify the properties of oligomers (RadTech, 1995). These products are specially formulated to cure upon exposure to radiation. The most common sources of radiation used are ultraviolet (UV) and electron beam (EB).

Eighty-five percent of the commercially available oligomers used in UV- and EB-curable formulations are based on the acrylation of chemical structures (RadTech, 2002). Some materials commonly used as base resin include acrylated urethanes, acrylated epoxies, acrylated polyesters, and acrylated silicones. UV- and EB-curable formulations may also contain components such as other non-reactive and reactive resins, specialized additives, pigments, and photoinitiators (RadTech, 1995).

Radiation curable formulations are applied by application methods such as roll coating, flow coating, curtain coating, spray coating, and vacuum coating; and then, subsequently cured. Radiation curable formulations are cured by polymerization during exposure to UV or EB radiation. Two types of polymerization processes are prevalent in radiation curing (RadTech, 1995).

- Cationic Curing – UV radiation activates photoinitiators in the formulation that propagate a crosslinking reaction via a ring-opening polymerization mechanism. This mechanism is not subject to oxygen inhibition and also provides less shrinkage and improved adhesion. The disadvantage for this type of curing is that the cationic curing photoinitiators are sensitive to moisture and other basic materials. These acidic species can also promote corrosion (SpecialChem, 2007). Cationic polymerization accounts for approximately eight percent of the radiation curable products industry (RadTech, 2002).
- Free Radical Curing – UV or EB radiation activates photoinitiators in the formulation that generate free radicals that propagate bulk polymerization and convert the liquid formulation into a cured solid material. Propagation can be

deactivated in the presence of oxygen. However, the high propagation rates during radiation curing minimize the effects of oxygen and other competing reactions. Free radical polymerization is a more popular form of radiation curing and accounts for the greater than 90 percent of the radiation curable products industry (SpecialChem, 2007).

1.1.1 UV Technology

UV curing is a chemical process that uses UV radiation (ranging from 180 to 400 nm) to polymerize and crosslink the polymeric product. Light energy is absorbed by a photoinitiator, which generates highly reactive free-radical or cationic species. Most current industrial applications use the free-radical type photopolymerization process (ACS, 1990a). These reactive species initiate the polymerization of the functionalized oligomers and monomers into highly crosslinked, chemically resistant films. Cure is rapid, on the order of 30-120 seconds (RadTech, 2000; Spectra, 2005).

The rate of the reaction can be affected by the light intensity, the selection of photoinitiator, and the selection and concentration of reactive monomers in formulation. A medium-pressure mercury lamp is the most common source of UV radiation. Lines speeds of several hundred feet per second may be achieved depending on the geometry of the substrate, the specific UV-curable formulation, and the intensity of the UV output (typically about 200 watts/inch) (ACS, 1990a).

1.1.2 EB Technology

EB curing is a chemical process that uses energy from accelerated electrons to polymerize and crosslink polymeric products. When electrons strike organic molecules, chemical bonds are broken and free radicals (e.g., free electrons) are created. The reactive species created (from the broken bonds) initiate free-radical polymerization of the functionalized oligomers and monomers comprising the EB curable formulation into highly crosslinked and chemical-resistant films. EB cure is more rapid than UV curing systems and occurs on the order of a fraction of a second (ACS, 1990b). However, one drawback to using EB is that curing must be carried out in a nitrogen atmosphere because oxygen acts as a reaction inhibitor by scavenging the free radicals and preventing polymerization.

Electron beams used in EB curing usually are generated for commercial applications in self-shielding EB curing equipment. Potentials in the range of 150,000 and 300,000 volts are typically used. Energy transfer is very efficient, as most of the energy is transferred directly to the target materials without notable energy loss. Well-designed EB curing units transform approximately 90 percent of the incoming kilowatts of line power to electron beam energy (Berejka, 1992; ACS, 1990b).

1.1.3 Use of UV/EB Technologies

UV curable products are more widely used than EB curable products, in part because of the high capital investment costs associated with the EB curing systems. Both radiation curing technologies are used for coatings, inks, and adhesives. These products may be manufactured and applied in a similar manner, regardless of the curing technology. However, EB-curing is more effective for highly filled or pigmented formulations that cannot be cured by UV radiation (RadTech, 1995).

UV curable products are used on plastic, metal, wire, textiles, glass, wood, paper, no-wax vinyl flooring, fiberglass, laminates, photoresists, printing plates, fiber optics, release coatings, magnetic tape, compact disks, and conformational coatings for electronic applications (Sawyer, 1991; ACS 1990a). One of the first applications for UV curable coatings was for furniture and filler boards. No-wax flooring was made possible by UV curable clearcoats on heat-sensitive vinyl sheets (ACS, 1990a).

In both UV and EB curable products, the radiation must penetrate the applied product to ensure proper curing. While UV radiation may be hindered by pigments in the coating, in EB curable products, the highly energetic electrons can initiate free-radical polymerization of the coating even in heavily pigmented systems (RadTech, 1992). Thus, EB-curable products are typically chosen for applications where pigmentation is desired. Additionally, because EB radiation can penetrate deeper into the coating, EB curable products are chosen for applications requiring film thickness greater than 12.7 μ m (0.5 mil¹).

EB curable products are used on plastic, metal, wire, textiles, glass, wood, paper, no-wax vinyl flooring, fiberglass laminates, and releases coatings. Pre-coated metal coils for white boards and appliances, clear finishes for wood, vinyl flooring, and automobiles are among some of the many applications in which these materials are used (Schrantz, 1992; ACS, 1990b; Burlant, 1992).

1.2 Market Description

Radiation curable products are a portion of the coatings, inks, and adhesives industries. Table 1-1 represents the major product markets for radiation curable products. The end use markets are intermingled with much of the end use markets for conventional coatings, inks, and adhesives and use a variety of manufacturing processes.

¹ mil = one-thousandth of an inch

Table 1-1. Product Markets for UV/EB Curing

Coatings	
Wood and particle board	Flexible plastics
Printed furniture laminates	Metal
Paper and board	Leather
Rigid Plastics	Textiles
Inks	
Lithographic	Gravure
Letterpress	Screen Print
Flexographic	
Adhesives	
Pressure sensitive adhesive and tape	Transfer tapes
Labels and decals	Laminating and packaging
Laminating-wood grain panels	Insulation
Automotive	Abrasive bonding
Footwear, including flocking	Textiles
Potting and encapsulation	Nonwovens
Jewelry assembly	Lamp assembly
Glass product assembly	Instrument and other product assembly

Source: RadTech, 1995.

Radiation curable products are associated with many different end use markets. A facility may apply radiation curable products to more than one different type of substrate or article. In terms of dollars, the 2000 North American market for radiation curable coatings has been placed at \$1.01 billion, or about 4 percent of the total U.S. industrial coatings market (Semiseek, 2001). Table 1-2 presents market data for the radiation curable products industry. Based on production volume, graphic arts accounted for 26 percent of the 2005 market for radiation curable products; inks, 23 percent; wood finishes, 20 percent; plastic coatings, 10 percent; adhesives, 4 percent; metal coatings, 14 percent; and electronics, 3 percent (RadTech, 2005). Table 1-2 also categorizes the end use markets into general end use categories that are used in the facility estimates for the applications sites (OECD, 2008).

In 2005, an estimated 211 million pounds (95.5 million kg) of radiation curable materials were produced (RadTech, 2005). The UV curable market was approximated as comprising 90-95 percent of the total radiation curable market, or about 190-200 million pounds (86 to 91 million kg). The EB curable market is approximated as comprising 10-15% of the total radiation curable market (RadTech, 2002). This could be as much as 21 million pounds (9.5 million kg) of EB-curable materials produced in the U.S. in 2005.

The radiation curable market is currently experiencing rapid growth in most end-use markets and is expanding the variety of end uses. The annual growth rate is estimated to be between 10-20 percent by volume (RadTech, 2005). This growth has been spurred by both economic and environmental considerations. Radiation curable materials have the following advantages in production over conventional coatings, inks, and adhesives (ACS, 1990):

- Fast, almost instantaneous cure times that are desirable for high productivity and throughput on production lines;

- Low energy use because heat is not required to cure the coatings;
- Efficient use of plant space because large ovens are not required;
- Little or no solvent content, thus minimizing or eliminating volatile organic compound (VOC) emissions during application operations; and
- Elimination of the high costs associated with the handling and disposal of the solvents, or solvent abatement systems.

Table 1-2. 2005 North American Market for Radiation Curable Materials by End Use Category

End Use	Production Volume (PV) (million kg)	Radiation Curable Market Share (%) by PV	General End-Use Category
Coatings – Graphic Arts			
Overprint Varnish, Clear – General	22.000	23.0	Paper, Paperboard, Film, and Foil Finishes
Overprint Varnish, Clear - Specialty	3.000	3.1	Paper, Paperboard, Film, and Foil Finishes
Coatings – Wood Finishes			
Fillers	6.100	6.4	Furniture (Wood)
Stains and Sealers	1.150	1.2	Furniture (Wood)
Pigmented Coatings	3.175	3.3	Furniture (Wood)
Clear Finishes	6.600	6.9	Furniture (Wood)
Flooring (Prefinished)	2.300	2.4	Furniture (Wood)
Coatings – Plastics			
Vinyl Flooring (Tile & Sheet)	4.500	4.7	Flooring
Automotive Lens & Reflector	2.000	2.1	Automotive
Interior Trim	0.740	0.8	Automotive
Flooring (Prefinished)	0.800	0.8	Flooring
Coatings – Metal Decorating (Can Coating)			
Inks	0.900	0.9	Metal Products and Machinery
Overprint Varnishes - Clear	0.875	0.9	Metal Products and Machinery
Can End Varnishes	0.425	0.4	Metal Products and Machinery
Coatings – Metal, General			
Tubing & Pipe	0.600	0.6	Metal Products and Machinery
Name Plates	0.018	0.0	Metal Products and Machinery
Wire Coating	0.011	0.0	Metal Products and Machinery
Coatings, Miscellaneous			
Optical Fiber - Coating, inks, matrix	3.150	3.3	Optical
Printing Plates (Flexographic & Off Set)	7.200	7.5	Metal Products and Machinery
Stereolithography/Solid Modeling	0.320	0.3	Metal Products and Machinery
Conformal Coatings (Electronics)	0.900	0.9	Electronic Assembly
Photoresists ^a	2.000	2.1	NA
Dental Applications ^a	0.021	0.0	NA

End Use	Production Volume (PV) (million kg)	Radiation Curable Market Share (%) by PV	General End-Use Category
Medical Apparatus ^a	0.030	0.0	NA
Inks – Printing			
Off-Set (Lithography)	7.900	8.3	Lithographic Inks
Screen	6.700	7.0	Screen Printing Inks
Flexography	6.000	6.3	Flexographic Inks
Letterpress	0.700	0.7	Letterpress Inks
Inkjet	0.350	0.4	Inkjet Inks
Adhesives			
Silicone Release Coatings	1.050	1.1	Pressure Sensitive
Optical	0.018	0.0	Optical
Pressure Sensitive	0.450	0.5	Pressure Sensitive
Laminating	3.200	3.3	Laminating
Electronic Adhesives	0.350	0.4	Electronic Assembly
Total	95.533	100.0	

a - Not included in the scope of this document. Photoresists are covered under the scope of the Photoresist Use in Semiconductor manufacturing ESD (OECD, 2004b). Dental and medical applications (e.g. dental fillings) are non-industrial applications.

Source: RadTech, 2005.

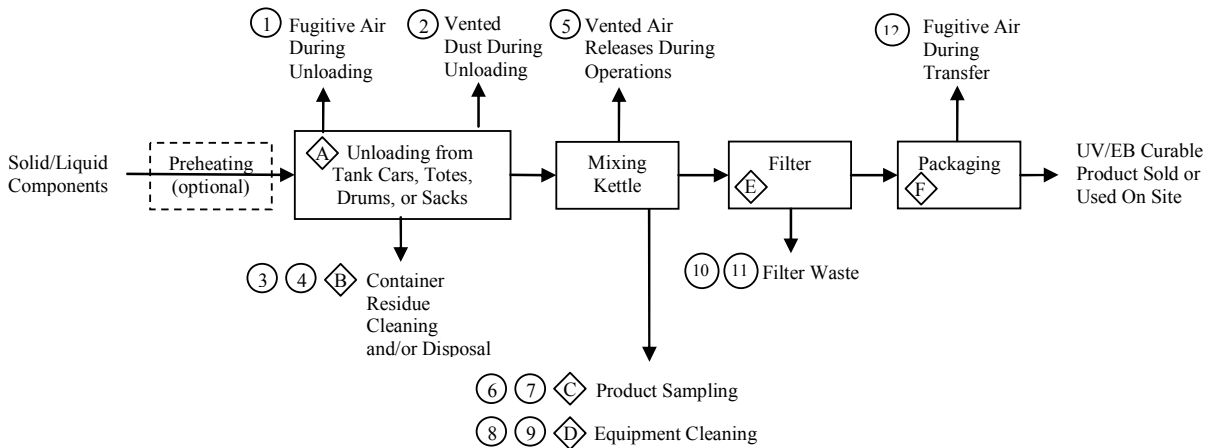
2 PROCESS DESCRIPTION

The following subsections discuss in detail the formulation of radiation curable products:

- Section 2.1 presents an overview of the formulation process;
- Section 2.2 presents information on the application process;
- Section 2.3 presents typical formulations of inks, coatings, and adhesives; and
- Section 2.4 presents physical properties of radiation curable chemicals.

2.1 Formulation

Figure 2-1 illustrates a sealed radiation curable formulation process and the associated release sources and worker exposure activities. Mixing vessels are, almost without exception, closed systems due to the radiation curable formulation's reactivity with light and ambient conditions, the high market value of radiation curable formulations, and the desire of the formulator to minimize process losses (RadTech, no date; EPA, 1992).



○=Environmental Releases:

1. Transfer operation losses of volatile chemicals to air during unloading the radiation curable component.
2. Dust losses vented of solid/powder radiation curable components to air during unloading. Vented dust is captured on vent filters or settles within the workspace, which is subsequently collected and released to water, incineration, or landfill.
3. Container residue losses to water, incineration, or landfill from radiation curable component transport containers.
4. Open surface losses of volatile chemicals to air during container cleaning.
5. Vented losses of volatile chemicals to air during mixing operations.
6. Product sampling losses to water, incineration, or landfill media (not quantified in this ESD).
7. Open surface losses of volatile chemicals to air during product sampling.
8. Equipment cleaning losses to incineration or landfill.
9. Open surface losses of volatile chemicals to air during equipment cleaning.
10. Filter waste losses to incineration or landfill during filter media replacement.
11. Open surface losses of volatile chemicals to air during filter media replacement.
12. Transfer operation losses of volatile chemicals to air during the radiation curable product loading.

◇=Occupational Exposures:

- A. Inhalation and dermal exposure to solid or liquid radiation curable component during unloading.
- B. Inhalation and dermal exposure to solid or liquid radiation curable component during container cleaning.
- C. Inhalation and dermal exposure to liquid radiation curable product during raw material sampling.
- D. Inhalation and dermal exposure to liquid radiation curable product during equipment cleaning.
- E. Inhalation and dermal exposure to wet filter wastes during filter media replacement.
- F. Inhalation and dermal exposure to liquid radiation curable product during packaging.

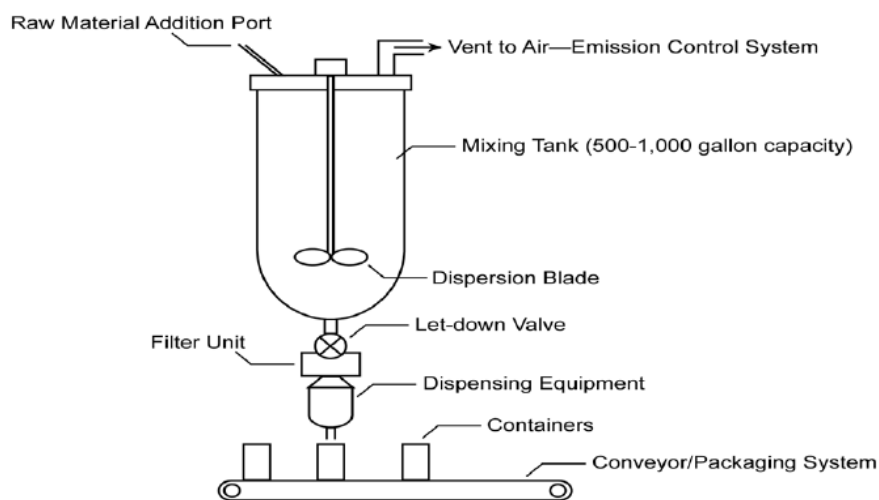
Figure 2-1. Sealed Radiation Curable Formulation Process

2.1.1 Preheating (Optional)

Preheating is optional and is typically used to lower the viscosity of components to facilitate transfer. The components are heated at 43°C to 54°C (109°F to 129°F), which may increase the vapor pressure of the raw materials (EPA, 1992).

2.1.2 Sealed Mixing/Transfer

The process for manufacturing radiation curable products involves blending volatile and nonvolatile raw materials into a homogeneously blended product. Figure 2-2 illustrates simple batch process equipment used at a formulation site. Raw materials are charged into the mixing kettle, blended, and dispensed into containers. Filling may take place at a larger scale. The formulation of radiation curable products is a specialty market, so the batch sizes used during manufacture vary greatly from as few as 15 to thousands of gallons of formulation (RadTech, no date; EPA, 1992).



Source: CEB, 1994

Figure 2-2. Schematic of Radiation Curable Formulation Equipment

Oligomers and monomers may be premixed by the raw material suppliers to meet the specifications of the formulators. In most cases, these components are transferred directly to the mixing kettle using closed lines and pumps; however, in some operations, a worker may pour the raw materials into the mixing kettle.

Solid raw materials may be received in bags or sacks and liquid raw materials may be received in tank trucks, totes, or drums depending on the quantity of the chemical utilized (RadTech, 2007). Solid or liquid components are unloaded from transport containers (tank trucks, totes, drums, sacks) either directly into the mixing equipment or into intermediate storage tanks (Release 1, Exposure A). During the unloading of solid/powdered components, dust may be generated during transfer operations. Dust may be collected in a baghouse or other control technology, be vented to the air outside of the facility, or settle out within the workspace. Dusts that collect on vent filters or within the workspace are collected and disposed (Release 2, Exposure A).

The relatively high cost of radiation curable raw materials have led to several common industrial practices to reduce container residues including heating containers to reduce the viscosity of the raw materials and inverting containers to allow the containers to drain (RadTech, 2007). While some transport containers are dedicated and reused without cleaning,

transport containers are commonly cleaned and neutralized with alkaline soapy water wash treatments and rinsed with water (RadTech, 1995). Liquid components may volatilize or may be sent to a publicly owned treatment works (POTW), landfill, or incineration. Empty bags and sacks that contained solid raw materials may also be sent to an off-site landfill or incinerator (Release 3, Release 4, Exposure B).

The oligomers and monomers are blended at low shear for a period of 30 minutes to four hours, depending on the size of the batch and the viscosity of the components (RadTech, no date). The mixing kettle may be heated at 43°C to 82°C (109°F to 180°F) to aid the blending process (EPA, 1992). After the oligomers and monomers are thoroughly blended, other materials such as the dispersion aids, stabilizers, and pigments are added to the blend. Most of the additives are in the liquid form and can be fed into the mixing kettle using pumps and feed tubes (RadTech, no date). Pigments can be in the solid form and may be unloaded manually. Mixing is continued to thoroughly disperse the additional materials. For UV curable formulations, the photoinitiator is the last ingredient added (RadTech, 1995). Heavily pigmented formulations may require substantial mixing for thorough dispersion.

In the sealed process, the mixing occurs with no direct contact from the workers in closed vessels. Typically, a high-speed dispenser combines the components using precise settings to avoid overstirring, which may adversely affect the viscosity and other properties of the formulation (Ullmann, 1985). It is assumed that the sealed system captures the volatile components released during the mixing process and vents them through a stack to air outside the facility (Release 5). Because the process is enclosed, worker exposure to the component vapors vented from the mixing vessel is expected to be negligible.

Once mixing is completed, quality assurance samples are drawn from the kettle for assessment (RadTech, no date; EPA, 1992). Additional alterations to the formulation are made at this time. Although no industry-specific data were found regarding product sampling practices for radiation curable formulators, it is generally assumed that some amount of product quality assurance/quality control (QA/QC) sampling is performed as part of the formulation process (engineering judgment). Releases and associated exposures are expected to occur as a result of sampling activities (Release 6, Release 7, Exposure C).

Industry-specific information indicates that typical industry practice is to recover and dispose of solvent washings and water washings. Equipment washes may volatilize or may be released to land or incineration (Release 8, Release 9, Exposure D). Particularly for clear coatings, equipment may not always be cleaned between batches, since formulators can campaign back-to-back batches of the same product or similar compatible products (RadTech, 2007). While some facilities may clean process equipment after a certain number of batches within a formulation campaign, this ESD assumes that the residues from each batch are removed prior to the next one as a conservative estimate.

2.1.3 *Filtration and Packaging*

Once the formulation obtains the desired properties, the formulation is filtered. Many formulations are filtered to remove any gel, pigment, or filler agglomerates that could affect

the product performance. Types of filters that are used in the formulation process include lint-free cheesecloth, fine mesh screen, or bag filters. For critical applications in electronics, magnetic media, and microfinishing products, pressure filtration through a cartridge may be required (RadTech, 1995). Filter media containing filter waste is also expected to be removed and released (i.e., disposed) from the formulation site (Release 10, Release 11, Exposure E). Filter media is typically sent to an off-site landfill or incinerator (RadTech, 2007).

The end product is fed into holding tanks or fed directly into containers for shipping. Shipping containers vary in size according to the end use. Most products are supplied in returnable or recyclable bulk (tote) containers. Under some circumstances, dedicated returnable totes may be refilled with the same product without cleaning. Large volume radiation curable products may be supplied in tank wagons (RadTech, 2007). Table 2-1 summarizes shipping containers for radiation curable components and products. The product containers may be filled from the mixing kettle by workers connecting transfer lines to tank wagons, totes, or drums (Release 12, Exposure F).

