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**EMISSION SCENARIO DOCUMENT ON RADIATION
CURABLE COATING, INKS AND ADHESIVES**

**OECD Environment, Health and Safety Publications
Series on Emission Scenario Documents Number 27**

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CURABLE COATING, INKS AND ADHESIVES**

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INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

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

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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The Environment, Health and Safety Division publishes free-of-charge documents in ten different series: **Testing and Assessment; Good Laboratory Practice and Compliance Monitoring; Pesticides and Biocides; Risk Management; Harmonisation of Regulatory Oversight in Biotechnology; Safety of Novel Foods and Feeds; Chemical Accidents; Pollutant Release and Transfer Registers; Emission Scenario Documents;** and **Safety of Manufactured Nanomaterials.** More information about the Environment, Health and Safety Programme and EHS publications is available on the OECD's World Wide Web site (www.oecd.org/ehs/).

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

The Inter-Organisation Programme for the Sound Management of Chemicals (IOMC) was established in 1995 following recommendations made by the 1992 UN Conference on Environment and Development to strengthen co-operation and increase international co-ordination in the field of chemical safety. The Participating Organisations are FAO, ILO, UNEP, UNIDO, UNITAR, WHO, World Bank and OECD. UNDP is an observer. The purpose of the IOMC is to promote co-ordination of the policies and activities pursued by the Participating Organisations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.

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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 application 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 Exposure Assessment (TFEA), which will review the comments every two years so that the lead country can update the document. Submitted information will also be made available to users within the OECD web site (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.

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.

The primary sources of information cited in this ESD include RadTech International, a leading trade association for the radiation curable products industry, the U.S. Census Bureau's Economic Census and Current Industrial Reports, 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.