Table 2-1. Shipping Containers for Radiation Curable Components and Products

Type of Material	Type of Containers
Acrylate Raw Materials (e.g. oligomers, monomers, blends)	Tank wagons, totes, drums, and 5 gallon pails
Formulated Coatings and Adhesives	Tank wagons (high volumes), totes, drums, 5 gallon pails, gallon jugs, and smaller cans for specialty adhesives
Formulated Inks	Drums, 5 gallon pails, gallon jugs, and smaller cans

2.2 Application

The application of radiation curable products is not included in the scope of this document and is discussed in a separate document (OECD, 2008). Radiation curable products may be applied using a variety of methods depending on the product properties, type of substrate (e.g., wood, metal, plastic, and paper), and the geometry of the substrate (e.g., tape backing, flat board, and three-dimensional part).

2.3 Radiation Curable Formulations

The main components of radiation curable products are oligomers and reactive monomers; however, other components may include initiators, fillers, pigments, stabilizers, viscosity control agents, and surfactants.

Table 2-2 presents general formulation information for radiation curable coatings, inks, and adhesives. If only the general component type is known, these data may be used. Table 2-3 provides more detailed composition information for radiation curable products. These data may be more appropriate if the specific function of the chemical within the radiation curable product is known. Table 2-3 only covers additives and specifically excludes based resins.

Table 2-2. Formulation Compositions of Radiation Curable Products

Component	Concentration (wt %)		
	Coatings	Inks	Adhesives
Oligomers	60-70 (Default)	20-50	10-15
Monomers	10-20	15-50	70-85
Additives	10-20	2-20	3-10
Pigments	NA	1-20	NA
Photoinitiator	0-4	0-10	0-4

Source: RadTech, 2007.

NA – Not Available.

Formulators measure the composition of components in parts per hundred parts of resin (PHR) as presented in Table 2-3. The difference between PHR and percentage formulations can seem small but can give large changes in the final product properties (RadTech, 1995). For screening-level assessments, this ESD assumes that the compositions reported in Table 2-3 can be used as weight fractions in formulation. PHR units will always be greater than the weight fraction; therefore, PHR values are conservative. Note that some component types are not used in every radiation curable formulation.

Table 2-3. Summary of Formulation Compositions of Radiation Curable Products

Component	Fraction of Component (PHR)	Function
Monomers		
Single double bond	0-0.8	Lower viscosity
Multiple double bonds	0-0.45	Increase crosslink density, stiff tough
Mixed functionality	0-0.1	Adhesion, modify properties
Other resins		
Nonreactive	0-0.15	Plasticize
Reactive	0-0.15	Adhesion, modify properties
Photoinitiator		
Free radical	0.0025-0.05	Cure speed, shelf life
Cationic type	0.02-0.05	Cure speed, shelf life
Photosensitizer	0-0.05	Cure speed, shelf life
Chain transfer	0-0.005	Controls MW
Stabilizer		
For raw materials	20-200 PPM	Shelf life
For formulation	As required	Inhibits pre-cure
Light stabilizer	As required	Color change, properties
Heat, hydrolytic, etc.	As required	Prevent property loss
Antioxidants	As required	Inhibit oxidation
Surfactants		
Dispersants	0-0.01	Disperse pigments and fillers
Flow Modifiers	0-0.05	Flow out leveling
Emulsifiers	0-0.01	Disperse oligomers in water, monomers
Defoamers	0-0.0015	Reduce foam, air bubbles

Component	Fraction of Component (PHR)	Function
Other	0-0.01	Wetting, prevent phase separation
Pigments, fillers, flatting agents	0-0.45	Viscosity, color, cure
Dyes	0-0.05	Color cure
Adhesion promoter	0-0.05	Adhesion
Coupling agents	0-0.005	Adhesion, aid in pigment binding
Viscosity stabilizer	0-0.01	Viscosity
Dual cure additive	0-0.03	Shelf life, second cure

Source: RadTech, 1995.

2.4 Physical Properties of Radiation Curable Chemicals

Table 2-4 presents the physical properties of example chemical compounds that may be used for each of the radiation curable component categories described in this ESD. The specific chemicals within each component category were identified through available references that discuss radiation curable formulations. These references include:

- RadTech's *UV/EB Curing Primer*;
- *Kirk-Othmer Encyclopedia of Chemical Technology*;
- Chemical properties databases; and
- Web sites of known radiation curable formulation companies.

EPA reviewed several sources of physical property data for each of the chemicals identified for the component categories. These sources are cited at the bottom of Table 2-4 and included in the *References* section (Section 8) of this ESD. The example chemicals shown in the table were selected based on the following data quality criteria:

- Available data are characterized as either experimental or extrapolated (estimated/modeled data are not included in Table 2-4);
- Physical property data were found to be relatively consistent among multiple sources; and
- A complete "set" of Table 2-4 physical property data were found for the chemical.

The physical properties of these chemicals are presented to provide the reader with a general understanding of potential characteristics of certain radiation curable components. It should be noted, however, that these chemicals are simply examples of the wide array of chemicals that may be used in specific radiation curable products.

Table 2-4. Physical Properties of Example Radiation Curable Component Chemicals

Component Category	Example Chemical (CAS, if available)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (mg/L)	Density, LogK _{ow}
Oligomer	Butadiene-acrylonitrile; urethane acrylates; epoxy acrylates; polyester acrylates; silicone acrylates	<p>The polymers used in radiation curable formulations may be solids or liquids and possess a wide range of molecular weights, vapor pressures, and other physical properties.</p> <p>Radiation curable polymers are generally expected to be of high, variable molecular weight and have a negligible vapor pressure.</p> <p>If the physical state of the polymer is not known, EPA recommends that the polymer be assessed as a solid, which will result in more conservative worker inhalation exposure assessment.</p>						
Monofunctional Monomer	Acrylic Acid (CAS # 79-10-7)	Colorless liquid with acrid odor ^(c)	72.0634 ^(c)	3.1 ^(c)	141.6 ^(c)	12 ^(c)	1E+006 ^(d)	1.06 ^(c)
Multifunctional Monomer	1,3-Propanediol, 2-ethyl-2-(hydroxymethyl) (CAS # 77-99-6) common name: Trimethylolpropane	Hygroscopic ^(c)	134.1748 ^(c)	4.49E-005 ^(d)	289 ^(d)	58 ^(c)	1E+006 ^(d)	1.176 ^(c)
Photoinitiator Photosensitizer	Benzophenone (CAS# 119-61-9)	White crystals ^(c)	182.2214 ^(c)	0.00193 ^(d)	305.4 ^(c)	48.5 ^(c)	137 ^(d)	1.11 ^(c)
Stabilizer	Zinc dibutyldithiocarbamate (CAS # 136-23-2); common name: Butyl zimate	White powder ^(b)	474.13 ^(d)	5.8E-011 ^(d)	296 ^(d)	105 ^(d)	0.0104 ^(d)	NA
Surfactants	NA	NA	NA	NA	NA	NA	NA	NA

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Component Category	Example Chemical (CAS, if available)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (mg/L)	Density, LogK _{ow}
Pigment / Dye	Copper phthalocyanine (CAS # 147-14-8); common name: Phthalocyanine Blue 15	Bright blue crystals with purple luster ^(c)	578.10 ^(d)	3.17E-019 ^(d)	NA	480 ^(d)	0.00103 ^(d)	NA
Adhesion Promoter	Styrene Maleic anhydride (CAS# 9011-13-6)	<p>The polymers used in radiation curable formulations may be solids or liquids and possess a wide range of molecular weights, vapor pressures, and other physical properties.</p> <p>Radiation curable polymers are generally expected to be of high, variable molecular weight and have a negligible vapor pressure.</p> <p>If the physical state of the polymer is not known, EPA recommends that the polymer be assessed as a solid, which will result in more conservative worker inhalation exposure assessment.</p>						
Coupling Agent	2-methyl-2-Propenoic acid 2-ethyl-2-[[[(2-methyl-1-oxo-2-propenyl)oxy]methyl]-1,3-propanediyl ester (CAS # 3920-92-74); common name: Trimethylolpropane trimethacrylate	NA	338.40 ^(d)	0.000137 ^(d)	NA	<-10 ^(d)	13 ^(d)	NA
Viscosity stabilizer	Polyurethane	<p>The polymers used in radiation curable formulations possess a wide range of molecular weights, vapor pressures, and other physical properties.</p> <p>Radiation curable polymers are generally expected to be of high, variable molecular weight and have a negligible vapor pressure.</p>						

NA = No data were found in the references reviewed for this ESD.

a – Source: Merck, 1996.

b – Source: Hawley's, 1997.

c – Source: ChemFinder, 2006.

d – Source: SRC, 2006.

3 OVERALL APPROACH AND GENERAL FACILITY ESTIMATES FOR THE FORMULATION OF RADIATION CURABLE PRODUCTS

This ESD presents EPA's standard approach for estimating environmental releases of and worker exposures to components used during the formulation of radiation curable materials. This section covers the blending of the components into radiation curable formulations.

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 radiation curable products industry data are needed. These data needs are summarized in Section 7 of this ESD. It should be noted that the default values cited throughout this ESD are intended to be used only when appropriate site-specific or industry-specific information is not available.

Because this ESD presents several alternative default assumptions or values for some estimation parameters, one must consider carefully how the selection of these defaults will affect the final assessment results.

This section of the ESD presents general facility calculations for formulators, which estimate daily use rates of radiation curable component chemicals, the number of formulation sites using the chemical of interest, and the number of days the chemical is expected to be used in the formulation process.

Section 4 of the ESD presents the environmental release assessments for the formulation of radiation curable products, which use the general facility estimates to estimate the quantity of chemical released from various points in the formulation process and the most likely media of release for each release source.

Section 5 of the ESD presents the occupational exposure assessments for the formulation of radiation curable products, which use 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) and routes of those exposures.

3.1 Introduction to the General Facility Estimates

Through the remainder of this section, a method utilizing available radiation curable products industry data is described to determine the daily use rate of the chemical of interest. The daily use rate can be estimated using several facility parameters, including the annual facility production rate ($Q_{\text{form_site_yr}}$); the number of formulation sites that may use a particular component containing the chemical of interest ($N_{\text{form_sites}}$); and the days of operation ($\text{TIME}_{\text{form_working_days}}$). Industry provided 2005 production data for coatings, inks, and adhesives (see Table 1-2). Additional information on the number of formulation sites was obtained from the Economic Census data (USCB, 2002).

Combined with available formulation data in Tables 2-2 and 2-3, market production data and census data can be used to calculate the annual facility production rate and

daily use rate of the chemical of interest. The number of shipping containers that are transferred into the operation annually and the number of containers that are filled with the radiation curable product annually were also determined.

The general facility estimates described in this section are summarized with their associated inputs/bases and corresponding ESD section number in Table 3-1. In addition, Table A-2 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.

Table 3-1. Summary of General Facility Parameters for Formulation Sites

Parameter	Description	ESD Section
$Q_{\text{form_site_yr}}$	Annual facility production rate for radiation curable formulations containing the chemical of interest (kg formulation/site-yr)	3.2
$F_{\text{chem_comp}}$	Mass fraction of the chemical of interest in the radiation curable component (kg chemical/kg component)	3.3
$F_{\text{comp_form}}$	Mass fraction of the component used in the formulated radiation curable product (kg component/kg formulation)	3.4
$F_{\text{chem_form}}$	Mass fraction of the chemical of interest in the formulated radiation curable product (kg chemical/kg formulation)	3.5
$N_{\text{form_sites}}$	Number of facilities using the chemical of interest to formulate a radiation curable product (sites)	3.6
$\text{TIME}_{\text{form_working_days}}$	Annual number of days the radiation curable product is formulated at each facility (days/yr)	3.7
$N_{\text{bt_site_yr}}$	Annual number of radiation curable formulation batches run at each facility (batches/site-yr)	3.8
$Q_{\text{form_chem_site_day}}$	Daily use rate for the chemical of interest at each facility (kg of chemical/site-day)	3.9
$N_{\text{comp_cont_empty_site_yr}}$	Annual number of chemical-containing radiation curable component containers emptied per facility (container/site-yr).	3.10
$N_{\text{form_cont_fill_site_yr}}$	Annual number of chemical-containing radiation curable product containers filled per facility (container/site-yr).	3.11

The method described in the remaining sections incorporates certain assumptions in cases where industry-specific data were not found. These key assumptions are presented throughout this section and are accompanied by a discussion of their uncertainties and potential effects on the estimates.

3.2 Annual Facility Radiation Curable Formulation Production Rate ($Q_{\text{form_site_yr}}$)

The average annual facility production of radiation curable products may be estimated based on available 2005 United States production data and available U.S. Census Bureau data on the total number of sites that may formulate radiation curable products. Table 3-2 summarizes the methodology for estimating the annual facility production rate ($Q_{\text{form_site_prod_rate}}$). The default value for this parameter depends on the type of radiation curable product.

Table 3-2. Annual Facility Production Rate of Radiation Curable Products for Formulation Sites

Type of Radiation Curable Product	Total U.S. Production Volume (million kg/yr) ^a	Total Number of Formulator Sites (N _{form sites})	Annual Facility Production Rate (Q _{form site prod rate}) (kg/site-yr) ^h
Coatings	69.87	195 ^b	360,000
Inks: Letterpress	0.70	10 ^c	70,000
Inks: Lithography	7.90	168 ^d	50,000
Inks: Flexography	6.00	59 ^e	100,000
Inks: Other	7.05	56 ^f	130,000
Adhesives	4.02	227 ^g	20,000

a – See Table 1-2.

b – Source: USCB, 2002a. NAICS 3255104: Manufacturers of product finishes for original equipment manufacture (OEM), excluding marine coatings.

c – Source: USCB, 2002b. NAICS 3259101: Manufacturers of letterpress printing inks.

d – Source: USCB, 2002b. NAICS 3259104: Manufacturers of lithographic and offset inks.

e – Source: USCB, 2002b. NAICS 325910A: Manufacturers of flexographic printing ink.

f – Source: USCB, 2002b. NAICS 3259107: Manufacturers of gravure printing ink manufacturers and NAICS 325910H: Manufacturers of all other printing inks.

g – Source: USCB, 2002c. NAICS 32552040: Manufacturers of synthetic resin and rubber adhesives, including all types of bonding and laminating adhesives.

h - The average facility annual production rate is estimated by the following:

(Estimated U.S. Production Volume) ÷ (Estimated Number of U.S. Sites)

Note that no facility-specific production rates were found; therefore, no ranges in the production rates are available to demonstrate their variability.

The default value for the average annual facility production rate in Table 3-2 depends on the type of radiation curable product. Figure 3-1 illustrates the logic that can be used to determine the appropriate default for the general facility estimates.

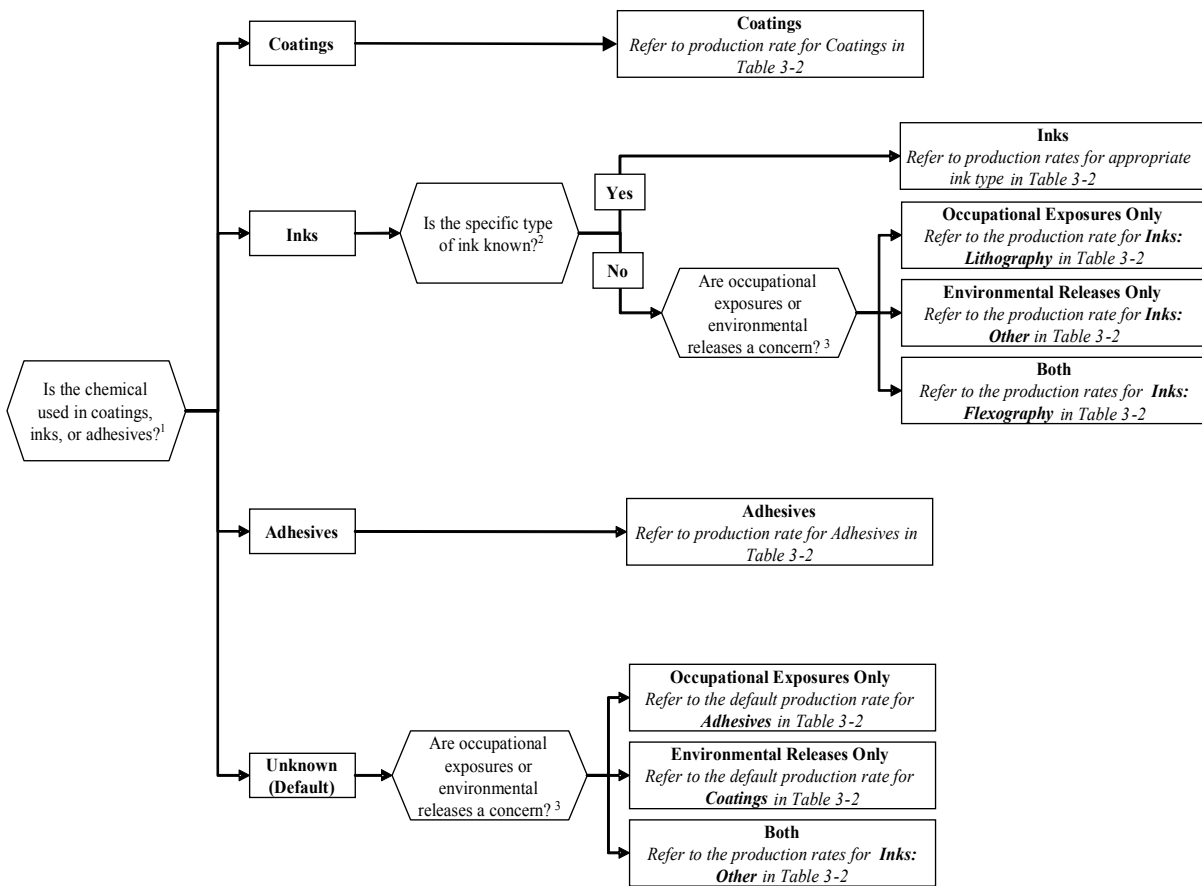


Figure 3-1. Logic Diagram to Determine the Default Facility Production Rate for the General Facility Estimates

Note: Footnotes for Figure 3-1 are presented on the following page.

Footnotes to Figure 3-1

- 1) If the specific radiation curable product (e.g., coatings, inks, or adhesives) is known, the appropriate annual facility production rate should be utilized. However, if the specific radiation curable product is unknown, then the occupational exposure and environmental releases concerns should be considered when selecting the appropriate default for the annual facility production rate.
- 2) If the specific type of radiation curable ink (e.g., lithographic, screen printing) is known, the appropriate annual facility production rate for the specific ink type should be utilized. However, if the specific radiation curable ink is unknown, then the occupational exposure and environmental releases concerns should be considered when selecting the appropriate default for the annual facility production rate for inks.
- 3) When selecting use rates based on potential concerns, EPA typically uses the following methodology to make conservative assessments. For conservative occupational exposure estimates, facilities with the lowest annual use rates are typically selected. This maximizes the number of use sites and therefore, maximizes the number of workers. For conservative environmental release assessments, facilities with the highest annual use rates are typically selected. This maximizes the daily use rate and therefore, results in the highest daily release. If both releases and exposures are a concern, average or median values are typically utilized. This methodology was utilized to select the defaults in Figure 3-1.

The chemical of interest may be used in all or only a portion of the radiation curable products formulated at a facility. Industry-specific information on the number of different radiation curable products formulated at a site was not available; therefore, this ESD assumes that the chemical of interest is formulated into all radiation curable formulations at a particular site. If site-specific information is available, it should be used in lieu of this general assumption.

The factor, F_{radcur} , accounts for the chemical of interest being used to formulate a portion of all radiation curable products at a facility. The recommended default value for $Q_{form_site_prod_rate}$ presented in this ESD assumes that the specific radiation curable product is a coating. The following calculation may be used to determine the annual facility production rate for the radiation curable product containing the chemical of interest ($Q_{form_site_yr}$):

$$Q_{form_site_yr} = Q_{form_site_prod_rate} \times F_{radcur} \tag{3-1}$$

Where:

- | | | |
|------------------------------|---|---|
| $Q_{form_site_yr}$ | = | Annual facility radiation curable production rate using the chemical of interest (kg material incorporating the chemical/site-yr) |
| $Q_{form_site_prod_rate}$ | = | Total annual facility radiation curable production rate (See Table 3-2 for alternative production rates.) |
| F_{radcur} | = | Fraction of the total radiation curable product type produced that incorporates the chemical of interest (Default: 1 kg |

material containing the chemical of interest/kg total product produced)

Several key assumptions are inherent in these default production rates:

Assumption #1: All of the formulation sites produce radiation curable products.

The values for the number of sites in Table 3-2 include all sites within a particular NAICS category. For example, the 195 coatings formulators represent those facilities categories under “Product finishes for OEM (excluding marine coatings)” under the 2002 Economic Census. This category includes coating formulators for automobile manufacturing, furniture and appliance products, metal products manufacturing, paper and paperboard coatings, and other product coatings. While many of these facilities will formulate radiation curable coatings, the calculation assumes all facilities under this category formulate radiation curable coatings.

While the production at some niche market formulators may be less than the default values presented in this ESD, this assumption will tend to under-predict the facility’s actual facility production volume and may not be conservative for environmental release assessments. Lacking more specific data on the number of formulation sites that produce each type of adhesive, coating, or ink, the assumption is made that the production amounts are evenly distributed across the entire industry.

Assumption #2: The chemical of interest is used to formulate all of a particular radiation curable product type at each site (i.e., $F_{\text{radcur}} = 1$ kg product incorporating the chemical/kg total product produced).

Most sites formulate more than one radiation curable product. No information or data were found that could be used to quantify the fraction of a site’s product that would incorporate a single component. It is possible that the chemical of interest is not used to formulate all of a particular radiation curable product, which would make the default production rate in Table 3-2 tends toward the high end (i.e., less conservative for exposures, more conservative for releases).

3.3 Mass Fraction of the Chemical of Interest in the Radiation Curable Component ($F_{\text{chem_comp}}$)

The chemical of interest may be shipped to the formulation site for use in a component product, or it may be the radiation curable component itself. If specific information about the chemical-containing component is not known, EPA assumes 100 percent chemical of interest when performing the calculations in this assessment⁵:

$F_{\text{chem_comp}}$ = Mass fraction of the chemical of interest in the radiation curable component (Default: 1 kg chemical/kg component)

3.4 Mass Fraction of the Component in the Radiation Curable Product ($F_{\text{comp_form}}$)

Available data for the general composition of a radiation curable formulation are presented in Tables 2-2 and 2-3. If only the general component type is known, these data may be used. Table 2-3 provides more detailed composition information for radiation curable products. These data may be more appropriate if the specific function of the chemical within the radiation curable product is known. If the specific function is a base resin, the compositions shown in Table 2-2 may be more appropriate. If the component type is not known, it is recommended that the type having the highest concentration (i.e., oligomer for coatings) be assumed from Table 2-2, as a default. If a range in concentration is presented, EPA suggests using the upper bound concentration¹.

$F_{\text{comp_form}}$ = Mass fraction of the component used in the formulated radiation curable product (Default: 0.7 kg component/kg material for an oligomer. See Tables 2-2 and 2-3 for alternative fractions, as appropriate.)

3.5 Mass Fraction of the Chemical of Interest in the Radiation Curable Product ($F_{\text{chem_form}}$)

The fraction of the chemical of interest contained in the radiation curable product can be determined using the following equation.

$$F_{\text{chem_form}} = F_{\text{chem_comp}} \times F_{\text{comp_form}} \quad (3-2)$$

Where:

$F_{\text{chem_form}}$ = Mass fraction of the chemical of interest in the formulated radiation curable product (kg chemical/kg product)

$F_{\text{chem_comp}}$ = Mass fraction of the chemical of interest in the radiation curable component (Default: 1 kg chemical/kg component)

$F_{\text{comp_form}}$ = Mass fraction of the component used in the formulated radiation curable product (Default: 0.7 kg component/kg material. See Tables 2-2 and 2-3 for alternative fractions, as appropriate.)

¹Using the upper bound concentration will provide a conservative (worst case) assessment for releases, as well as worst case exposure doses; however, it will not provide a conservative result in the total number of workers potentially exposed to the chemical of interest (i.e., the total number of sites, and thus the number or workers will be minimized).

3.6 Number of Formulation Sites ($N_{\text{form_sites}}$)

The following calculation combines the radiation curable formulation production rate ($Q_{\text{form_site_yr}}$), the annual production rate of the chemical ($Q_{\text{chem_yr}}$), and the fraction of the chemical of interest in the radiation curable product ($F_{\text{chem_form}}$) to estimate the number of formulator sites expected to utilize the amount of chemical of interest in producing radiation curable products:

$$N_{\text{form_sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{form_site_yr}} \times F_{\text{chem_form}}} \quad (3-3)$$

Where:

$N_{\text{form_sites}}^1$	=	Number of formulators using the component that contains the chemical of interest (sites)
$Q_{\text{chem_yr}}$	=	Annual production volume of the chemical of interest (kg chemical/yr)
$Q_{\text{form_site_yr}}$	=	Annual facility radiation curable production rate (kg product/site-yr) (See Section 3.2)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the formulated radiation curable product (kg chemical/kg component) (See Section 3.5)

The number of sites that formulate the chemical of interest into radiation curable product is estimated based on the total amount of the chemical-containing component produced (kg/yr) and the annual facility production rate of the radiation curable product (kg/site-yr). The maximum number of sites should not exceed those listed in Table 3-2 for coatings, inks, and adhesives, per U.S. Economic Census data (USCB, 2002).

3.7 Days of Operation ($\text{TIME}_{\text{form_working_days}}$)

No site-specific information was found to indicate the typical days of operation for a formulation site. If the number of days of operation is not known, EPA assumes a maximum of 250 days per year based on a 2 week downtime for maintenance and operating schedule of 50 weeks per year.

Alternatively, if industry provides the formulated batch size, the annual number of days of operation (i.e., $\text{TIME}_{\text{form_working_days}}$) can be calculated using the following equation:

¹The value for $N_{\text{form_sites}}$, calculated using Equation 3-3 should be rounded up to the nearest integer value. $Q_{\text{form_site_yr}}$ should then be adjusted for the $N_{\text{form_sites}}$ integer value (to avoid errors due to rounding):

$$Q_{\text{form_site_yr}} = \frac{Q_{\text{chem_yr}}}{N_{\text{form_sites}} \times F_{\text{chem_form}}}$$

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

$$\text{TIME}_{\text{form_working_days}} = \frac{Q_{\text{form_site_yr}}}{Q_{\text{form_bt}} \times N_{\text{bt_site_day}}} \quad (3-4)$$

Where:

$\text{TIME}_{\text{form_working_days}}$	=	Annual number of days the radiation curable product is formulated (days/yr)
$Q_{\text{form_site_yr}}$	=	Annual facility radiation curable production rate (kg product/site-yr) (See Section 3.2)
$Q_{\text{form_bt}}$	=	Mass of radiation curable product formulated per batch (kg product/batch)
$N_{\text{bt_site_day}}$	=	Daily number of batches formulated at each site (Default: 1 batch/site-day)

The next subsection describes the method for estimating the annual number of batches based on the CEB default assumption of one batch per day per site.

3.8 Annual Number of Batches ($N_{\text{bt_site_yr}}$)

To estimate the annual number of batches, a batch size must be calculated. The batch size can be estimated using the following equation, assuming the number of days of operation ($\text{TIME}_{\text{form_working_days}}$) is 250 days per year and the number of batches formulated per site per day is one:

$$Q_{\text{form_bt}} = \frac{Q_{\text{form_site_yr}}}{\text{TIME}_{\text{form_working_days}} \times N_{\text{bt_site_day}}} \quad (3-5)$$

Where:

$Q_{\text{form_bt}}$	=	Mass of radiation curable product formulated per batch (kg product/batch)
$Q_{\text{form_site_yr}}$	=	Annual facility production rate (kg product/site-yr) (See Section 3.2)
$\text{TIME}_{\text{form_working_days}}$	=	Annual number of days the radiation curable product is formulated (Default: 250 days/yr) (See Section 3.7)
$N_{\text{bt_site_day}}$	=	Daily number of batches formulated at each site (Default: 1 batch/site-day)

The batch mixing operation may take thirty minutes to four hours, depending on the batch size and viscosity of the components (RadTech, no date). It is assumed that a typical batch size takes four hours.

The following calculation estimates the annual number of batches for each formulator site based on the annual facility production rate and the batch size:

$$N_{bt_site_yr} = \frac{Q_{form_site_yr}}{Q_{form_bt}} \quad (3-6)$$

Where:

$N_{bt_site_yr}$	=	Annual number of batches of product formulated, per site (batches/site-yr)
$Q_{form_site_yr}$	=	Annual facility production rate (kg product/site-yr) (See Section 3.2)
Q_{form_bt}	=	Mass of radiation curable product formulated per batch (kg product/batch) (See Equation 3-5)

3.9 Daily Use Rate of the Chemical of Interest ($Q_{form_chem_site_day}$)

The daily use rate for the chemical of interest in formulating radiation curable products is estimated using the following equation, based on the formulation production rate, the number of operating days, and the concentration of the chemical of interest in the formulated product:

$$Q_{form_chem_site_day} = \frac{Q_{form_site_yr} \times F_{chem_form}}{TIME_{form_working_days}} \quad (3-7)$$

Where:

$Q_{form_chem_site_day}$	=	Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day)
$Q_{form_site_yr}$	=	Annual production volume of radiation curable products containing the chemical per site (kg product/site-yr) (See Section 3.2)
F_{chem_form}	=	Mass fraction of the chemical of interest in the radiation curable product (kg chemical/kg product) (See Section 3.5)
$TIME_{form_working_days}$	=	Annual number of days the radiation curable product is formulated (days/yr) (Default: 250 days/yr, See Section 3.7)

Summary of the Relationship of General Facility Parameters

The values for days of operation, daily use rate of the chemical of interest ($Q_{form_chem_site_day}$), and number of sites (N_{form_sites}) are related. This ESD presents one method for estimating $Q_{form_chem_site_day}$ using estimated default values for: 1) the total annual U.S. production volume of the radiation curable product per site ($Q_{form_site_yr}$); 2) the mass fractions of the chemical and component in formulation; and 3) number of operating days ($TIME_{form_working_days}$).

If $N_{bt_site_day}$ and Q_{form_bt} are known, $Q_{form_chem_site_day}$ can be calculated alternatively:

$$Q_{form_chem_site_day} = Q_{form_bt} \times N_{bt_site_day} \times F_{chem_form}$$

However, it is recommended to calculate the chemical of interest throughput based on the methodology presented in Section 3.9, and compare it to the throughput based on batch size and number of batches per day, as calculated above.

3.10 Annual Number of Radiation Curable Component Containers Emptied per Facility ($N_{\text{comp_cont_empty_site_yr}}$)

The number of radiation curable component containers unloaded annually per site can be estimated based on the daily use rate, container size, and concentration of the chemical of interest in the component. EPA suggests that a default transportation container size of a 55-gallon drum could be used (CEB, 2002b). This is consistent with industry-specific information on the typical transport containers for radiation curable components (RadTech, 2007). Engineering judgment should be used to determine if another container type or size is more appropriate (e.g., a 50-pound bag may be more appropriate for a solid component). If the density of a liquid component is not known, the density for water can be used as a default (1 kg/L).

$$N_{\text{comp_cont_empty_site_yr}} = \frac{Q_{\text{form_chem_site_day}} \times \text{TIME}_{\text{form_working_days}}}{F_{\text{chem_comp}} \times Q_{\text{cont_empty}}} \quad (3-8)$$

Where:

$N_{\text{comp_cont_empty_site_yr}}$	=	Annual number of component containers emptied containing chemical of interest per site (containers/site-yr)
$Q_{\text{form_chem_site_day}}$	=	Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day) (Section 3.9)
$\text{TIME}_{\text{form_working_days}}$	=	Annual number of days the radiation curable product is formulated (days/yr) (Section 3.7)
$F_{\text{chem_comp}}$	=	Mass fraction of the chemical of interest in the radiation curable component (kg chemical/kg component) (See Section 3.3)
$Q_{\text{cont_empty}}^1$	=	Mass of the radiation curable component in the container (kg component/container)

3.11 Annual Number of Radiation Curable Product Containers Filled per Facility ($N_{\text{form_cont_fill_site_yr}}$)

The number of radiation curable product containers filled annually per site can be estimated similar to the methodology described in Section 3.10 above. The calculation is based on the daily use rate, container size, and concentration of the chemical of interest in the

¹If the mass of the component in each container is not known, it can be calculated using the volume of the container and the density of the component:

$$Q_{\text{cont_empty}} = V_{\text{cont_empty}} \times \text{RHO}_{\text{component}}$$

Where:

$V_{\text{cont_empty}}$	=	Volume of radiation curable component per container (Default: 208 L component/container (55-gallon drum); See Table B-3 in Appendix B for alternative default container volumes)
$\text{RHO}_{\text{component}}$	=	Density of the radiation curable component (Default: 1 kg component/L component)

formulated radiation curable product. EPA suggests that a default transportation container size of a 55-gallon drum could be used. Engineering judgment should be used to determine if another container type or size is more appropriate. If the density of a radiation curable product is not known, the density for water can be used as a default (1 kg/L).

$$N_{\text{form_cont_fill_site_yr}} = \frac{Q_{\text{form_chem_site_day}} \times \text{TIME}_{\text{form_working_days}}}{F_{\text{chem_form}} \times Q_{\text{cont_fill}}} \quad (3-9)$$

Where:

$N_{\text{form_cont_fill_site_yr}}$	=	Annual number of containers filled containing chemical of interest per site (containers/site-yr)
$Q_{\text{form_chem_site_day}}$	=	Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day) (See Section 3.9)
$\text{TIME}_{\text{form_working_days}}$	=	Annual number of days the radiation curable product is formulated (days/yr) (See Section 3.8)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (kg chemical/kg product) (See Section 3.5)
$Q_{\text{cont_fill}}^1$	=	Mass of the radiation curable product in the filled container (kg product/container)

¹If the mass of the radiation curable product in each container is not known, it can be calculated using the volume of the container and the density of the product:

$$Q_{\text{cont_fill}} = V_{\text{cont_fill}} \times \text{RHO}_{\text{radprod}}$$

Where:

$V_{\text{cont_fill}}$	=	Volume of radiation curable product per filled container (Default: 208 L product/container (55-gallon drum); See Table B-3 in Appendix B for alternative default container volumes)
$\text{RHO}_{\text{radprod}}$	=	Density of the formulated radiation curable product (Default: 1 kg product/L product)

4 ENVIRONMENTAL RELEASE ASSESSMENTS FOR THE FORMULATION OF RADIATION CURABLE PRODUCTS

This section presents approaches for estimating the amount of the chemical of interest released from each process source during the formulation of the radiation curable material. The release sources are discussed in the order that they occur in the process (See Figure 2-1), and include the most likely receiving media (i.e., air, water, landfill, or incineration). The primary sources of release are container residue, process equipment cleaning, and filter media waste. Key default values used to calculate the release estimates, accompanied by their respective references, are provided in Table A-2 of Appendix A.

It is generally assumed that during the formulation of radiation curable products, the losses of the chemical of interest are minimized in actual practice; however, some pre-process or other upstream releases will occur. Because losses are assumed to be minimized, the methodology presented in this section for estimating the releases of the chemical of interest from the formulation process does not include adjustments to account for pre-process or other upstream releases of the chemical (e.g., while some material may remain in the transport container, the entire volume received in the container is assumed when estimating equipment cleaning releases). These omissions of mass balance adjustments should not result in a negative throughput of the chemical of interest in these calculations (i.e., the total amount of chemical released from the process should not exceed the amount that enters the process).

All release equations 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 total number of formulation sites using the chemical of interest ($N_{\text{form_sites}}$) (See Equation 3-3).

Some process releases are expected to be released to the same receiving medium on the same days. Therefore, daily and annual releases to a given medium may be summed to yield total amounts released.

Many of the environmental release estimates presented in this document are based on standard EPA release models, with the exception of the estimates described in Section 4.11 for filter waste containing the chemical during filter media replacement. This release estimate is based on industry specific information provided by RadTech. Additionally, industry specific information is consistent with several of EPA's standard release models. Table 4-1 summarizes the release estimation methods used in this ESD.

Note that the standard model default values cited are current as of the date of this ESD; however, EPA may update these models as additional data become available. It is recommended 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 air release models, ChemSTEER is recommended for estimating air releases. 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 models.

Table 4-1. Summary of Radiation Curable Formulation Scenario Release Models

Release Source #	Description	Model Name or Description ^a	Standard EPA Model (✓)
1	Transfer operation losses of volatile chemical to air during unloading	EPA/OAQPS AP-42 Loading Model	✓
2	Dust losses of solid chemicals to air during unloading	EPA/OPPT Dust Emissions from Transferring Solids Model	✓
3	Container residue losses to non-air media during container cleaning and/or disposal	Specific model used is based on the type and size of the containers, and on the physical state of the radiation curable component: <ul style="list-style-type: none"> • EPA/OPPT Bulk Transport Residual Model • EPA/OPPT Drum Residual Model • EPA/OPPT Small Container Residual Model • EPA/OPPT Solid Residuals in Transport Containers Model 	✓
4	Open surface losses of volatile chemical to air during container cleaning	EPA/OPPT Penetration Model	✓
5	Vented losses of volatile chemical to air during mixing operations	EPA/OPPT Penetration Model	✓
6	Product sampling losses to non-air media.	No methodology for quantifying the release from this source has been developed	
7	Open surface losses of volatile chemical to air during product sampling	EPA/OPPT Penetration Model	✓
8	Equipment cleaning losses to non-air media	EPA/OPPT Single Process Vessel Residual Model	✓
9	Open surface losses of volatile chemical to air during equipment cleaning	EPA/OPPT Penetration Model	✓
10	Filter waste losses to non-air media during filter media replacement	Loss rate is based on available industry-specific data.	
11	Open surface losses of volatile chemical to air during filter media replacement	EPA/OPPT Penetration Model	✓
12	Transfer operation losses of volatile chemical to air during container loading	EPA/OAQPS AP-42 Loading Model	✓

OPPT – Office of Pollution Prevention and Toxics.

OAQPS – Office of Air Quality Planning and Standards.

a – Additional detailed descriptions for each of the models presented in this section are provided in Appendix B.

4.1 Control Technologies

Industry-specific information indicate that less than one percent of all waste generated at a radiation curable product formulation site is discharged to water. Therefore, on-site wastewater treatment is typically not required. Facilities that do discharge process wastes to water may utilize pretreatment of their process wastewaters; however, data were not found on typical pollution prevention control technologies used in this industry. EPA suggests that as a default, it should be assumed that all aqueous wastes are discharged directly to a publicly owned treatment works (POTW) for pretreatment prior to discharge to surface waters.

Facilities may also collect and dispose of liquid and solid process wastes by incineration or in landfills; however data were not found on the types of incinerators or landfill typically utilized (e.g., municipal, hazardous). Additionally, while facilities may utilize technologies to control air emissions, data were not found on the typical pollution control technologies used by the radiation curable products industry.

4.2 Transfer Operation Losses to Air from Unloading the Radiation Curable Component (Release 1)

For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

If the chemical is volatile (e.g., the vapor pressure is > 0.001 torr), releases to air may occur from the displacement of saturated air when the chemical is transferred ($E_{\text{local}_{\text{air_transfers}}}$). The standard EPA estimation model for transfer operations may be used to estimate the release to air (*EPA/OAQPS AP-42 Loading Model*). The transfer operations model provides worst and typical case estimates for releases and exposures during transfer operations (e.g., transferring liquids from transport containers into storage tanks or mixers).

Table 4-2 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 4-2. EPA/OAQPS AP-42 Loading Model Parameter Default Values for Air Releases During Unloading

Input Parameter	Default Values
Saturation Factor	EPA defaults 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (CEB, 2002b) (See Appendix B for alternative default saturation factors)
Frequency of Release	Equal to the lesser of $TIME_{form_working_days}$ or $N_{comp_cont_empty_site_yr}$ (See Sections 3.7 and 3.10).
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6.
Operating Hours for the Activity	Number of containers per site, per day (See Section 4.4) divided by the unload rate (CEB, 2002b) (default unload rates are found in Appendix B)
Unloading Rate	EPA default 20 containers/hr for volumes between 20 and 1,000 gallons (CEB, 1991) (Alternative default unload rates are found in Appendix B)
Container Volume	Default: 55-gallon drum (208 L) (See Section 3.10)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

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

4.3 Dust Generation from Transfer Operations Released to Air, or Collected and Released to Water, Incineration, or Landfill (Release 2)

For liquid radiation curable components received at the radiation curable product formulation site, this release is negligible.

For solid radiation curable components, 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. 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.

Most facilities utilize some type of control technology 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 are not anticipated for this industry. 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.

The daily release of fugitive dust emissions can be estimated using the daily use rate ($Q_{\text{form_chem_site_day}}$).

If the facility-specific information states a control technology is employed, the release may be partitioned to the appropriate media. Table 4-3 provides estimated efficiencies for more common control technologies that may be used in the radiation curable products industry.

Table 4-3. Estimated Control Technology Efficiencies

Control Technology	Estimated Efficiency (%)	Notes	Default Media of Release for Controlled Release
Filter (such as a baghouse)	>99%	For particles >1 μm	Incineration or Land
Cyclone/Mechanical Collectors:	80-99	For particles >15 μm	Incineration or Land

Source: CEB, 1991.

The portion of release that may be captured by the control technology may be disposed to incineration or land or may be recycled. If the control technology is not known, it can be assumed that none of the dust generated is captured. If the control technology is known, the quantity captured may be estimated using the following equation:

$$E_{\text{local_dust_captured}} = Q_{\text{form_chem_site_day}} \times F_{\text{dust_generation}} \times F_{\text{dust_control}} \quad (4-1)$$

Where:

$E_{\text{local_dust_captured}}$	=	Daily amount captured by control technology from transfers or unloading (kg/site-day)
$Q_{\text{form_chem_site_day}}$	=	Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day) (See Section 3.9)
$F_{\text{dust_generation}}$	=	Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$F_{\text{dust_control}}$	=	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 4-3 for alternative efficiencies).

The portion of the release that will not be captured by the control technology and may be released to air or settle onto the facility floor may be estimated using the following equation:

$$E_{\text{local_dust_fugitive}} = Q_{\text{form_chem_site_day}} \times F_{\text{dust_generation}} \times (1 - F_{\text{dust_control}}) \quad (4-2)$$

Where:

$E_{\text{local dust fugitive}}$	=	Daily amount not captured by control technology from transfers or unloading (kg/site-day)
$Q_{\text{form chem site day}}$	=	Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day) (See Section 3.9)
$F_{\text{dust generation}}$	=	Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$F_{\text{dust control}}$	=	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 4-3).

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.

4.4 Radiation Curable Component Container Residue Released to Water, Incineration, or Landfill (Release 3)

Industry specific information indicates that 1 to 2 percent of the raw material received may be lost as container residue; however, larger containers may be dedicated and reused without cleaning. The relatively high cost of radiation curable raw materials have led to several common industrial practices to reduce container residues including heating containers to reduce the viscosity of the raw materials and inverting containers to allow the containers to drain (RadTech, 2007).

The amount of radiation curable component remaining in transportation containers will likely depend on the size of the transport container and the physical form of the component product. Therefore, the following standard EPA models may be used to estimate container residue releases:

- *EPA/OPPT Bulk Transport Residual Model* may be used for large containers (e.g., totes, tank trucks, rail cars) containing greater than or equal to 100 gallons of liquid;
- *EPA/OPPT Drum Residual Model* may be used for drums containing between 20 and 100 gallons of liquid;
- *EPA/OPPT Small Container Residual Model* may be used for liquid containers containing less than 20 gallons; and
- *EPA/OPPT Solid Residuals in Transport Containers Model* may be used for containers of all sizes containing solids.

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

Radiation curable components may be received as liquids or solids. If the physical state of the component is not known, EPA suggests reviewing the physical property data summarized in Table 2-5 for some example radiation curable component chemicals and using engineering judgment to determine if the chemical of interest should be assumed a solid or liquid for the purposes of the assessment.

Industry-specific information on the types of containers used by the radiation curable formulation industry is summarized in Table 2-1. EPA suggests that a default transportation container size of a 55-gallon drum should be used. Engineering judgment should be used to determine if another container type or size is more appropriate (e.g., a 50-pound bag may be more appropriate for a solid component).

Radiation curable formulators typically pump cleaning solutions into the transport containers and dispose the washes as hazardous waste (RadTech, no date). Container cleaning may involve an organic and water wash, which could be released to water, incineration, or landfill. Empty bags and sacks that contained solid raw materials may also be sent to an off-site landfill or incinerator.

The annual number of containers emptied ($N_{\text{comp_cont_empty_site_yr}}$) is estimated based on the daily use rate of the component (Section 3.9) and the container size (Section 3.10). EPA recommends assuming 55-gallon (208 L) drums and density of 1 kg/L (density of water) as defaults. If the fraction of the chemical in the component is unknown, assume 100 percent concentration (see Section 3.3).

If the $N_{\text{comp_cont_empty_site_yr}}$ value is fewer than the days of operation ($\text{TIME}_{\text{form_working_days}}$), the days of release equal $N_{\text{comp_cont_empty_site_yr}}$ (as calculated in Equation 3-10) and the daily release is calculated based on the following equation:

$$\text{Elocal}_{\text{comp_cont_residue_disp}} = Q_{\text{cont_empty}} \times F_{\text{chem_comp}} \times F_{\text{container_residue}} \times N_{\text{comp_cont_empty_site_day}} \quad (4-3a)$$

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

Where:

$\text{Elocal}_{\text{comp_cont_residue_disp}}$ = Daily release of chemical of interest from container residue (kg chemical/site-day)

$Q_{\text{cont_empty}}$ = Mass of the radiation curable component in the container (kg component/container) (Default: use the same value used to estimate $N_{\text{cont_empty_site_yr}}$ in Section 3.10)

$F_{\text{chem_comp}}$	=	Mass fraction of the chemical of interest in the radiation curable component (kg chemical/kg component) (See Section 3.3)
$F_{\text{container_residue}}$	=	Fraction of radiation curable component remaining in the container as residue (Default: 0.03 kg component remaining/kg shipped for drums (CEB, 2002a); See Appendix B for defaults used for other container types)
$N_{\text{comp_cont_empty_site_day}}^1$	=	Number of containers unloaded per site, per day (Default: 1 container/site-day)

If $N_{\text{comp_cont_empty_site_yr}}$ is greater than $\text{TIME}_{\text{form_working_days}}$ (see Section 3.7), more than one container is unloaded per day (i.e., $N_{\text{comp_cont_empty_site_day}} > 1$). The days of release should equal the days of operation, and the average daily release can be estimated based on the following equation:

$$E_{\text{local_comp_cont_residue_disp}} = Q_{\text{form_chem_site_day}} \times F_{\text{container_residue}} \quad (4-3b)$$

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

Where:

$E_{\text{local_comp_cont_residue_disp}}$	=	Daily release of chemical of interest from container residue (kg chemical/site-day)
$Q_{\text{form_chem_site_day}}$	=	Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day) (See Section 3.9)
$F_{\text{container_residue}}$	=	Fraction of radiation curable component remaining in the container as residue (Default: 0.03 kg component remaining/kg shipped for drums (CEB, 2002a); See Appendix B for defaults used for other container types)

Note: This equation may also be used if a container size is not assumed in Equations 3-8 and 4-3a, and $N_{\text{comp_cont_empty_site_yr}}$ is unknown.

¹ The daily number of containers unloaded per site may be estimated as (consistent with Section 3.10):

$$N_{\text{comp_cont_empty_site_day}} = \frac{N_{\text{comp_cont_empty_site_yr}}}{\text{TIME}_{\text{form_working_days}}}$$

($N_{\text{comp_cont_empty_site_day}}$ should be rounded up to the nearest integer.)

Where:

$N_{\text{comp_cont_empty_site_yr}}$	=	Annual number of containers emptied containing chemical of interest per site (containers/site-yr) (See Section 3.10)
$\text{TIME}_{\text{form_working_days}}$	=	Annual number of days the radiation curable product is formulated (days/yr) (See Section 3.7)

4.5 Open Surface Losses to Air During Container Cleaning (Release 4)

For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

If the chemical is volatile (e.g., the vapor pressure is > 0.001 torr), it may volatilize and be emitted from the process while empty containers are being rinsed and cleaned ($E_{\text{local,air_cleaning}}$). To estimate this release, the EPA standard model for estimating releases to air from containers cleaned indoors may be used (*EPA/OPPT Penetration Model*).

Table 4-4 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 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 4-4. EPA/OPPT Penetration Model Parameter Default Values During Container Cleaning

Input Parameter	Default Values
Diameter of Opening	EPA 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 Release	Equal to the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (See Sections 3.7 and 3.10)
Molecular Weight	Chemical-specific parameter.
Number of Sites	Calculated in Section 3.6.
Operating Hours for the Activity	Number of containers per site, per day ($N_{\text{comp_cont_empty_site_day}}$, consistent with Release 3) 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	Chemical-specific parameter
Air Speed	EPA default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

4.6 Vented Losses to Air During Process Operations (Release 5)

During formulation of the radiation curable products, the mixing kettle may be heated up to 82°C to aid in blending viscous components. If the operating temperature of the mixing kettle is not known, EPA assumes the temperature of the kettle to be 82°C as a default. The vapor pressure of the chemical of interest at elevated temperatures should be estimated to determine whether it should be considered volatile for the purposes of this assessment (e.g., has a vapor pressure > 0.001 torr at operating temperature of 82°C). If the chemical is volatile at these temperatures, the volatile releases should be estimated at the elevated temperature conditions.

For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr at the operating temperature), releases to air are expected to be negligible from volatilization.

If the chemical is volatile (e.g., the vapor pressure is > 0.001 torr at the operating temperature), chemicals may volatilize and be emitted from the process during mixing ($E_{\text{local_air_process_vent}}$). In an operation where the radiation curable product is generally nonvolatile or that incorporates relatively stable, non-reactive components, the mixing vessel and other operations may be open. In this case, volatile chemicals may be emitted into the workspace and subsequently vented to the air outside of the facility.

Because the components in radiation curable formulations have a high market value and may volatilize or degrade/react when exposed to ambient conditions, it is expected that their formulation process is sealed and vented to the air outside of the facility (e.g., through a stack), minimizing the losses and fugitive emissions into the workspace. Scrubbers or other

pollution control devices may be required to prevent excess air emissions; however, pollution control devices are not standard across the industry.

The EPA standard model for estimating releases to air from open vessels or process vents may be used (*EPA/OPPT Penetration Model*). The model inputs and default values are listed in Table 4-5. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate open surface losses to air during process operations. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 4-5. EPA/OPPT Penetration Model Parameter Default Values During Process Operations

Input Parameter	Default Values
Diameter of Opening	EPA default 4-in vent (10 cm) (engineering judgment)
Frequency of Release	Equal to TIME _{form} working days (See Section 3.7)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Operating Hours for the Activity	24 hrs/day or 4 hrs/batch × N _{bt_site_day} (See Section 3.8), whichever is less (CEB, 2002b) and consistent with calculations described in Section 3.8
Temperature	For non-heated processes, use the standard EPA default of 298 K (CEB, 1991). For heated processes (default), assume temperature of 355 K (82°C).
Vapor Pressure	Chemical-specific chemical parameter (for heated processes, EPA recommends using the vapor pressure of the chemical at the operating temperature (e.g., worst-case default of 82°C (355K))
Air Speed	EPA default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

Batch times for the formulation of radiation curable products may be up to four hours (RadTech, no date); therefore, a default of hour hours per batch may be assumed. Two parameters required for using the model are release time and diameter of the opening. Mixing vessels will most likely be closed since radiation curable components may react to ambient conditions; therefore, EPA also suggests assuming the vent has an opening diameter of four inches (engineering judgment¹). These defaults should be used in absence of site-specific data for the *EPA/OPPT Penetration Model*.

¹ Note: The 4-inch vent diameter default is based on professional experience in the radiation-curable adhesives formulation, fermentation, and petroleum processing industries. Based on these industries, a 4-inch vent is assumed to provide conservative estimates for potential air releases during operations. Similar vent sizes are anticipated throughout the radiation curable product formulation industry; however, the applicability of this default to the entire industry is uncertain. Additionally, the vessel may be vented through control

4.7 Radiation Curable Product Sampling Wastes Disposed to Water, Incineration, or Landfill (Release 6)

EPA generally assumes that formulation processes incorporate product sampling activities for quality assurance/quality control (QA/QC) and that some amount of waste from this sampling will be generated and disposed to either water, incineration, or landfill (engineering judgment). No industry-specific data were found in the references reviewed for this ESD (refer to Section 8), nor does EPA currently have data on QA/QC sampling waste amounts that can be used to generally quantify the release of these process wastes to non-air media.

It should be noted that EPA expects releases of the chemical from product sampling activities to be relatively low in comparison to the other sources of release in the formulation process.

4.8 Open Surface Losses to Air During Product Sampling (Release 7)

For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

If the chemical is volatile (e.g., the vapor pressure is > 0.001 torr), it may volatilize and be emitted from the process during product QA/QC sampling activities ($E_{\text{local}_{\text{air_sample}}}$). The EPA standard model for estimating releases to air from sampling activities performed indoors may be used (*EPA/OPPT Penetration Model*). It should be noted that EPA expects releases of the chemical from product sampling activities to be relatively low in comparison to the other sources of release in the formulation process.

In the case of a heated mixing process, the vapor pressure of the chemical of interest at these elevated temperatures should be estimated to determine whether it should be considered volatile for the purposes of this assessment (e.g., the vapor pressure is > 0.001 torr at 82°C). If the chemical is volatile at these temperatures, the volatile releases should be estimated at the elevated temperature conditions.

The model inputs and default values are listed in Table 4-6. The models and all current EPA 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.

technologies; however, industry-specific information on vent sizes or control technologies for volatile components was not identified.

Table 4-6. EPA/OPPT Penetration Model Parameter Default Values During Product Sampling

Input Parameter	Default Values
Diameter of Opening	EPA defaults are 1 in. (2.5 cm) typical; and 4 in. (10 cm) worst case (CEB, 2002b)
Frequency of Release	Equal to $TIME_{form\ working\ days}$ (See Section 3.7)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Operating Hours for the Activity	1 hour/day (CEB, 1991)
Temperature	Default 82°C (See Section 4.6)
Vapor Pressure	Chemical-specific chemical parameter (for heated processes, EPA recommends using the vapor pressure of the chemical at the operating temperature (e.g., worst-case default of 82°C))
Air Speed	EPA default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

4.9 Equipment Cleaning Releases to Incineration or Landfill (Release 8)

The amount of residual radiation curable chemical remaining in the process equipment may be estimated using the *EPA/OPPT Single Process Vessel Residual Model*. The model assumes that no more than one percent of the batch size or capacity of the process remains in the equipment as residue that is released as equipment cleaning waste. This is consistent with industry specific information that estimates one percent of the throughput is lost during daily equipment cleaning. Based on information provided by RadTech, >99% of releases are sent to incineration or landfill; therefore, EPA assumes these residues are typically released to landfill or incineration (RadTech, 2007).

If $N_{bt_site_yr}$ or known number of cleanings is fewer than the days of operation ($TIME_{form_working_days}$), the days of release equal $N_{bt_site_yr}$ (as calculated in Section 3.8) and the daily release of chemical residue in the process equipment is calculated using the following equation:

$$E_{local_equipment_cleaning} = Q_{form_bt} \times F_{chem_form} \times N_{bt_site_day} \times F_{equipment_cleaning} \quad (4-4a)$$

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

If $N_{bt_site_yr}$ is greater than $TIME_{form_working_days}$, the days of release equal the days of operation, and the daily release of chemical residue in the process equipment is calculated using the following equation:

$$E_{\text{local}_{\text{equipment_cleaning}}} = Q_{\text{form_chem_site_day}} \times F_{\text{equipment_cleaning}} \quad (4-4b)$$

This release will occur over $[\text{TIME}_{\text{form_working_days}}]$ days/year from $[\text{N}_{\text{form_sites}}]$ sites

Where:

$E_{\text{local}_{\text{equipment_cleaning}}}$	=	Daily release of chemical of interest from equipment cleaning (kg chemical/site-day)
$Q_{\text{form_bt}}$	=	Mass of radiation curable product formulated per batch (kg material/batch) (See Section 3.8)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (kg chemical/kg product) (See Section 3.5)
$N_{\text{bt_site_day}}$	=	Daily number of batches formulated at each site (batches/site-day) (See Section 3.8)
$F_{\text{equipment_cleaning}}$	=	Fraction of radiation curable product released as residual in process equipment (Default: 0.01 kg product released/kg batch holding capacity (CEB, 1992a))
$Q_{\text{form_chem_site_day}}$	=	Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day) (See Section 3.9)

4.10 Open Surface Losses to Air During Equipment Cleaning (Release 9)

For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

If the chemical is volatile (e.g., the vapor pressure is > 0.001 torr) it may evaporate and be released to the air during equipment cleaning ($E_{\text{local}_{\text{air_eqpt_cleaning}}}$). This operation is likely to occur indoors; therefore, the *EPA/OPPT Penetration Model* (EPA default for indoor operations) may be used to estimate the release of volatile chemicals during equipment cleaning. Model inputs and default values are listed in Table 4-7. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate open surface losses to air during equipment cleaning. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 4-7. EPA/OPPT Penetration Model Parameter Default Values During Equipment Cleaning

Input Parameter	Default Values
Diameter of Opening	EPA default 3-ft manhole (92 cm) (CEB, 2002b)
Frequency of Release	$TIME_{form}$ working days or N_{bt} site yr (whichever is greater).
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.5
Operating Hours for the Activity	EPA default 1 hr/batch \times N_{bt} site day (See Section 3.8), consistent with calculations described in Section 3.8
Temperature	Default 82°C (see Section 4.6)
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

The default assumption for the diameter of the opening and the operating hours for this activity are based on the EPA defaults of 3 feet diameter and one hour for cleaning a single, large vessel (CEB 2002b).

4.11 Filter Waste Releases to Incineration or Landfill during Filter Media Changeout (Release 10)

Many formulations are filtered to remove any gel, pigment, or filler agglomerates that may affect the final product quality. Filtration may occur prior to packaging the radiation curable product. Examples of filter media used in the radiation curable industry are lint-free cheesecloth and a fine mesh screen. Critical applications in niche markets may require pressure filtration through a cartridge (RadTech, 1995). Residuals containing the chemical of interest will remain on the filter media and will be disposed when the spent filter media is replaced.

Although EPA recognizes the potential for filter waste releases from the radiation curable formulation process, there is currently no standard EPA methodology for quantifying the amount of release.

Based on industry-specific information, filter media releases were estimated. For pigmented radiation curable products, two to four percent of the formulation is lost as filter waste and disposed to land or incineration. Clear, unpigmented radiation curable products release less than one percent to land or incineration (RadTech, 2007). The daily release of the chemical of interest contained on the waste filter is calculated based on the following formula:

$$E_{\text{local}}_{\text{filter_waste}} = \frac{Q_{\text{form_site_yr}} \times F_{\text{chem_form}} \times F_{\text{filter}}}{\text{TIME}_{\text{form_working_days}}} \quad (4-5)$$

Where:

$E_{\text{local}}_{\text{filter_waste}}$	=	Daily release of chemical of interest from filter waste (kg chemical/site-day)
$Q_{\text{chem_yr}}$	=	Annual production volume of the chemical of interest (kg chemical/yr)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical in the radiation curable product (kg chemical/kg product) (See Section 3.5)
F_{filter}	=	Fraction of chemical of interest adhered to the spent filters (kg chemical adhered/kg chemical processed)
$\text{TIME}_{\text{form_working_days}}$	=	Annual number of days the radiation curable product is formulated (days/yr) (see Section 3.7)

A default filter loss fraction (F_{filter}) of 0.01 kg chemical adhered/kg chemical processed should be used for clear, unpigmented radiation curable products (e.g., adhesives). If pigments are present in the product (e.g., ink formulations), the default filter loss fraction of 0.04 kg chemical adhered/kg chemical processed should be used. Radiation curable formulations for coatings may or may not contain pigments. Based on the known specific radiation curable product, the appropriate default should be used. If the coating pigmentation is unknown, the default for pigmented products provides the most conservative estimate for coatings.

4.12 Open Surface Losses to Air During Filter Media Changeout (Release 11)

For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible.

If the chemical is volatile (e.g., the vapor pressure is > 0.001 torr) it may be released to the air ($E_{\text{local}}_{\text{air_filter_change}}$). This operation is likely to occur indoors; therefore, the *EPA/OPPT Penetration Model* (EPA default for indoor operations) may be used to estimate the release of volatile chemicals during filter media change out. Model inputs and default values are listed in Table 4-8. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate open surface losses to air during equipment cleaning. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 4-8. EPA/OPPT Penetration Model Parameter Default Values During Filter Media Change Out

Input Parameter	Default Values
Diameter of Opening	6-inch filter (15 cm) (engineering judgment)
Frequency of Release	Equal to the number of replacements per year, as determined in Section 4.11
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Operating Hours for the Activity	0.25 hours (engineering judgment)
Temperature	Default 82°C (see Section 4.6)
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 100 feet/min for indoor conditions (CEB, 1991)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

4.13 Transfer Operation Losses to Air from Loading Radiation Curable Product into Transport Containers (Release 12)

For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr) at the operating temperature, releases to air are expected to be negligible.

If the chemical is volatile (e.g., the vapor pressure is > 0.001 torr) at the operating temperature, the chemical may evaporate and be emitted during radiation curable product transfer (e.g., filling drums) operations (Elocal_{air_packaging}). In an operation where the radiation curable product is generally nonvolatile and the components are relatively stable, non-reactive components, the transfer operations may be open. In this case, volatile chemicals may be emitted into the workspace and subsequently vented to the air outside of the facility.

Because the components in radiation curable formulations may volatilize or degrade/react when exposed to ambient conditions, it is expected that the transfer process is sealed and vented to the air outside of the facility (e.g., through a stack), minimizing the losses and fugitive emissions into the workspace. Scrubbers or other pollution control devices may be required to prevent excess emissions; however, pollution control devices are not standard across the industry.

As previously discussed in Section 3.6, most components in radiation curable are not expected to be volatile even at elevated temperatures; however, the elevated temperature could result in air releases for some components. The vapor pressure of the chemical of interest at these elevated temperatures should be estimated to determine whether it should be considered volatile for the purposes of this assessment (e.g., the vapor pressure is > 0.001 torr at 82°C). If the

chemical is volatile at these temperatures, the volatile releases should be estimated at the elevated temperature conditions.

For volatile chemicals (e.g., the vapor pressure is > 0.001 torr), the *EPA/OAQPS AP-42 Loading Model* may be used. Model parameter defaults are based on the type and size of the containers. A default transportation container size of a 55-gallon drum should be used in the absence of site-specific information, consistent with the values used in Section 3.11. Model inputs and default values are listed in Table 4-9. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate open surface losses to air during container loading. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 4-9. *EPA/OAQPS AP-42 Loading Model* Parameter Default Values During Product Packaging

Input Parameter	Default Values
Saturation Factor	EPA defaults 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (CEB, 1991) (See Appendix B for alternative default diameters)
Frequency of Release	Equal to the lesser of $N_{\text{form_cont_fill_site_yr}}$ (Section 3.11) or $\text{TIME}_{\text{form_working_days}}$ (Section 3.7)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Operating Hours for the Activity	Number of containers per site, per day ¹ divided by the fill rate (CEB, 2002b) (Default: 20 containers/hr for volumes between 20 and 1,000 gallons (CEB, 1991); Alternative default fill rates are found in Appendix B)
Temperature	Default 82°C (see Section 4.6)
Vapor Pressure	Chemical-specific chemical parameter (for heated processes, EPA recommends using the vapor pressure of the chemical at the operating temperature (e.g., worst-case default of 82°C))
Container Volume	Default: 55-gallon drum (208 L) (See Appendix B for alternative default container volumes)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

¹The daily number of containers filled per site may be estimated as:

$$N_{\text{form_cont_fill_site_day}} = \frac{N_{\text{form_cont_fill_site_yr}}}{\text{TIME}_{\text{form_working_days}}}$$

($N_{\text{form_cont_fill_day}}$ should be rounded up to the nearest integer.)

Where:

$N_{\text{form_cont_fill_site_yr}}$ = Annual number of containers filled containing chemical of interest per site (containers/site-yr) (See Section 3.11)

$\text{TIME}_{\text{working_days}}$ = Annual number of days the radiation curable product is formulated (days/yr) (See Section 3.7)

5 OCCUPATIONAL EXPOSURE ASSESSMENTS FOR THE FORMULATION OF RADIATION CURABLE PRODUCTS

The following section presents estimation methods for worker exposures to the chemical of interest. Figure 2-1 illustrates the occupational activities performed within a sealed and potentially heated formulation process that have the greatest potential for worker exposure to the chemical.

Industry-specific occupational exposure information was not found in the references reviewed for this ESD (refer to Section 8 for a description of the sources reviewed and full citations for those specifically used in these calculations), with the exception of the total number of workers employed by the radiation curable products industry available from the U.S. Census Bureau. The occupational exposure estimates presented in this document are based on standard EPA exposure models. Table 5-1 summarizes the exposure estimation methods used in this ESD.

Note that the standard model default values cited are current as of the date of this ESD; however, EPA may update these models as additional data become available. It is recommended 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 models.

Table 5-1. Summary of Radiation Curable Formulation Scenario Exposure Models

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description^a	Standard EPA Model (✓)
A	Unloading solid or liquid radiation curable components	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 radiation curable component handled: <ul style="list-style-type: none"> • 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 radiation curable components 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 radiation curable component handled: <ul style="list-style-type: none"> • 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 to liquid radiation curable product during sampling	Inhalation of volatile liquid chemical vapors	EPA/OPPT Mass Balance Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 1-Hand Dermal Contact with Liquid Model	✓
D	Exposure to liquid radiation curable product during equipment cleaning	Inhalation of volatile liquid chemical vapors	EPA/OPPT Mass Balance Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description ^a	Standard EPA Model (✓)
E	Exposure to liquid radiation curable product during filter media change out	Inhalation of volatile liquid chemical vapors	EPA/OPPT Mass Balance Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
F	Exposure to liquid radiation curable product during packaging	Inhalation of volatile liquid chemical vapors	EPA/OPPT Mass Balance Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓

a – Additional detailed descriptions for each of the models presented in this section are provided in Appendix B to this ESD.

5.1 Personal Protective Equipment

Based on information provided by industry, current practices may have an effect on worker exposures during normal handling and processing operations. Workers who handle radiation curable raw materials and formulations use personal protective equipment (PPE) when there is a possibility of contact. The type of PPE depends on the type of potential exposure. Typically, PPE used in the workplace include fabric or non-woven long sleeved shirts and pants, coveralls, and neoprene or rubber gloves. Barrier creams may be used to facilitate hand washing when materials or products penetrate gloves or other PPE. A rubber apron or rubber suit and rubber boots may also be worn in cases where there is potential for splashing on or penetration through clothing (RadTech, 2007).

Please note that EPA does not assess the effectiveness of PPE at mitigating occupational exposures in this ESD. The exposure mitigation by PPE is affected by many factors including availability, cost, worker compliance, impact on job performance, chemical and physical properties of the substance and protective clothing, and the use, decontamination, maintenance, storage, and disposal practices applicable to the industrial operation (CEB, 1997). Therefore, the conservative, screening-level occupational exposure estimates presented in this ESD do not account for PPE. Actual occupational exposure may be significantly less than the estimates presented in this ESD.

5.2 Number of Workers Exposed Per Site

Radiation curable product-specific data on the numbers of workers potentially exposed while performing each of the formulation activities were not found in the references reviewed for this ESD (refer to Section 8). Table 5-1 summarizes data collected from the 2002 Economic Census for the coating, inks, and adhesives formulation industries (NAICS codes 325510, 325520, and 325910). Coatings formulators average 76 workers employed at each facility (USCB, 2002); however, not all are expected to work in the production areas. The 2002 Economic Census estimates approximately 51 percent of these workers are *production* workers (USCB, 2002), which are defined by the U.S. Census Bureau to include.....workers (up through the line-supervisor level) engaged in fabricating, processing, assembling, inspecting, receiving,

storing, handling, packing, warehousing, shipping (but not delivering), maintenance, repair, janitorial and guard services, product development, auxiliary production for plant's own use (e.g., power plant), record keeping, and other services closely associated with these production operations at the establishment (USCB, 2002).

All other “non-production” employees include...

...those engaged in supervision above the line-supervisor level, sales (including driver-salespersons), sales delivery (highway truck drivers and their helpers), advertising, credit, collection, installation and servicing of own products, clerical and routine office functions, executive, purchasing, financing, legal, personnel (including cafeteria, medical, etc.), professional, technical employees, and employees on the payroll of the manufacturing establishment engaged in the construction of major additions or alterations utilized as a separate work force (USCB, 2002).

Inks and adhesives formulators employ an average of 20 and 32 production workers per facility (approximately 57 and 59 percent of the total number of employees, respectively). No information was found that would provide bases for estimating the specific numbers of production workers that perform each of the exposure activities discussed in this section. In the absence of data, the total number of workers estimated for each specific type of radiation curable product (shown in Table 5-2) is assessed for each exposure activity. This methodology will provide the most conservative estimate of workers exposed during each activity. Using this methodology, the total number of workers assessed for each formulation site has been predetermined and does not need to be summed for each activity.

No information was found on the typical hours of operation per day or the number of shifts supporting operations at radiation curable formulation facilities; however, an estimate for the duration of exposure for each worker activity is presented in the remainder of this section (based on standard EPA defaults and methodology).

Table 5-2. Number of Workers Potentially Exposed During the Formulation Process

Type of Formulator	NAICS Code	Number of Production Workers per Facility ^a
Coatings (Default)	3255104	39
Inks	325910	18 to 23
Adhesives	3255204	32

a – Total number of workers potentially exposed during specific activities was not found. The numbers presented in this table should be used for each exposure activity identified.

5.3 Exposure from Unloading Solid or Liquid Chemicals (Exposure A)

Workers may connect transfer lines or manually unload chemicals from transport containers into the mixing tanks. If the concentration of the chemical in the component ($F_{\text{chem_comp}}$) is unknown, 100 percent concentration may be assumed as a conservative default, as previously discussed in Section 3.3. The default number of workers exposed during this activity is 39 workers per site (see Section 5.2).

Inhalation Exposure:

Liquids:

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

The vapor generation rate calculated in Release 1 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 defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during transfer operations. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5-2 lists the model inputs and default values. Note that the exposure hours per day is equivalent to the operating hours per day for this activity (consistent with Section 4.4 calculations), but EPA assumes an exposure duration of eight hours per day. Similarly, the exposure days per site, per year should be consistent with the release days, but EPA assumes a maximum of 250 days per year. These exposure duration maximum defaults are based on full-time employment and considers an individual worker's vacation, sick, and weekend time (i.e., a 40-hour work week over 50 weeks per year).

Table 5-3. 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 4.2, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OPPT Penetration Model</i> (Section 4.2)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.2, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Ventilation Rate	EPA defaults 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (default for containers less than 1,000 gallons (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

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

Solids:

The transfer of nonvolatile powdered radiation curable components from containers to storage or mixing vessels generates particulates. The degree of inhalation exposure to particulates depends on the concentration of the chemical of interest in the component ($F_{\text{chem_comp}}$), the potential concentration of the component in the worker's breathing zone ($C_{\text{particulate}}$), and the total amount of component the worker is exposed to per day in performing this activity ($Q_{\text{comp_site_day}}$).

The daily transfer rate of the radiation curable component may be estimated using the following equation:

$$Q_{\text{comp_site_day}} = \frac{Q_{\text{form_chem_site_day}}}{F_{\text{chem_comp}}} \quad (5-1)$$

Where:

$Q_{\text{comp_site_day}}$ = Daily amount of radiation curable component transferred into the process (kg component/site-day)

$Q_{\text{form_chem_site_day}}$ = Daily use rate of the chemical of interest used to formulate the radiation curable product (kg chemical/site-day) (See Section 3.9)

$F_{\text{chem_comp}}$ = Mass fraction of the chemical of interest in the radiation curable component (kg chemical/kg component) (See Section 3.3)

Two equations can be used to determine worker exposure. Selection of the appropriate equation should be based on the amount of component the worker is exposed to per day ($Q_{\text{comp_site_day}}$), not the amount of chemical of interest the worker is exposed to ($Q_{\text{form_chem_site_day}}$). Additional explanation of the two standard EPA models used to estimate inhalation exposure to solid powder is presented in Appendix B.

If the transfer rate of the solid powder radiation curable component containing the chemical of interest ($Q_{\text{comp_site_day}}$) is *greater than 54 kg/site-day*, EPA recommends using the OSHA Total Particulates Not Otherwise Regulated (PNOR) PEL-Limiting Model:

$$EXP_{\text{inhalation}} = C_{\text{particulate}} \times RATE_{\text{breathing}} \times TIME_{\text{exposure}} \times F_{\text{chem_comp}} \quad (5-2a)$$

This exposure will occur over [the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{form_working_days}}$, up to 250] days/year

Where:

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

$C_{\text{particulate}}$ = Concentration of particulate radiation curable component in the workers breathing zone (Default: 15 mg component/m³; based on OSHA Total PNOR PEL (8-hr TWA*) (29 CFR 1910.1000))

$RATE_{\text{breathing}}$ = Typical worker breathing rate (Default: 1.25 m³/hr (CEB, 1991))

$TIME_{\text{exposure}}$ = Duration of exposure (Default: 8 hrs/day; Note: because the default value for $C_{\text{particulate}}$ is an 8-hr TWA*, the 8 hrs/day value must be used)

$F_{\text{chem_comp}}$ = Mass fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)

*TWA = Time-weighted average

The accuracy of solid component inhalation estimates are limited by the estimated airborne concentration of the chemical of interest and the assumed breathing rate.

If the transfer rate of the solid powder radiation curable component containing the chemical of interest ($Q_{\text{comp_site_day}}$) is *less than or equal to 54 kg/site-day*, EPA recommends using the EPA/OPPT Small Volume Solids Handling Inhalation Model:

$$EXP_{\text{inhalation}} = Q_{\text{comp_site_day}} \times F_{\text{chem_comp}} \times F_{\text{exposure}} \quad (5-2b)$$

This exposure will occur over [the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{form_working_days}}$, up to 250] days/year

Where:

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

$Q_{\text{comp_site_day}}$	=	Daily amount of radiation curable component transferred into the process (kg component/site-day) (See Equation 5-1)
$F_{\text{chem_comp}}$	=	Mass fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)
F_{exposure}	=	Weight fraction of the total particulate radiation curable component in the workers breathing zone (Default: 0.0477 (typical) to 0.161 (worst) mg component exposure/kg of component handled (CEB, 1992b))

Dermal Exposure:

Dermal exposure is expected for both automated and manual unloading activities. Automated systems may limit the extent of dermal exposure more than manual unloading; however, workers may still be exposed when connecting transfer lines or transferring the liquid chemicals from the transport container to mixing vessels. Workers may manually scoop or pour solid or liquid radiation curable chemicals into the process equipment.

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:

To estimate the potential worker exposure to the chemical of interest in a liquid radiation curable component for this activity, EPA recommends using the following equation:

$$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (5-3a)$$

This exposure will occur over [the lesser of $N_{\text{bt_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.2), up to 250] days per year

Where:

$\text{EXP}_{\text{dermal}}$	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid radiation curable component remaining on skin (Defaults: 2.1 mg component/cm ² -incident (high-end) and 0.7 mg component/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000a))
$\text{AREA}_{\text{surface}}$	=	Surface area of contact (Default: 840 cm ² for 2 hands (CEB, 2000a))
$N_{\text{exp_incident}}^1$	=	Number of exposure incidents per day (Default: 1 incident/day)

¹Only one contact per day ($N_{\text{exp_incident}} = 1$ event/worker-day) is assumed because $Q_{\text{liquid_skin}}$, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by

$F_{\text{chem_comp}}$ = Mass fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)

Solids:

To estimate the potential worker exposure to the chemical of interest in a solid radiation curable component for this activity, EPA recommends using the following equation (CEB, 2000a):

$$\text{EXP}_{\text{dermal}} = \text{up to } 3,100 \text{ mg component/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (5-3b)$$

This exposure will occur over [the lesser of $N_{\text{bt_site_yr}}$ or $\text{TIME}_{\text{working_days}}$ (consistent with Section 4.2, up to 250] days per year

Where:

$\text{EXP}_{\text{dermal}}$ = Potential dermal exposure to the chemical of interest per day (mg chemical/day)

$N_{\text{exp_incident}}$ = Number of exposure incidents per day (Default: 1 incident/day) (see Equation 5-3a)

$F_{\text{chem_comp}}$ = Mass fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)

5.4 Exposure to Solids or Liquids During Container Cleaning (Exposure B)

Workers may be exposed while rinsing containers used to transport the radiation curable component. If the concentration of the chemical in the component ($F_{\text{chem_comp}}$) is unknown, 100 percent concentration may be assumed as a conservative default, as previously discussed in Section 3.3. The default number of workers exposed during this activity is 39 workers per site (see Section 5.2).

Inhalation Exposure:

Liquids:

The method used to calculate inhalation exposure ($\text{EXP}_{\text{inhalation}}$) 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 3, the *EPA/OPPT Mass Balance Model* can 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 5-3 lists the model inputs and default values. Note that the

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.

exposure hours per day are equivalent to the operating hours per day for this activity (consistent with Section 4.4 calculations), but EPA assumes a maximum exposure duration of eight hours per day. Similarly, the exposure days per site, per year, should be consistent with the release days, but EPA assumes a maximum of 250 days per year, as previously discussed in Section 5.3.

Table 5-4. 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 4.4, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OPPT Penetration Model</i> (Section 4.4)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.4, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Ventilation Rate	EPA defaults 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (default for containers less than 1,000 gallons (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

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

The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends this software to calculate inhalation exposure to volatile chemicals during container cleaning. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

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_comp}), the potential concentration of the radiation curable chemical in the worker's breathing zone ($C_{particulate}$), and the total amount of radiation curable component residual removed from the containers ($Q_{comp_residue_site_day}$). EPA recommends using the following equation to estimate the amount of component residual handled by a worker during container cleaning:

$$Q_{comp_residue_site_day} = \frac{E_{local_comp_cont_residue_disp}}{F_{chem_comp}} \quad (5-4)$$

Where:

$Q_{\text{comp_residue_site_day}}$	=	Quantity of radiation curable component handled during container cleaning (kg component/site-day)
$E_{\text{local_comp_cont_residue_disp}}$	=	Daily release of chemical of interest from container residue (kg chemical/site-day) (See Equation 4-3a or 4-3b, consistent with Section 4.4 calculations)
$F_{\text{chem_comp}}$	=	Mass fraction of the chemical of interest in the radiation curable component (kg chemical/kg component) (See Section 3.3)

Two equations can be used to determine worker exposure. Selection of the appropriate equation should be based on the amount of solid radiation curable component the worker is exposed to per day ($Q_{\text{comp_residue_site_day}}$), not the amount of chemical of interest the worker is exposed to per day ($E_{\text{local_comp_cont_residue_disp}}$). A further explanation, including the background and model defaults, of the two standard EPA models used to estimate inhalation exposure to solid powder is presented in Appendix B.

If the daily amount of the solid powder radiation curable component containing the chemical of interest ($Q_{\text{comp_residue_site_day}}$) is *greater than* 54 kg/site-day, EPA recommends using the OSHA Total PNOR PEL-Limiting Model:

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

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

Where:

$EXP_{\text{inhalation}}$	=	Inhalation exposure to the chemical of interest per day (mg chemical/day)
$C_{\text{particulate}}$	=	Concentration of particulate radiation curable component in the workers breathing zone (Default: 15 mg component/m ³ ; based on OSHA Total PNOR PEL (8-hr TWA*) (29 CFR 1910.1000))
$RATE_{\text{breathing}}$	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
$TIME_{\text{exposure}}$	=	Duration of exposure (Default: 8 hrs/day; Note: because the default value for $C_{\text{particulate}}$ is an 8-hr TWA*, the 8 hrs/day value <u>must</u> be used)
$F_{\text{chem_comp}}$	=	Mass fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)

*TWA = Time-weighted average

The accuracy of solid component inhalation estimates are limited by the estimated airborne concentration of the chemical of interest and the assumed breathing rate.

If the daily amount of the solid powder radiation curable component containing the chemical of interest ($Q_{\text{comp_residue_site_day}}$) is *less than or equal to* 54 kg/site-day, EPA recommends using the EPA/OPPT Small Volume Solids Handling Inhalation Model:

$$EXP_{\text{inhalation}} = Q_{\text{comp_residue_site_day}} \times F_{\text{chem_comp}} \times F_{\text{exposure}} \quad (5-5b)$$

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

Where:

$EXP_{\text{inhalation}}$	=	Inhalation exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{comp_residue_site_day}}$	=	Quantity of radiation curable component handled during container cleaning (kg component/site-day) (See Equation 5-4)
$F_{\text{chem_comp}}$	=	Mass fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)
F_{exposure}	=	Weight fraction of the total particulate radiation curable component in the workers breathing zone (Default: 0.0477 (typical) to 0.161 (worst) mg component exposure/kg of component handled (CEB, 1992b))

Dermal Exposure:

Dermal exposure is expected during the cleaning of transport containers. 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 explained in Appendix B.

Liquids:

To estimate the potential worker exposure to the chemical of interest in a liquid radiation curable component for this activity, EPA recommends using the following equation:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (5-6a)$$

This exposure will occur over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $TIME_{\text{working_days}}$ (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/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid radiation curable component remaining on skin (Defaults: 2.1 mg component/cm ² -incident (high-end) and 0.7 mg component/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000a))

$AREA_{\text{surface}}$	=	Surface area of contact (Default: 840 cm ² for 2 hands (CEB, 2000a))
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day) (See Equation 5-3a)
$F_{\text{chem_comp}}$	=	Mass fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)

Solids:

To estimate the potential worker exposure to the chemical of interest in a solid radiation curable component for this activity, EPA recommends using the following equation (CEB, 2000a):

$$EXP_{\text{dermal}} = \text{up to } 3,100 \text{ mg component/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (5-6b)$$

This exposure will occur over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $TIME_{\text{form_working_days}}$ (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/day)
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day) (see Equation 5-3a)
$F_{\text{chem_comp}}$	=	Weight fraction of the chemical of interest in the radiation curable component (mg chemical/mg component) (See Section 3.3)

5.5 Exposure from Sampling Liquid Radiation Curable Product (Exposure C)

Workers may collect samples of the radiation curable product for quality analysis/quality control (QA/QC). The default number of workers exposed during this activity is 39 workers per site (see Section 5.2).

Inhalation Exposure:

The method used to calculate inhalation exposure ($EXP_{\text{inhalation}}$) depends on the volatility and the physical state of the chemical of interest at the operating temperature. Radiation curable products may be formulated in a heated mixing process and subsequently sampled/analyzed in part as a warm liquid at 82°C (default). Inhalation exposure to liquids is assumed negligible for nonvolatile liquids (e.g., the vapor pressure is < 0.001 torr).

Radiation curable products may be sensitive to ambient conditions; therefore, losses of product are expected to be minimized, this operation may be closed and this exposure may be negligible. However, unless site-specific information is available, EPA recommends assuming that fugitive emission of volatile chemicals may occur during product sampling and estimating the associated worker inhalation exposure as conservative.

Using the vapor generation rate calculated in Release 7, the *EPA/OPPT Mass Balance Model* can be used to calculate worker inhalation exposure due to volatilization during sampling activities. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure. Table 5-5 lists the model inputs and default values. Note that the exposure days per site, per year should be consistent with the release days, but EPA assumes a maximum of 250 days per year, as discussed in Section 5.3.

The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during sampling activities. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

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

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 4.8, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OPPT Penetration Model</i> (Section 4.8)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.8, up to 8 hours per day (default: 1 hour/day (CEB, 1991))
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Ventilation Rate	EPA defaults 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (default for containers less than 1,000 gallons (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Temperature	Consistent with the Temperature used in Section 4.8
Vapor Pressure	Consistent with the Vapor Pressure used in Section 4.8
Vapor Pressure Correction Factor	Standard EPA default = 1

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

Dermal Exposure:

Dermal exposure to liquid radiation curable products is expected during sampling activities. The *EPA/OPPT 1-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during product sampling. The rationale, defaults, and limitations of this model are explained in Appendix B.

As described for the inhalation exposure to liquid radiation curable products above, the product may be sampled at elevated temperatures. If the product is sampled/analyzed at temperatures above 60°C, EPA recommends that the dermal exposure to hot materials be

assumed. EPA typically assumes that dermal exposures to hot materials are mitigated through the use of PPE (CEB, 2002b).

To estimate the potential worker exposure to the chemical of interest in a liquid radiation curable component sampled at temperatures less than 60°C, EPA recommends using the following equation:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (5-7)$$

This exposure will occur over [the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{form_working_days}}$ (consistent with Section 4.8), up to 250] days per year

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid radiation curable product remaining on skin (Defaults: 2.1 mg product/cm ² -incident (high-end) and 0.7 mg product/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000a))
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 420 cm ² for 1 hand (CEB, 2000a))
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day) (See Equation 5-3a)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

5.6 Exposure to Liquids During the Equipment Cleaning of Mixers and Other Process Equipment (Exposure D)

Workers may be exposed while cleaning the mixing tanks or other process equipment with water or organic solvents. Because some equipment cleaning may be performed manually, exposures during equipment cleaning should be assessed. The default number of workers exposed during this activity is 39 workers per site (see Section 5.2).

Inhalation Exposure:

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

Using the vapor generation rate calculated in Release 9, the *EPA/OPPT Mass Balance Model* can be used to calculate worker inhalation exposure due to volatilization during equipment cleaning activities. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure. Table 5-6 lists the model inputs and default values. Note that the exposure hours per day are equivalent to the operating hours per day for this activity (consistent with Section 4.10 calculations), but EPA assumes an exposure duration of eight hours per day. Similarly, the exposure days per site, per year should be consistent with the release days, but EPA assumes a maximum of 250 days per year, as discussed in Section 5.3.

The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during equipment cleaning. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5-6. EPA/OPPT Mass Balance Model Parameter Default Values During Equipment 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 4.10, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OPPT Penetration Model</i> (Section 4.10)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.10, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Ventilation Rate	EPA defaults 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Temperature	Default 82°C (see Section 4.6)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

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

Dermal Exposure:

Dermal exposure to liquids is expected during the cleaning of process equipment. 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. The rationale, defaults, and limitations of this model are explained in Appendix B.

To estimate the potential worker exposure to the chemical of interest in a liquid radiation curable component for this activity, use the following equation:

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

This exposure will occur over [$N_{\text{bt_site_yr}}$ or $TIME_{\text{form_working_days}}$, up to 250] days per year

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid radiation curable product remaining on skin (Defaults: 2.1 mg product/cm ² -incident (high-end) and

		0.7 mg product/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000a))
AREA _{surface}	=	Surface area of contact (Default: 840 cm ² for 2 hands (CEB, 2000a))
N _{exp_incident}	=	Number of exposure incidents per day (Default: 1 incident/day) (See Equation 5-3a)
F _{chem_form}	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

5.7 Exposure from Changing Spent Filter Media (Exposure E)

Workers may remove spent filters plugged with residual wastes that contain the chemical of interest. Spent filter media may be regenerated and reused, further minimizing exposure and frequency of exposure during change outs. The default number of workers exposed during this activity is 39 workers per site (see Section 5.2).

Inhalation Exposure:

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).

Unless site-specific information is available, EPA recommends assuming that fugitive emission of volatile chemicals may occur and estimating the associated worker inhalation exposure as conservative.

Using the vapor generation rate calculated in Release 11, the *EPA/OPPT Mass Balance Model* can be used to calculate worker inhalation exposure due to volatilization during filter change out activities. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure. Table 5-7 lists the model inputs and default values. Note that the exposure hours per day are equivalent to the operating hours per day for this activity (consistent with Section 4.11 calculations), but EPA assumes a maximum exposure duration of eight hours per day. Similarly, the exposure days per site, per year, should be consistent with the release days, but EPA assumes a maximum of 250 days per year, as discussed in Section 5.3.

Table 5-7. EPA/OPPT Mass Balance Model Parameter Default Values During Filter Media Change Out

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 4.12, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OAQPS AP-42 Loading Model</i> (Section 4.12)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.12, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Ventilation Rate	EPA defaults 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (default for containers less than 1,000 gallons (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Temperature	Default 82°C (see Section 4.6)
Vapor Pressure	Chemical-specific parameter (at operating temperature)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during packaging/loading activities. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Dermal Exposure:

Dermal exposure to liquid radiation curable products is expected during spent filter media change out. 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. The rationale, defaults, and limitations of this model are explained in Appendix B.

To estimate the potential worker exposure to the chemical of interest in a liquid radiation curable component adhered to filter media, EPA recommends using the following equation:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (5-9)$$

This exposure will occur over [the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{form_working_days}}$ (consistent with Section 4.12), up to 250] days per year

Where:

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

$Q_{\text{liquid_skin}}$	=	Quantity of liquid radiation curable product remaining on skin (Defaults: 2.1 mg product/cm ² -incident (high-end) and 0.7 mg product/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000a))
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 840 cm ² for 2 hands (CEB, 2000a))
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day) (see Equation 5-3a)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

5.8 Exposure from Packaging Radiation Curable Product (Exposure F)

Workers may connect transfer lines to load the liquid radiation curable products containing the chemical into transport containers. Due to the high value of the products and the desire to minimize releases, loading processes may be automated or enclosed; thus, minimizing exposure. The default number of workers exposed during this activity is 39 workers per site (see Section 5.2).

Inhalation Exposure:

The method used to calculate inhalation exposure ($EXP_{\text{inhalation}}$) depends on the volatility and the physical state of the chemical of interest at the operating temperature. Radiation curable products may be formulated in a heated mixing process and subsequently packaged in part as a warm liquid at 82°C. Inhalation exposure to liquids is assumed negligible for nonvolatile liquids (e.g., the vapor pressure is < 0.001 torr).

Because radiation curable products may be sensitive to ambient conditions and losses of product are expected to be minimized, this operation may be closed and this exposure may be negligible. However, unless site-specific information is available, EPA recommends assuming that fugitive emission of volatile chemicals may occur and estimating the associated worker inhalation exposure as a worst-case.

Using the vapor generation rate calculated in Release 12, the *EPA/OPPT Mass Balance Model* can be used to calculate worker inhalation exposure due to volatilization during packaging activities. The default ventilation rates and mixing factors provide a typical and worst case estimate of exposure. Table 5-7 lists the model inputs and default values. Note that the exposure hours per day are equivalent to the operating hours per day for this activity (consistent with Section 4.13 calculations), but EPA assumes a maximum exposure duration of eight hours per day. Similarly, the exposure days per site, per year, should be consistent with the release days, but EPA assumes a maximum of 250 days per year, as discussed in Section 5.3.

Table 5-8. EPA/OPPT Mass Balance Model Parameter Default Values During Loading

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 4.13, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OAQPS AP-42 Loading Model</i> (Section 4.13)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.13, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (CEB, 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Ventilation Rate	EPA defaults 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (default for containers less than 1,000 gallons (CEB, 1991) (See Appendix B for alternative default ventilation rates)
Temperature	Consistent with the Temperature used in Section 4.13
Vapor Pressure	Consistent with the Vapor Pressure used in Section 4.13
Vapor Pressure Correction Factor	Standard EPA default = 1

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

The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during packaging/loading activities. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Dermal Exposure:

Dermal exposure to liquid radiation curable products is expected during packaging activities. 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. The rationale, defaults, and limitations of this model are explained in Appendix B.

As described for the inhalation exposure to liquid radiation curable products above, the product may be packaged at an elevated temperature. If the product is packaged at temperatures above 60°C, EPA recommends that the dermal exposure to hot materials be assumed negligible. EPA typically assumes that dermal exposures to hot materials are mitigated through the use of PPE (CEB, 2002b).

To estimate the potential worker exposure to the chemical of interest in a liquid radiation curable component packaged at temperatures less than 60°C, EPA recommends using the following equation:

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

This exposure will occur over [the lesser of $N_{\text{form_cont_fill_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.13), up to 250] days per year

Where:

$\text{EXP}_{\text{dermal}}$	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid radiation curable product remaining on skin (Defaults: 2.1 mg product/cm ² -incident (high-end) and 0.7 mg product/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000a))
$\text{AREA}_{\text{surface}}$	=	Surface area of contact (Default: 840 cm ² for 2 hands (CEB, 2000a))
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day) (See Equation 5-3a)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

6 SAMPLE CALCULATIONS

This section presents an example of how the equations introduced in Sections 3, 4, and 5 might be used to estimate releases of and exposures to a volatile chemical present in a liquid component used to formulate a radiation curable product that is spray applied onto a substrate. The default values used in these calculations are presented in Sections 3 through 5 and should be used only in the absence of site-specific information. The following data are used in the example calculations:

1. Chemical of interest production volume ($Q_{\text{chem_yr}}$) is *5,000,000 kg chemical/yr* and is used as an oligomer added to the radiation curable formulation.
2. Chemical of interest has a molecular weight ($MW_{\text{chem.}}$) of 100 g/mol and a vapor pressure ($VP_{\text{chem.}}$) of 0.1 torr @ 82°C (i.e., the chemical is volatile for the purposes of the assessment).
3. Chemical of interest is distributed to the formulators in *liquid* form to be incorporated into an *unknown radiation curable product*.

6.1 General Facility Estimates for the Formulation of Radiation Curable Products

6.1.1 Annual Radiation Curable Production Rate ($Q_{\text{form_site_yr}}$)

Aside from the annual production volume and physical state of the chemical of interest, no other site-specific information or data are known for the Equation 3-3 parameters (i.e., $Q_{\text{form_site_yr}}$, $F_{\text{chem_comp}}$, and $F_{\text{comp_form}}$) used to estimate the number of formulation sites using the chemical ($N_{\text{form_sites}}$). Therefore, use of the default assumptions is appropriate. Using Figure 3-1, for an unknown radiation curable product with both release and exposure concerns, the *Inks: Other* product was used. The following default assumptions about the type of formulator and radiation curable product are made from Table 3-2:

Type of radiation curable product: *Inks: Other*

The resulting default production rate ($Q_{\text{form_site_prod_rate}}$) from Table 3-2 is *130,000 kg coating/site-yr*:

$$Q_{\text{form_site_yr}} = Q_{\text{form_site_prod_rate}} \times F_{\text{radcur}} \quad [\text{Eqn. 3-1}]$$

$Q_{\text{form_site_yr}} = 130,000 \text{ kg total coating/site - yr} \times 1 \text{ kg coating with chem./kg total coating}$

$$Q_{\text{form_site_yr}} = 130,000 \text{ kg total coating/site - yr}$$

6.1.2 Concentration (Mass Fraction) of the Chemical of Interest in the Radiation Curable Component (F_{chem_comp})

If the concentration of the chemical of interest in the radiation curable component (F_{chem_comp}) is not known, assume 100 percent (or 1 kg chemical/kg component).

6.1.3 Concentration (Mass Fraction) of the Radiation Curable Component in the Product (F_{comp_form})

Since the component is used as an oligomer within the radiation curable product, and since the concentration of the component in the final product is not known, the high-end oligomer concentration (weight fraction) for a coating presented in Table 2-2 is assumed. The high-end concentration for oligomers used in radiation curable coatings (F_{comp_form}) is 0.70 kg component/kg coating.

6.1.4 Concentration (Mass Fraction) of the Chemical of Interest in the Radiation Curable Product (F_{chem_form})

The concentration of the chemical of interest in the radiation curable product can be calculated using the concentrations that were determined for the chemical in component and the component in formulation.

$$F_{chem_form} = F_{chem_comp} \times F_{comp_form} \quad [\text{Eqn. 3-2}]$$

$$F_{chem_form} = 1\text{kg chemical} / 1\text{kg component} \times 0.7\text{kg component} / 1\text{kg coating product}$$

$$F_{chem_form} = 0.7\text{kg chemical} / 1\text{kg coating product}$$

6.1.5 Number of Formulation Sites (N_{form_sites})

$$N_{form_sites} = \frac{Q_{chem_yr}}{Q_{form_site_yr} \times F_{chem_form}} \quad [\text{Eqn. 3-3}]$$

$$N_{form_sites} = \frac{5,000,000 \text{ kg chem./yr}}{130,000 \text{ kg coating/site - yr} \times 0.7 \text{ kg chem./kg product}}$$

$$N_{form_sites} = 54.8 \text{ sites}$$

Round N_{sites} up to next integer (55 formulation sites) and recalculate $Q_{form_site_yr}$:

$$Q_{form_site_yr} = \frac{5,000,000 \text{ kg chem./yr}}{55 \text{ sites} \times 0.7 \text{ kg chem./kg product}}$$

$$Q_{form_site_yr} = 129,870 \text{ kg product/site - yr}$$

6.1.6 Days of Operation ($TIME_{form_working_days}$, days/year)

The number of operating days is assumed a maximum of 250 days per year. The batch size was not provided; therefore, Equation 3-4 was not used.

6.1.7 Number of Batches ($N_{bt_site_yr}$ batches/site-year)

If the batch size (Q_{form_bt}) is not known, assumptions can be reasonably made to estimate the batch size:

$$Q_{form_bt} = \frac{Q_{form_site_yr}}{TIME_{form_working_days} \times N_{bt_site_day}} \quad [Eqn. 3-5]$$

$$Q_{form_bt} = \frac{129,870 \text{ kg product/yr}}{250 \text{ days/yr} \times 1 \text{ bt/site - day}}$$

$$Q_{form_bt} = 519.5 \text{ kg product/batch}$$

Equation 3-4 can be estimated using the batch size of 519.5 kg product/batch, calculated above:

$$N_{batch_site_yr} = \frac{Q_{form_site_yr}}{Q_{form_bt}} \quad [Eqn. 3-6]$$

$$N_{batch_site_yr} = \frac{129,870 \text{ kg prod./site - yr}}{519.5 \text{ kg prod./bt}}$$

$$N_{batch_site_yr} = 250 \text{ bts/site - yr}$$

6.1.8 Daily Use Rate of the Chemical of Interest ($Q_{form_chem_site_day}$, kg chemical/site-day)

$$Q_{form_chem_site_day} = \frac{Q_{form_site_yr} \times F_{chem_form}}{TIME_{form_working_days}} \quad [Eqn. 3-7]$$

$$Q_{form_chem_site_day} = \frac{\frac{129,870 \text{ kg prod.}}{\text{site - yr}} \times \frac{0.7 \text{ kg chem.}}{\text{kg prod.}}}{250 \text{ days/yr}}$$

$$Q_{form_chem_site_day} = \frac{363.6 \text{ kg chem.}}{\text{site - day}}$$

6.1.9 Annual Number of Component Containers Emptied per Site ($N_{comp_cont_empty_site_yr}$, container/site-year)

It is assumed that the radiation curable component (which is 100% chemical of interest, by default) is shipped to the formulators in 55-gallon drums, as a default. A density of 1 kg/L is also assumed for the component. The mass capacity for each of the drums is calculated as:

$$Q_{cont_empty} = V_{cont_empty} \times RHO_{component} = \frac{208 \text{ L comp.}}{\text{container}} \times \frac{1 \text{ kg comp.}}{\text{L}} = \frac{208 \text{ kg comp.}}{\text{container}}$$

The number of shipping containers that are emptied per site, per year is calculated as:

$$N_{comp_cont_empty_site_yr} = \frac{Q_{form_chem_site_day} \times TIME_{form_working_days}}{F_{chem_comp} \times Q_{cont_empty}} \quad [\text{Eqn. 3-8}]$$

$$N_{comp_cont_empty_site_yr} = \frac{363.6 \text{ kg chem./site - day} \times 250 \text{ days/yr}}{1 \text{ kg chem./kg comp.} \times 208 \text{ kg comp./container}}$$

$$N_{comp_cont_empty_site_yr} = 437 \text{ containers/site - yr}$$

6.1.10 Annual Number of Radiation Curable Product Containers Filled per Site ($N_{form_cont_fill_site_yr}$, container/site-year)

It is assumed that the radiation curable product (which is 70 percent chemical of interest, by default) is packaged in 55-gallon drums, as a default. A density of 1 kg/L is also assumed for the radiation curable product. The mass capacity for each of the drums is calculated as:

$$Q_{cont_fill} = V_{cont_fill} \times RHO_{product} = \frac{208 \text{ L prod.}}{\text{container}} \times \frac{1 \text{ kg prod.}}{\text{L}} = \frac{208 \text{ kg prod.}}{\text{container}}$$

The number of shipping containers that are filled per site, per year is calculated as:

$$N_{form_cont_fill_site_yr} = \frac{Q_{form_chem_site_day} \times TIME_{form_working_days}}{F_{chem_form} \times Q_{cont_fill}} \quad [\text{Eqn 3-9}]$$

$$N_{form_cont_fill_site_yr} = \frac{\left(\frac{363.6 \text{ kg chem.}}{\text{site - day}} \times \frac{250 \text{ days}}{\text{yr}} \right)}{\left(\frac{0.7 \text{ kg chem.}}{\text{kg prod.}} \times \frac{208 \text{ kg prod.}}{\text{container}} \right)}$$

$$N_{form_cont_fill_site_yr} = 625 \text{ containers/site - yr}$$

6.2 Release Assessments for the Formulation of Radiation Curable Products

6.2.1 Transfer Operation Losses to Air from Unloading the Radiation Curable Component (Release 1)

Since the chemical of interest is volatile, it will be emitted from the process from the displacement of saturated air when the chemical is transferred. The *EPA/OAQPS AP-42 Loading Model* is used to estimate the rate at which the chemical is emitted during this activity:

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

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

Parameter	Units	ChemSTEER Input
MW _{chem}	g/mol	100
F _{saturation_factor}	Dimensionless	Typical = 0.5 Worst Case = 1
VP _{chem}	Torr	0.1
V _{cont empty}	Gal	55
RATE _{fill}	containers/hour	20
TEMP _{ambient}	K	298
F _{correction factor}	Dimensionless	1
R	Atm	82.05

Therefore:

$$Q_{\text{vapor_generation}} = 3.1 \times 10^{-4} \text{ g/s for typical and } Q_{\text{vapor_generation}} = 6.2 \times 10^{-4} \text{ g/s for worst case}$$

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

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

$$\text{Elocal}_{\text{air_transfers}} = (3.1 \times 10^{-4} \text{ to } 6.2 \times 10^{-4}) \text{ g chem./sec} \times \left(\frac{437 \text{ containers/site - yr}}{250 \text{ days/yr} \times 20 \text{ containers/hr}} \right) \times \frac{3600 \text{ sec/hr}}{1000 \text{ g/kg}}$$

Elocal_{air_transfers} = 9.8x10⁻⁵ – 2.0x10⁻⁴ kg chem. emitted/site-day
 ...over 250 days/year from 55 sites.

6.2.2 *Dust Generation from Transfer Operations Released to Air, or Collected and Released to Water, Incineration, or Landfill (Release 2)*

The chemical is received as a liquid component; therefore, dust generation is not expected.

6.2.3 *Radiation Curable Component Container Residue Released to Water, Incineration, or Landfill (Release 3)*

Since $N_{\text{comp_cont_empty_site_yr}}$ is greater than $\text{TIME}_{\text{form_working_days}}$, it is assumed that more than one container is emptied on each operating day. The following equation is used to estimate the daily release:

$$E_{\text{local_comp_cont_residue_disp}} = Q_{\text{form_chem_site_day}} \times F_{\text{container_residue}} \quad [\text{Eqn. 4-3b}]$$

Since it is known that the radiation curable component is in a liquid form when shipped to the formulation site, and the container is assumed to be a 55-gallon drum by default, the *EPA/OPPT Drum Residual Model* is used to estimate this release. The default fraction of liquid chemical that remains in the empty container ($F_{\text{container_residue}}$) is 0.03 kg chemical remaining/kg chemical in full container (see Table B-3 in Appendix B):

$$E_{\text{local_comp_cont_residue_disp}} = \frac{363.6 \text{ kg chem.}}{\text{site} - \text{day}} \times \frac{0.03 \text{ kg chem. remain}}{\text{kg chem. full}}$$

$$E_{\text{local_container_residue_disp}} = \frac{11 \text{ kg chem. released}}{\text{site} - \text{day}}$$

...over 250 days/year from 55 sites.

6.2.4 *Open Surface Losses to Air During Container Cleaning (Release 4)*

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:

$$Q_{\text{vapor_generation}} = \frac{(8.24 \times 10^{-8}) \times \text{MW}_{\text{chem}}^{0.835} \times F_{\text{correction_factor}} \times \text{VP}_{\text{chem}} \times \left(\frac{1}{29} + \frac{1}{\text{MW}_{\text{chem}}} \right)^{0.25} \times \text{RATE}_{\text{air_speed}}^{0.5} \times \text{AREA}_{\text{opening}}}{\text{TEMP}_{\text{ambient}}^{0.05} \times D_{\text{opening}}^{0.5} \times P_{\text{ambient}}^{0.5}} \quad [\text{Eqn. B-1}]$$

Table 6-2. Summary of ChemSTEER Inputs for Release 4

Parameter	Units	ChemSTEER Input
MW _{chem}	g/mol	100
F _{correction factor}	Dimensionless	1
VP _{chem}	Torr	0.1
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:

$$Q_{\text{vapor_generation}} = 1.2 \times 10^{-5} \text{ g/s}$$

Using $Q_{\text{vapor_generation}}$ calculated in Equation B-1 and the other standard default values presented in Table 4-2 for container cleaning, the model then estimates the daily release to air using the following equation:

$$E_{\text{local air_cleaning}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{Eqn. B-2}]$$

$$E_{\text{local air_cleaning}} = 1.2 \times 10^{-5} \text{ g chem./sec} \times \left(\frac{437 \text{ containers/site - yr}}{250 \text{ days/yr} \times 20 \text{ containers/hr}} \right) \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

$$E_{\text{local air_cleaning}} = 3.6 \times 10^{-6} \text{ kg chem. emitted/site - day}$$

...over 250 days/year from 20 sites.

6.2.5 Vented Losses to Air During Process Operations (Release 5)

Since the chemical of interest is volatile, it will be emitted from the process during radiation curable product mixing and formulation. Because of the volatility of the chemical, it is also assumed that the vessel is closed with a 4-inch (10 cm) diameter vent. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

$$Q_{\text{vapor_generation}} = \frac{(8.24 \times 10^{-8}) \times \text{MW}_{\text{chem}}^{0.835} \times F_{\text{correction_factor}} \times \text{VP}_{\text{chem}} \times \left(\frac{1}{29} + \frac{1}{\text{MW}_{\text{chem}}} \right)^{0.25} \times \text{RATE}_{\text{air_speed}}^{0.5} \times \text{AREA}_{\text{opening}}}{\text{TEMP}_{\text{ambient}}^{0.05} \times \text{D}_{\text{opening}}^{0.5} \times \text{P}_{\text{ambient}}^{0.5}} \quad [\text{Eqn. B-1}]$$

Table 6-3. Summary of ChemSTEER Inputs for Release 5

Parameter	Units	ChemSTEER Input
MW _{chem}	g/mol	100
F _{correction factor}	Dimensionless	1
VP _{chem.}	Torr	0.1
RATE _{air speed}	ft/min	100
AREA _{opening}	cm ²	79
TEMP _{ambient}	K	355
D _{opening}	Cm	10
P _{ambient}	Atm	1

Therefore:

$$Q_{\text{vapor_generation}} = 3.3 \times 10^{-5} \text{ g/s}$$

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

$$E_{\text{local air_process_vent}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{Eqn. B-2}]$$

$$E_{\text{local air_process_vent}} = 3.3 \times 10^{-5} \text{ g chem./sec} \times (8 \text{ hrs/bt} \times 1 \text{ bt/site - day}) \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

$$E_{\text{local air_process_vent}} = 9.5 \times 10^{-4} \text{ kg chem. emitted /site - day}$$

...over 250 days/year from 55 sites.

6.2.6 *Radiation Curable Product Sampling Wastes Disposed to Water, Incineration or Landfill (Release 6)*

While a release from this source is likely to occur, EPA does not currently have data to support quantifying the release.

6.2.7 *Open Surface Losses to Air During Product Sampling (Release 7)*

Since the chemical of interest is volatile, it will be emitted from the process during radiation curable product QA/QC sampling. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

[Eqn. B-1]

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

Table 6-4. Summary of ChemSTEER Inputs for Release 7

Parameter	Units	ChemSTEER Input
MW _{chem}	g/mol	100
F _{correction factor}	Dimensionless	1
VP _{chem}	Torr	0.1
RATE _{air speed}	ft/min	100
AREA _{opening}	cm ²	4.9-78.5
TEMP _{ambient}	K	355
D _{opening}	Cm	2.5-10
P _{ambient}	Atm	1

Therefore:

$$Q_{\text{vapor_generation}} = 4.2 \times 10^{-6} - 3.3 \times 10^{-5} \text{ g/s}$$

Using $Q_{\text{vapor_generation}}$ calculated in Equation B-1 and the other standard default values presented in Table 4-5 for radiation curable product sampling, the model then estimates the daily release to air using the following equation:

$$E_{\text{local air_sample}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{Eqn. B-2}]$$

$$E_{\text{local air_sample}} = (4.2 \times 10^{-6} \text{ to } 3.3 \times 10^{-4}) \text{ g chem./sec} \times 1 \text{ hr/site - day} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

$$E_{\text{local air_sample}} = 1.5 \times 10^{-5} - 1.2 \times 10^{-4} \text{ kg chem. emitted /site - day}$$

...over 250 days/year from 55 sites.

6.2.8 *Equipment Cleaning Releases to Incineration or Landfill (Release 8)*

Since it is assumed that one batch is formulated per day ($N_{\text{bt_site_yr}}$ is equivalent to $\text{TIME}_{\text{working_days}}$), the following equation is used to estimate the daily release:

$$E_{\text{local equipment_cleaning}} = Q_{\text{form_bt}} \times F_{\text{chem_form}} \times N_{\text{bt_site_day}} \times F_{\text{equipment_cleaning}} \quad [\text{Eqn. 4-4a}]$$

$$\begin{aligned} \text{Elocal}_{\text{equipment_cleaning}} &= \frac{363.6 \text{ kg chem.}}{\text{site - day}} \times \frac{0.7 \text{ kg chem.}}{1 \text{ kg prod.}} \times \frac{1 \text{ kg prod.}}{\text{site - day}} \times \frac{0.01 \text{ kg chem released}}{\text{kg chem used}} \\ \text{Elocal}_{\text{equipment_cleaning}} &= \frac{2.6 \text{ kg chem. released}}{\text{site - day}} \end{aligned}$$

...over 250 days/year from 55 sites

6.2.9 Open Surface Losses to Air During Equipment Cleaning (Release 9)

Since the chemical of interest is volatile, it will be emitted from the process during process equipment cleaning. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

$$Q_{\text{vapor_generation}} = \frac{(8.24 \times 10^{-8}) \times \text{MW}_{\text{chem}}^{0.835} \times F_{\text{correction_factor}} \times \text{VP}_{\text{chem}} \times \left(\frac{1}{29} + \frac{1}{\text{MW}_{\text{chem}}} \right)^{0.25} \times \text{RATE}_{\text{air_speed}}^{0.5} \times \text{AREA}_{\text{opening}}}{\text{TEMP}_{\text{ambient}}^{0.05} \times \text{D}_{\text{opening}}^{0.5} \times \text{P}_{\text{ambient}}^{0.5}} \quad [\text{Eqn. B-1}]$$

Table 6-5. Summary of ChemSTEER Inputs for Release 9

Parameter	Units	ChemSTEER Input
MW _{chem}	g/mol	100
F _{correction factor}	Dimensionless	1
VP _{chem}	Torr	0.1
RATE _{air speed}	ft/min	100
AREA _{opening}	cm ²	6,648
TEMP _{ambient}	K	298
D _{opening}	cm	92

Therefore:

$$Q_{\text{vapor_generation}} = 9.2 \times 10^{-4} \text{ g/s}$$

Using $Q_{\text{vapor_generation}}$ calculated in Equation B-1 and the other standard default values presented in Table 4-6 for process equipment cleaning, the model then estimates the daily release to air using the following equation:

$$\text{Elocal}_{\text{air_eqpt_cleaning}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{Eqn. B-2}]$$

$$\text{Elocal}_{\text{air_eqpt_cleaning}} = 9.2 \times 10^{-4} \text{ g chem./sec} \times (1 \text{ hrs/bt} \times 1 \text{ bt/site - day}) \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

$$\text{Elocal}_{\text{air_sample}} = 0.003 \text{ kg chem. emitted /site - day}$$

...over 250 days/year from 55 sites.

6.2.10 Filter Waste Releases to Incineration or Landfill during Filter Media Changeout (Release 10)

The pigmentation of the radiation curable product formulated was not provided. Therefore, by default, four percent of each batch is disposed as filter waste.

$$E_{\text{local}}_{\text{filter_waste}} = \frac{Q_{\text{form_site_yr}} \times F_{\text{chem_form}} \times F_{\text{filter}}}{\text{TIME}_{\text{form_working_days}}} \quad [\text{Eqn. 4-5}]$$

$$E_{\text{local}}_{\text{filter_waste}} = \frac{\frac{129,870 \text{ kg product}}{\text{site - yr}} \times \frac{0.7 \text{ kg chemical}}{\text{kg product}} \times 0.04 \text{ kg adhered/kg processed}}{250 \text{ days/yr}}$$

$$E_{\text{local}}_{\text{filter_waste}} = 14.6 \text{ kg chem. released / site - day}$$

...over 250 days/yr for 55 sites

6.2.11 Open Surface Losses to Air During Filter Media Changeout (Release 11)

Since the chemical of interest is volatile, it will be emitted from the process during filter media replacement. The *EPA/OPPT Penetration Model* is used to estimate the rate at which the chemical is emitted during this activity:

[B-1]

$$Q_{\text{vapor_generation}} = \frac{(8.24 \times 10^{-8}) \times MW_{\text{chem}}^{0.835} \times F_{\text{correction_factor}} \times VP_{\text{chem}} \times \left(\frac{1}{29} + \frac{1}{MW_{\text{chem}}} \right)^{0.25} \times \text{RATE}_{\text{air_speed}}^{0.5} \times \text{AREA}_{\text{open}}}{\text{TEMP}_{\text{ambient}}^{0.05} \times D_{\text{opening}}^{0.5} \times P_{\text{ambient}}^{0.5}}$$

Table 6-6. Summary of ChemSTEER Inputs for Release 11

Parameter	Units	ChemSTEER Input
MW _{chem}	g/mol	100
F _{correction factor}	Dimensionless	1
VP _{chem}	Torr	0.1
RATE _{air speed}	ft/min	100
AREA _{opening}	cm ²	182.4
TEMP _{ambient}	K	298
D _{opening}	cm	15.24

Therefore:

$$Q_{\text{vapor_generation}} = 6.2 \times 10^{-5} \text{ g/s}$$

Using $Q_{\text{vapor_generation}}$ calculated in Equation B-1 and the other standard default values presented in Table 4-6 for process equipment cleaning, the model then estimates the daily release to air using the following equation:

$$\text{Elocal}_{\text{air_eqpt_cleaning}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{Eqn. B-2}]$$

$$\text{Elocal}_{\text{air_eqpt_cleaning}} = 6.2 \times 10^{-5} \text{ g chem./sec} \times (1 \text{ hrs/bt} \times 1 \text{ bt/site} - \text{day}) \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

$$\text{Elocal}_{\text{air_sample}} = 0.0002 \text{ kg chem. emitted /site} - \text{day}$$

...over 250 days/year from 55 sites.

6.2.12 *Transfer Operation Losses to Air from Loading Radiation Curable Product into Transport Containers (Release 12)*

Since the chemical of interest is volatile, it will be emitted from the process from the displacement of saturated air when the chemical is transferred. The *EPA/OAQPS AP-42 Loading Model* is used to estimate the rate at which the chemical is emitted during this activity:

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

Table 6-7. Summary of ChemSTEER Inputs for Release 12

Parameter	Units	ChemSTEER Input
MW_{chem}	g/mol	100
$F_{\text{saturation_factor}}$	dimensionless	Typical = 0.5 Worst Case = 1
VP_{chem}	torr	0.1
$V_{\text{cont_empty}}$	gal	1
$\text{RATE}_{\text{fill}}$	containers/hour	20
$\text{TEMP}_{\text{ambient}}$	K	298
$F_{\text{correction_factor}}$	dimensionless	1
R	atm	82.05

Therefore:

$$Q_{\text{vapor_generation}} = 3.1 \times 10^{-4} \text{ g/s for typical and } Q_{\text{vapor_generation}} = 6.2 \times 10^{-4} \text{ g/s for worst case}$$

Using $Q_{\text{vapor_generation}}$ calculated in Equation B-5 and the other standard default values presented in Table 4-7 for radiation curable packaging, the model then estimates the daily release to air using the following equation:

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

$$E_{\text{local_air_packaging}} = (3.1 \times 10^{-4} \text{ to } 6.2 \times 10^{-4}) \text{ g chem./sec} \times \left(\frac{625 \text{ containers /site - yr}}{250 \text{ days/yr} \times 20 \text{ containers /hr}} \right) \times \frac{3600 \text{ sec/hr}}{1000 \text{ g/kg}}$$

$E_{\text{local_air_packaging}} = 1.4 \times 10^{-4} - 2.8 \times 10^{-4} \text{ kg chem. emitted/site-day}$
 ...over 250 days/year from 55 sites.

6.3 Occupational Exposure Assessments for the Formulation of Radiation Curable Products

6.3.1 Total Number of Workers Potentially Exposed to the Chemical

It is assumed that the chemical is used in a coating formulation. 39 radiation curable coating formulation workers are potentially exposed to the chemical at each site; therefore, the total number of workers is calculated as:

$$39 \frac{\text{workers}}{\text{site}} \times N_{\text{sites}} = 39 \frac{\text{workers}}{\text{site}} \times 55 \text{ sites} = 2,145 \text{ total radiation curable formulation workers}$$

Note that all 39 workers are assumed to be exposed during each of the exposure activities performed at each of the 55 formulation sites.

6.3.2 Exposure from Unloading Solid or Liquid Chemicals (Exposure A)

Inhalation Exposure:

The density of the liquid component is assumed 1 kg/L, which is not typical of a viscous component. Based on this assumption, preheating is not expected. The liquid component will likely be unloaded at ambient temperatures.

Using the vapor generation rate calculated in Release 1 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 6-8. 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	100
RATE _{ventilation}	ft ³ /min	Typical = 3000 Worst Case = 500
Q _{vapor_generation}	g/s	Typical = 3.1×10^{-4} Worst Case = 6.2×10^{-4}
RATE _{breathing}	m ³ /hour	1.25
V _{molar}	L/mol	24.45
RATE _{fill}	containers/hr	20
TIME _{exposure}	hours/day	0.24

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

$$C_{\text{chem_volumetric}} = 0.1 \text{ ppm for typical and } 6.3 \text{ ppm for worst case}$$

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

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

$$C_{\text{chem_mass}} = 0.4 \text{ mg/m}^3 \text{ for typical and } C_{\text{chem_mass}} = 25.8 \text{ mg/m}^3 \text{ for worst case}$$

Finally, the mass concentration of the chemical and the standard default values presented in Table 5-2 for the container unloading activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

$$\text{EXP}_{\text{inhalation}} = C_{\text{chem_mass}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \quad [\text{Eqn. B-10}]$$

$$\text{EXP}_{\text{inhalation}} = (0.41 \text{ to } 25) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times \left(\frac{437 \text{ containers/site - yr}}{250 \text{ days/yr} \times 20 \text{ containers/hr}} \right)$$

$$\text{EXP}_{\text{inhalation}} = 0.04 - 2.8 \text{ mg chem./worker - day} \\ \dots \text{over } 250 \text{ days/year.}$$

Dermal Exposure:

The potential worker exposure to the chemical within the liquid radiation curable component is calculated using the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*:

$$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad [\text{Eqn. 5-3a}]$$

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

$$\text{EXP}_{\text{dermal}} = \frac{588 - 1,764 \text{ mg chem.}}{\text{day}}$$

...over 250 days/year

6.3.3 Exposure to Liquids During Container Cleaning (Exposure B)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 6-9. 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	100
RATE _{ventilation}	ft ³ /min	Typical = 3000 Worst Case = 500
Q _{vapor generation}	g/s	Typical = 1.2 x 10 ⁻⁵
RATE _{breathing}	m ³ /hour	1.25
V _{molar}	L/mol	24.45
RATE _{fill}	containers/hr	20
TIME _{exposure}	hours/day	0.72

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

$C_{\text{chem_volumetric}} = 4.0 \times 10^{-3}$ ppm for typical and $C_{\text{chem_volumetric}} = 0.12$ ppm for worst case

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

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

$$C_{\text{chem_mass}} = 1.7 \times 10^{-2} \text{ mg/m}^3 \text{ for typical and } C_{\text{chem_mass}} = 0.5 \text{ mg/m}^3 \text{ for worst case}$$

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

$$\text{EXP}_{\text{inhalation}} = C_{\text{chem_mass}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \quad [\text{Eqn. B-10}]$$

$$\text{EXP}_{\text{inhalation}} = (0.017 \text{ to } 0.49) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times \left(\frac{437 \text{ containers/site - yr}}{250 \text{ days/yr} \times 20 \text{ containers/hr}} \right)$$

$$\text{EXP}_{\text{inhalation}} = 1.8 \times 10^{-3} - 0.04 \text{ mg chem./worker - day}$$

...over 250 days/year.

Dermal Exposure:

The potential worker exposure to the chemical within the liquid radiation curable component is calculated using the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*:

$$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad [\text{Eqn. 5-6a}]$$

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

$$\text{EXP}_{\text{dermal}} = \frac{588 - 1,764 \text{ mg chem.}}{\text{day}}$$

...over 250 days/year

6.3.4 Exposure from Sampling Liquid Radiation Curable Product (Exposure C)

Inhalation Exposure:

Using the vapor generation rate calculated in Release 7 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 6-10. Summary of ChemSTEER Inputs for Exposure C

Parameter	Units	ChemSTEER Input
$F_{\text{mixing_factor}}$	dimensionless	Typical = 0.5 Worst Case = 0.1
$TEMP_{\text{ambient}}$	K	298
MW_{chem}	g/mol	100
$RATE_{\text{ventilation}}$	ft ³ /min	Typical = 3000 Worst Case = 500
$Q_{\text{vapor_generation}}$	g/s	Typical = 4.1×10^{-6} Worst Case = 3.3×10^{-5}
$RATE_{\text{breathing}}$	m ³ /hour	1.25
V_{molar}	L/mol	24.45
$TIME_{\text{exposure}}$	hours/day	1

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

$C_{\text{chem_volumetric}} = 1.4 \times 10^{-3}$ ppm for typical and $C_{\text{chem_volumetric}} = 0.3$ ppm for worst case

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

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

$C_{\text{chem_mass}} = 5.7 \times 10^{-3}$ mg/m³ for typical and $C_{\text{chem_mass}} = 1.2$ mg/m³ for worst case

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

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

$$EXP_{\text{inhalation}} = (5.7 \times 10^{-3} \text{ to } 1.2) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times 1 \text{ hr/site} - \text{day}$$

$$EXP_{\text{inhalation}} = 7.1 \times 10^{-3} - 1.5 \text{ mg chem./worker} - \text{day} \\ \dots \text{over 250 days/year.}$$

Dermal Exposure:

The potential worker exposure to the chemical within the liquid radiation curable product is calculated using the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [\text{Eqn. 5-7}]$$

$$= \left[\frac{0.7 \text{ to } 2.1 \text{ mg prod.}}{\text{cm}^2 \text{ - incident}} \right] \times 420 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.7 \text{ mg chem.}}{\text{mg prod.}}$$

$$EXP_{\text{dermal}} = \frac{206 - 618 \text{ mg chem.}}{\text{day}}$$

...over 250 days/year

6.3.5 Exposure to Liquids During the Equipment Cleaning of Mixers and Other Process Equipment (Exposure D)

Inhalation Exposure:

Using the vapor generation rate calculated in Release 9 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 6-11. Summary of ChemSTEER Inputs for Exposure D

Parameter	Units	ChemSTEER Input
F _{mixing_factor}	dimensionless	Typical = 0.5 Worst Case = 0.1
TEMP _{ambient}	K	298
MW _{chem}	g/mol	100
RATE _{ventilation}	ft ³ /min	Typical = 3000 Worst Case = 500
Q _{vapor_generation}	g/s	9.2 x 10 ⁻⁴
RATE _{breathing}	m ³ /hour	1.25
V _{molar}	L/mol	24.45
TIME _{exposure}	hours/day	1

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

$$C_{\text{chem_volumetric}} = 0.01 - 0.09 \text{ ppm}$$

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

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

$$C_{\text{chem_mass}} = \frac{(0.01 \text{ to } 0.09) \text{ ppm} \times 100 \text{ g/mol}}{24.45 \text{ L/mol}}$$

$$C_{\text{chem_mass}} = 0.04 - 0.37 \text{ mg/m}^3$$

Finally, the mass concentration of the chemical and the standard default values presented in Table 5-6 for the process equipment cleaning activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

$$\text{EXP}_{\text{inhalation}} = C_{\text{chem_mass}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \quad [\text{Eqn. B-10}]$$

$$\text{EXP}_{\text{inhalation}} = (0.04 \text{ to } 0.37) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times 1 \text{ hrs/site} - \text{day}$$

$$\text{EXP}_{\text{inhalation}} = 0.05 - 0.46 \text{ mg chem./worker} - \text{day}$$

...over 250 days/year.

Dermal Exposure:

$$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [\text{Eqn. 5-8}]$$

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

$$\text{EXP}_{\text{dermal}} = \frac{411 - 1,234 \text{ mg chem.}}{\text{day}}$$

...over 250 days/year

6.3.6 Exposure from Changing Spent Filter Media (Exposure E)

Inhalation Exposure:

Using the vapor generation rate calculated in Release 11 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 6-12. Summary of ChemSTEER Inputs for Exposure E

Parameter	Units	ChemSTEER Input
F _{mixing_factor}	dimensionless	Typical = 0.5 Worst Case = 0.1
TEMP _{ambient}	K	298
MW _{chem}	g/mol	100
RATE _{ventilation}	ft ³ /min	Typical = 3000 Worst Case = 500
Q _{vapor_generation}	g/s	6.2 x 10 ⁻⁵
RATE _{breathing}	m ³ /hour	1.25
V _{molar}	L/mol	24.45
TIME _{exposure}	hours/day	0.25

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

$C_{\text{chem_volumetric}} = 0.02$ ppm for typical and $C_{\text{chem_volumetric}} = 0.63$ ppm for worst case

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

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

$C_{\text{chem_mass}} = 0.02$ mg/m³ for typical and $C_{\text{chem_mass}} = 2.58$ mg/m³ for worst case

Finally, the mass concentration of the chemical and the standard default values presented in Table 5-7 for the filter media replacement activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

$$\text{EXP}_{\text{inhalation}} = C_{\text{chem_mass}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \quad [\text{Eqn. B-10}]$$

$$\begin{aligned} \text{EXP}_{\text{inhalation}} &= (0.02 \text{ to } 2.58) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times 0.25 \text{ hrs/site} - \text{day} \\ \text{EXP}_{\text{inhalation}} &= 0.03 - 0.81 \text{ mg chem./worker} - \text{day} \\ &\dots \text{over } 250 \text{ days/year.} \end{aligned}$$

Dermal Exposure:

$$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [\text{Eqn. 5-9}]$$

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

$$EXP_{\text{dermal}} = \frac{411 - 1,234 \text{ mg chem.}}{\text{day}}$$

...over 250 days/year

6.3.7 Exposure from Packaging Radiation Curable Product (Exposure F)

Inhalation Exposure:

Using the vapor generation rate calculated in Release 12 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 6-13. Summary of ChemSTEER Inputs for Exposure F

Parameter	Units	ChemSTEER Input
F _{mixing_factor}	dimensionless	Typical = 0.5 Worst Case = 0.1
TEMP _{ambient}	K	298
MW _{chem}	g/mol	100
RATE _{ventilation}	ft ³ /min	Typical = 3000 Worst Case = 500
Q _{vapor_generation}	g/s	Typical = 3.1×10^{-4} Worst Case = 6.2×10^{-4}
RATE _{breathing}	m ³ /hour	1.25
V _{molar}	L/mol	24.45
TIME _{exposure}	hours/day	8

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

$C_{\text{chem_volumetric}} = 0.10$ ppm for typical and $C_{\text{chem_volumetric}} = 6.3$ ppm for worst case

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

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

$C_{\text{chem_mass}} = 0.41$ mg/m³ for typical and $C_{\text{chem_mass}} = 26$ mg/m³ for worst case

Finally, the mass concentration of the chemical and the standard default values presented in Table 5-7 for the radiation curable product packaging activity are used to estimate the amount of inhalation exposure per worker using the following calculation:

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

$$EXP_{\text{inhalation}} = (0.41 \text{ to } 26) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times \left(\frac{625 \text{ containers/site - yr}}{250 \text{ days/yr} \times 20 \text{ containers/hr}} \right)$$

$$EXP_{\text{inhalation}} = 0.07 - 4 \text{ mg chem./worker - day}$$

...over 250 days/year.

Dermal Exposure:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [\text{Eqn. 5-10}]$$

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

$$EXP_{\text{dermal}} = \frac{411 - 1,234 \text{ mg chem.}}{\text{day}}$$

...over 250 days/year

7 DATA GAPS/UNCERTAINTIES AND FUTURE WORK

This ESD relies on anecdotal data, industry data and information gathered from various sources to generate general facility estimates, release estimates, and exposure estimates. EPA wishes to make this ESD as detailed and up-to-date as possible, such that the risk-screening assessments reflect current industrial practices. This ESD could be improved by collecting measured data and associated information to verify or supersede the anecdotal data and information.

EPA is most interested in obtaining information about the radiation curable products industry that is characterized as “typical” or “conservative” (i.e., worse case), and is applicable to a generic formulation site. While EPA welcomes site-specific information as valuable to this ESD, additional qualifiers of how reflective it is to the industry are needed to ensure its transparency if used in the ESD. Reviewers should also feel free to recommend additional resources that may be useful to the development of this ESD.

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

1. The ESD incorporates average facility production rates that are estimated using the radiation curable products industry market data and U.S. Census data for the number of U.S. formulation sites. The quality of these production rates could be improved with additional data on typical formulation site component use rates or radiation curable production rates for the various types of radiation curable products (e.g., kg/batch, kg/site-day).
2. The ESD assumes that formulators use a single component product (containing the chemical of interest) for all radiation curable products of the same type. Additional information on the validity of these assumptions would improve the quality of the estimates. In other words, might formulators alternately use one of several available types of stabilizers when formulating a radiation curable product?
3. No specific information was found on the typical release control technologies employed in radiation curable formulation processes (e.g., wastewater treatment, air release controls). The releases calculated in this ESD reflect the amount of chemical released directly from the process. Information on control technologies and the prevalence of their use would further improve this ESD.
4. Specific data on the numbers of workers performing the various exposure activities in the radiation curable formulation processes were not found. Therefore, the ESD assumed that the number of workers per facility estimated for each radiation curable product and market (Table 5-2 and Table 8-2) perform each of the exposure activities. Additional information on the numbers workers performing each exposure activity would further enhance the calculations.

5. Specific input on the reasonableness of the default values used in the general facility estimates (e.g., batch duration, number of operating days per year) would enhance the quality of the calculations.
6. Industry-specific monitoring data for operations involving volatile liquids would enhance the estimates for vented or fugitive releases and associated worker inhalation exposures.
7. Industry-specific dermal monitoring data for all operations involving workers manually handling the radiation curable components or formulated products would enhance the estimates.

8 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 ESD 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., RadTech – www.radtech.org, Federation of Societies for Coating Technologies – www.coatingstech.com); and
- Industry specific journals and technical literature (e.g., SpecialChem Innovations and Solutions in Adhesives and Sealants - www.specialchem4adhesives.com, Converting Magazine – www.convertingmagazine.com).

While each of these sources was reviewed for information, not all provided information specific to the radiation curable products industry. The references specifically cited in this ESD are provided below.

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**APPENDIX A:
ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES**

Summary of Release and Exposure Estimation Equations for Formulation Sites

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

Table A-1. Radiation Curable Formulation Release and Exposure Calculation Summary

General Facility Estimates	
Annual Facility Production Rate ($Q_{form_site_yr}$):	
$Q_{form_site_yr} = Q_{form_site_prod_rate} \times F_{radcur}$	(Eqn. 3-1)
Mass Fraction of Chemical in Radiation Curable Product (F_{chem_form}):	
$F_{chem_form} = F_{chem_comp} \times F_{comp_form}$	(Eqn. 3-2)
Number of Formulation Sites (N_{form_sites}):	
$N_{form_sites} = \frac{Q_{chem_yr}}{Q_{form_site_yr} \times F_{chem_form}}$	(Eqn. 3-3)
<p>The value for N_{form_sites}, calculated using Equation 3-3 should be rounded up to the nearest integer value. $Q_{form_site_yr}$ should then be adjusted for the N_{form_sites} integer value (to avoid errors due to rounding):</p> $Q_{form_site_yr} = \frac{Q_{chem_yr}}{N_{form_sites} \times F_{chem_form}}$	
<p>*Note: If the number of formulation sites is known, the previous equation may also be used to estimate the resulting average annual production rate for use in subsequent calculations.</p>	
Days of Operation (days/year) ($TIME_{form_orking_days}$):	
$TIME_{form_orking_days} = \frac{Q_{form_site_yr}}{Q_{form_bt} \times N_{bt_site_day}}$	(Eqn.3-4)
Batch Size (kg product/batch) (Q_{form_bt}):	
$Q_{form_bt} = \frac{Q_{form_site_yr}}{TIME_{form_orking_days} \times N_{bt_site_day}}$	(Eqn. 3-5)
Annual Number of Batches (batch/site-year) ($N_{bt_site_yr}$):	
$N_{bt_site_yr} = \frac{Q_{form_site_yr}}{Q_{form_bt}}$	(Eqn. 3-6)

Daily Use Rate of the Chemical of Interest (kg chemical/site-day) ($Q_{\text{form_chem_site_day}}$):

$$Q_{\text{form_chem_site_day}} = \frac{Q_{\text{form_site_yr}} \times F_{\text{chem_form}}}{\text{TIME}_{\text{form_working_days}}} \quad (\text{Eqn. 3-7})$$

The daily use rate can be alternatively estimated using this equation:

$$Q_{\text{form_chem_site_day}} = Q_{\text{form_bt}} \times N_{\text{bt_site_day}} \times F_{\text{chem_form}}$$

Annual Number of Radiation Curable Component Containers Emptied per Facility (containers/site-year)

($N_{\text{comp_cont_emptry_ite_yr}}$):

$$N_{\text{comp_cont_empty_site_yr}} = \frac{Q_{\text{form_chem_site_day}} \times \text{TIME}_{\text{form_working_days}}}{F_{\text{chem_comp}} \times Q_{\text{cont_empty}}} \quad (\text{Eqn. 3-8})$$

Annual Number of Radiation curable Product Containers Filled per Facility (containers/site-year)

($N_{\text{cont_fill_site_yr}}$):

$$N_{\text{form_cont_fill_site_yr}} = \frac{Q_{\text{form_chem_site_day}} \times \text{TIME}_{\text{form_working_days}}}{F_{\text{chem_form}} \times Q_{\text{cont_fill}}} \quad (\text{Eqn. 3-9})$$

Release Calculations		
Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Transfer Operations (Volatile Releases)	Air	EPA/OAQPS AP-42 Loading Model (See Section 4.2)
Transfer Operations (Dust Releases)	Air Water Landfill Incineration	EPA/OPPT Generic Model to Estimate Dust Releases from Transfer/Unloading Operations of Solid Powders (See Section 4.3)
Container Residue	Water Landfill Incineration	<p>If $N_{\text{comp_cont_empty_site_yr}}$ is fewer than $\text{TIME}_{\text{form_working_days}}$:</p> $\text{Elocal}_{\text{comp_cont_residue_disp}} = Q_{\text{cont_empty}} \times F_{\text{chem_comp}} \times F_{\text{container_residue}} \times N_{\text{comp_cont_empty_site_day}}$ <p>... released over $[N_{\text{comp_cont_empty_site_yr}}]$ days/year from $[N_{\text{form_sites}}]$ sites (Eqn. 4-3a)</p> <p>If $N_{\text{comp_cont_empty_site_yr}}$ is greater than $\text{TIME}_{\text{form_working_days}}$:</p> $\text{Elocal}_{\text{comp_cont_residue_disp}} = Q_{\text{form_chem_site_day}} \times F_{\text{container_residue}}$ <p>... released over $[\text{TIME}_{\text{form_working_days}}]$ days/year from $[N_{\text{form_sites}}]$ sites (Eqn. 4-3b)</p>
Container Cleaning (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.5)
Process Vents (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.6)
Raw Material/Product Sampling Wastes	Water Landfill Incineration	EPA does not currently have a model for quantifying this release.
Raw Material/Product Sampling (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.8)
Process Equipment Residue	Landfill Incineration	<p>If $N_{\text{bt_site_yr}}$ or known number of cleanings is fewer than $\text{TIME}_{\text{form_working_days}}$:</p> $\text{Elocal}_{\text{equipment_cleaning}} = Q_{\text{form_bt}} \times F_{\text{chem_form}} \times N_{\text{bt_site_day}} \times F_{\text{equipment_cleaning}}$ <p>... released over $[N_{\text{bt_site_yr}}]$ days/year from $[N_{\text{form_sites}}]$ sites (Eqn. 4-4a)</p> <p>If $N_{\text{bt_site_yr}}$ is greater than $\text{TIME}_{\text{working_days}}$:</p> $\text{Elocal}_{\text{equipment_cleaning}} = Q_{\text{form_chem_site_day}} \times F_{\text{equipment_cleaning}}$ <p>... released over $[\text{TIME}_{\text{form_working_days}}]$ days/year from $[N_{\text{form_sites}}]$ sites (Eqn. 4-4b)</p>
Equipment Cleaning (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.10)

Release Calculations		
Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Filter Media Wastes	Landfill Incineration	$E_{\text{local}}_{\text{filter_waste}} = \frac{Q_{\text{form_chem_site_day}} \times F_{\text{chem_form}} \times F_{\text{filter}}}{\text{TIME}_{\text{form_working_days}}} \quad (\text{Eqn. 4-5})$ <p>...released over [TIME_{form working days}] days/year from [N_{form sites}] sites</p>
Filter Media Wastes (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.12)
Packaging Operations (Volatile Releases)	Air	EPA/OAQPS AP-42 Loading Model (See Section 4.13)

Occupational Exposure Calculations	
Number of Workers Exposed Per Site: See Section 5.2.	
Inhalation Exposure from Unloading Solid or Liquid Chemicals:	
<i>Liquid Chemicals:</i>	
EPA/OPPT Mass Balance Inhalation Model (See Section 5.3)	
<i>Solid Chemicals:</i>	
$Q_{\text{comp_site_day}} = \frac{Q_{\text{form_chem_site_day}}}{F_{\text{chem_comp}}} \quad (\text{Eqn. 5-1})$	
If $Q_{\text{comp_site_day}}$ is <i>greater than</i> 54 kg/site-day:	
$\text{EXP}_{\text{inhalation}} = C_{\text{particulate}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \times F_{\text{chem_comp}} \quad (\text{Eqn. 5-2a})$	
...over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$, up to 250] days/year	
If $Q_{\text{comp_site_day}}$ is <i>less than or equal to</i> 54 kg/site-day:	
$\text{EXP}_{\text{inhalation}} = Q_{\text{comp_site_day}} \times F_{\text{chem_comp}} \times F_{\text{exposure}} \quad (\text{Eqn. 5-2b})$	
.....over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$, up to 250] days/year	
Dermal Exposure from Unloading Solid or Liquid Chemicals:	
<i>Liquid Chemicals:</i>	
$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (\text{Eqn. 5-3a})$	
... over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.2), up to 250] days per year	
<i>Solid Chemicals:</i>	
$\text{EXP}_{\text{dermal}} = \text{up to } 3,100 \text{ mg component/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (\text{Eqn. 5-3b})$	
... over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$, up to 250] days per year	

Occupational Exposure Calculations
<p>Inhalation Exposure to Solids or Liquids During Container Cleaning:</p> <p><i>Liquid Chemicals:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.4)</p> <p><i>Solid Chemicals:</i></p> $Q_{\text{comp_residue_site_day}} = \frac{E_{\text{local}}_{\text{container_residue_disp}}}{F_{\text{chem_comp}}} \quad (\text{Eqn. 5-4})$ <p>If $Q_{\text{comp_residue_site_day}}$ is <i>greater than</i> 54 kg/site-day:</p> $\text{EXP}_{\text{inhalation}} = C_{\text{particulate}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \times F_{\text{chem_comp}} \quad (\text{Eqn. 5-5a})$ <p>... over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.4), up to 250] days per year</p> <p>If $Q_{\text{comp_residue_site_day}}$ is <i>less than or equal to</i> 54 kg/site-day:</p> $\text{EXP}_{\text{inhalation}} = Q_{\text{comp_residue_site_day}} \times F_{\text{chem_comp}} \times F_{\text{exposure}} \quad (\text{Eqn. 5-5b})$ <p>... over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.4), up to 250] days per year</p>
<p>Dermal Exposure to Solids or Liquids During Container Cleaning:</p> <p><i>Liquid Chemicals:</i></p> $\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (\text{Eqn. 5-6a})$ <p>... over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.4), up to 250] days per year</p> <p><i>Solid Chemicals:</i></p> $\text{EXP}_{\text{dermal}} = \text{up to } 3,100 \text{ mg component/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \quad (\text{Eqn. 5-6b})$ <p>... over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.4), up to 250] days per year</p>
<p>Exposure from Sampling Liquid Product:</p> <p><i>Inhalation Exposure:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.5)</p> <p><i>Dermal Exposure:</i></p> $\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (\text{Eqn. 5-7})$ <p>... over [the lesser of $N_{\text{comp_cont_empty_site_yr}}$ or $\text{TIME}_{\text{form_working_days}}$ (consistent with Section 4.8), up to 250] days per year.</p>
<p>Exposure to Liquids During the Equipment Cleaning of Mixers and Other Process Equipment:</p> <p><i>Inhalation Exposure:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.8)</p> <p><i>Dermal Exposure:</i></p> $\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (\text{Eqn. 5-8})$ <p>... over [the number of cleanings per year (consistent with Section 4.9), up to 250] days per year.</p>

Occupational Exposure Calculations
<p>Exposure to Liquids During Filter Media Changeout:</p> <p><i>Inhalation Exposure:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.7)</p> <p><i>Dermal Exposure:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (\text{Eqn. 5-9})$ <p>... over [the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{form_working_days}}$ (consistent with Section 4.12), up to 250] days per year.</p>
<p>Exposure from Packaging Liquid Product:</p> <p><i>Inhalation Exposure:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.8)</p> <p><i>Dermal Exposure:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_comp}} \times F_{\text{chem_form}} \quad (\text{Eqn. 5-10})$ <p>... over [the lesser of $N_{\text{cont_fill_site_yr}}$ or $TIME_{\text{working_days}}$ (consistent with Section 4.11), up to 250] days per year.</p>

Table A-2. Summary of Equation Parameter Default Values Used in the ESD

Variable	Variable Description	Default Value	Data Source
AREA _{surface}	Surface area of contact (cm ²)	840 cm ² (2 hands) 420 cm ² (1 hand)	CEB, 2000
C _{particulate}	Concentration of particulate in workers breathing zone (OSHA Total PNOR PEL (8-hr TWA) (mg/m ³))	15	29 CFR 1910.1000
F _{radcure}	Fraction of the total radiation curable type produced that incorporates the chemical of interest (kg radiation curable product with chemical/kg total radiation curable product produced)	1	EPA assumption
F _{chem_comp}	Mass fraction of the chemical of interest in the component (kg chemical/kg component)	1	EPA assumption
F _{comp_form}	Mass fraction of the component in the formulated product (kg component/kg product)	0.70 For oligomer used in a radiation curable coating	See Table 2-4
F _{container_residue}	Fraction of component remaining in the container as residue (kg component remaining/kg component in full container)	0.03	CEB, 2002a
F _{equipment_cleaning}	Fraction of radiation curable product released as residual in process equipment (kg radiation curable released/kg batch capacity)	0.01	CEB, 1992a
F _{exposure}	Weight fraction of total particulate radiation curable component or product in the workers' breathing zone (mg chemical/kg handled)	0.0477 (typical) 0.161 (worst case)	CEB, 1992b
F _{filter}	Fraction of the chemical adhered to the filter and disposed as waste (kg adhered/kg processed)	0.04	RadTech, 2007
N _{bt_site_day}	Daily number of batches formulated at each site (batches/site-day)	1	EPA assumption
N _{exp_incident}	Number of exposure incidents per day (incidents/day)	1	CEB, 2000
Q _{form_site_yr}	Annual facility production rate (kg product/site-yr)	360,000 For radiation curable coating	See Table 3-2
Q _{liquid_skin}	Quantity of liquid component or product remaining on skin (mg/cm ² -incident)	0.7 (low end) 2.1 (high end)	CEB, 2000
Q _{liquid_skin} × AREA _{surface} (for solids)	Quantity of dermal exposure to solids	3,100 mg/incident	CEB, 2000
RATE _{breathing}	Typical worker breathing rate (m ³ /hr)	1.25	CEB, 1991
RHO _{form}	Density of the radiation curable product (kg/L)	1	EPA assumption

Variable	Variable Description	Default Value	Data Source
$RHO_{\text{component}}$	Density of the radiation curable component (kg/L)	1	EPA assumption
$TIME_{\text{form_working}}$ days	Days of operation for formulation sites	250	CEB, 1992a
$V_{\text{cont_fill}}$	Volume of radiation curable product per filled container (L/container)	208 (55-gallon drum)	EPA assumption
$V_{\text{cont_empty}}$	Volume of radiation curable component per container (L/container)	208 (55-gallon drum)	EPA 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/opptintr/exposure/docs/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 ($Q_{\text{vapor_generation}}$; g/sec) and the resulting daily release rate of the chemical vapors to air. The *EPA/OPPT Mass Balance Inhalation Model* (discussed in Section B.2.2) uses the value of $Q_{\text{vapor_generation}}$, calculated by the appropriate release model, to estimate the resulting inhalation exposure to that released vapor.

B.2.1 Vapor Generation Rate and Volatile Air Release Models

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

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

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

B.2.1.1 EPA/OPPT Penetration Model

Model Description and Rationale:

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

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

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

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

Model Equations:

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

[B-1]

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

Where:

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

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

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

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

Where:

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

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

References:

- Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.
- U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-24 and Appendix K). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.2 EPA/OPPT Mass Transfer Coefficient Model*Model Description and Rationale:*

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

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

¹Similar air releases from surfaces located at *indoor* locations (air speeds ≤ 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]

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

Where:

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

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

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

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

Where:

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

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

References:

- Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.
- U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.3 EPA/OAQPS AP-42 Loading Model*Model Description and Rationale:*

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

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

Model Equations:

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

[B-5]

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

Where:

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

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

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

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

Where:

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

Reference:

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

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

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)		20		
Drums (Indoors)	55 (Range: 20 to <100)				
Totes (Indoors)	550 (Range: 100 to <1,000)				
Tank Trucks (Outdoors)	5,000 (Range: 1,000 to <10,000)	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:					

Activity Type (Location)	V_{cont empty} (gallons)	D_{opening} (cm)	RATE_{fill} (containers/hour)	F_{saturation factor}	TIME_{activity hours} (hours/site-day)
Sampling Liquids (Indoors)	Not applicable	Typical: 2.5 ^a Worst Case: 10	Not applicable	1	1
Other Activities:					
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate/air release models described in this section, the ESD will describe the model and provide appropriate default values for the model parameters.			1	24
Batch Operation					Lesser of: (Hours/batch × Batches/site-day) or 24

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

B.2.2 Chemical Vapor Inhalation Model

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

B.2.2.1 EPA/OPPT Mass Balance Model

Model Description and Rationale:

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

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

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

Model Equations:

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

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

Where:

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

$F_{\text{mixing_factor}}$ = Mixing factor (dimensionless; see Table B-2 for appropriate EPA default values)

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

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

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

Where:

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

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

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

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

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

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

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

Where:

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

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

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

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

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

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

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

Where:

$EXP_{\text{inhalation}}$	=	Inhalation exposure to the chemical vapor per day (mg chemical/worker-day)
$C_{\text{chem_mass}}$	=	Mass concentration of the chemical vapor in air (mg/m^3 ; see Equation B-9]
$RATE_{\text{breathing}}$	=	Typical worker breathing rate (EPA default = $1.25 \text{ m}^3/\text{hr}$)
$TIME_{\text{exposure}}$	=	Duration of exposure for the activity (hours/worker-day; see Table B-2 for appropriate EPA default values (≤ 8 hours/worker-day))

References:

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

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

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	440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × RATE _{air_speed}) 5,280) ³ (Outdoors)		
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

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

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

B.3. CONTAINER RESIDUE RELEASE MODELS (NON-AIR)*Model Description and Rationale:*

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

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

Model Equation:

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

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

Where:

$E_{\text{local_container_residue_disp}}$	=	Daily release of the chemical residue to water, incineration, or landfill from the cleaning or disposal of empty shipping containers (kg/site-day)
$F_{\text{container_residue}}$	=	Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table B-3 for appropriate EPA default values)
$Q_{\text{total_daily_container}}$	=	Total (daily) quantity of the chemical contained in the shipping containers prior to emptying (kg of chemical/site-day; see Table B-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 ($\text{TIME}_{\text{days_container_residue}}$, days/site-year) must be appropriately “paired” with the total daily quantity

of chemical contained in the containers ($Q_{\text{total_daily_container}}$) used in calculating the daily release. Thus, Table B-4 also contains the appropriate EPA default values for $\text{TIME}_{\text{days_container_residue}}$.

References:

- U.S. EPA. Chemical Engineering Branch. Memorandum: *Standard Assumptions for PMN Assessments*. From the CEB Quality Panel to CEB Staff and Management. October 1992.
- U.S. EPA. Office of Pesticides and Toxic Substances. *Releases During Cleaning of Equipment*. July 1988.

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

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

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

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

than 110 gallons in size...”. The 3 percent high-end default is consistent with the range of experimental results documented in the 1988 EPA study (see *References* in this section for a citation of this study).

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

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

B.4. 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:

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

Where:

$E_{\text{local}_{\text{equip_cleaning}}}$	=	Daily release of the chemical residue to water, incineration, or landfill from cleaning of empty process equipment (kg/site-day)
$F_{\text{equip_residue}}$	=	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)
$Q_{\text{equip_chem_capacity}}$	=	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 ($\text{TIME}_{\text{days_equip_residue}}$, days/site-year) must be appropriately “paired” with the total capacity of the equipment to contain the chemical of interest ($Q_{\text{equip_chem_capacity}}$) used in calculating the daily release. Thus, Table B-6 also contains the appropriate EPA default values for $\text{TIME}_{\text{days_equip_residue}}$.

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	$F_{\text{equip residue}}^a$
<i>EPA/OPPT Single Process Vessel Residual Model</i>	Conservative: 0.01 (for <u>pumping</u> process materials from the vessel) *Alternative defaults: Central Tendency: 0.0007 High End to Bounding: 0.002 (alternative defaults for <u>gravity-draining</u> materials from the vessel)
<i>EPA/OPPT Multiple Process Vessel Residual Model</i>	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 $Q_{\text{equip_chem_capacity}}$ and $\text{TIME}_{\text{days_equip_residue}}$ Values for Use in the Process Equipment Residual Models

Process Type	Number of Batches per Day	$Q_{\text{equip chem. capacity}}$ (kg/site-day)	$\text{TIME}_{\text{days equip residue}}$ (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 $\text{TIME}_{\text{days_equip_residue}}$ summarized above in Table B-6. Care should be given in defining the appropriate $Q_{\text{total_daily_container}}$ and $\text{TIME}_{\text{days_container_residue}}$ 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, Organisation 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.

$$E_{\text{local}_{\text{dust_fugitive}}} = Q_{\text{transferred}} \times F_{\text{dust_generation}} \times (1 - F_{\text{dust_control}}) \quad [\text{B-13}]$$

Where:

$E_{\text{local}_{\text{dust_fugitive}}}$	=	Daily amount not captured by control technology from transfers or unloading (kg/site-day)
$Q_{\text{transferred}}$	=	Quantity of chemical transferred per day (kg chemical/site-day)
$F_{\text{dust_generation}}$	=	Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$F_{\text{dust_control}}$	=	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.

$$E_{\text{local}_{\text{dust_captured}}} = Q_{\text{transferred}} \times F_{\text{dust_generation}} \times F_{\text{dust_control}} \quad [\text{B-14}]$$

Where:

$E_{\text{local}_{\text{dust_captured}}}$	=	Daily amount captured by control technology from transfers or unloading (kg/site-day)
$Q_{\text{transferred}}$	=	Quantity of chemical transferred per day (kg chemical/site-day)

$F_{\text{dust_generation}}$	=	Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$F_{\text{dust_control}}$	=	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". November 2006.
- 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 Handling 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*¹ (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 ($Q_{\text{facility_day}}$; kg/site-day) is equal to the amount handled per worker ($Q_{\text{shift_handled}}$; 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:

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

Where:

$\text{EXP}_{\text{inhalation}}$	=	Inhalation exposure to the particulate chemical per day (mg chemical/worker-day)
$Q_{\text{shift_handled}}$	=	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)

¹Worker 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).

		values; must be ≤ 54 kg/worker-shift for this model to be valid)
N_{shifts}^1	=	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))

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

Activity Type	Default $Q_{\text{shift handled}}^2$ (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 Division³. *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.

¹Note 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.

²The 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 $Q_{\text{daily_handled}}$.

³Note: This reference is currently available for viewing in the ChemSTEER Help System.

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.

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*¹. 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:

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

Where:

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

¹Worker 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).

$C_{\text{total_mass}}$	=	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 ($C_{\text{mass_chem}}$) in Equation B-16, to calculate the inhalation exposure to the particulate chemical using the following equation:

$$\text{EXP}_{\text{inhalation}} = C_{\text{chem_mass}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \quad [\text{B-17}]$$

Where:

$\text{EXP}_{\text{inhalation}}$	=	Inhalation exposure to the airborne particulate chemical per day (mg chemical/worker-day)
$C_{\text{chem_mass}}$	=	Mass concentration of the particulate chemical in air (mg/m ³ ; see Equation B-17)
$\text{RATE}_{\text{breathing}}$	=	Typical worker breathing rate (EPA default = 1.25 m ³ /hr)
$\text{TIME}_{\text{exposure}}$	=	Duration of exposure for the activity (EPA default = 8 hours/worker-day ¹)

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.

¹Since 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.

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:

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

Where:

EXP_{dermal}	=	Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)
$AREA_{\text{surface}}$	=	Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm ² ; see Table B-9 for appropriate EPA default values)
$Q_{\text{remain_skin}}$	=	Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm ² -event; see Table B-9 for appropriate EPA default values)
F_{chem}	=	Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
N_{event}^1	=	Frequency of events for the activity (EPA default = 1 event/worker-day)

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.*

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

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.

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} × Q _{remain skin} (mg/event)
Physical Form: Liquids				
<i>EPA/OPPT 1-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> Liquid sampling activities Ladling liquid/bench-scale liquid transfer 	420 (1 hand mean)	Low: 0.7 High: 2.1	Low: 290 High: 880
<i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> Maintenance Manual cleaning of equipment and containers Filling drum with liquid Connecting transfer line 	840 (2 hand mean)	Low: 0.7 High: 2.1	Low: 590 High: 1,800
<i>EPA/OPPT 2-Hand Dermal Immersion in Liquid Model</i>	<ul style="list-style-type: none"> Handling wet surfaces Spray painting 	840 (2 hand mean)	Low: 1.3 High: 10.3	Low: 1,100 High: 8,650
Physical Form: Solids				
<i>EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model</i>	<ul style="list-style-type: none"> Handling bags of solid materials (closed or empty) 	No defaults	No defaults	< 1,100 ^c
<i>EPA/OPPT 2-Hand Dermal Contact with Solids Model</i>	<ul style="list-style-type: none"> Solid sampling activities Filling/dumping containers of powders, flakes, granules Weighing powder/scooping/mixing (i.e., dye weighing) Cleaning solid residues from process equipment Handling wet or dried material in a filtration and drying process 	No defaults	No defaults	< 3,100 ²³

a - These default values were adopted in the 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. Breele, 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.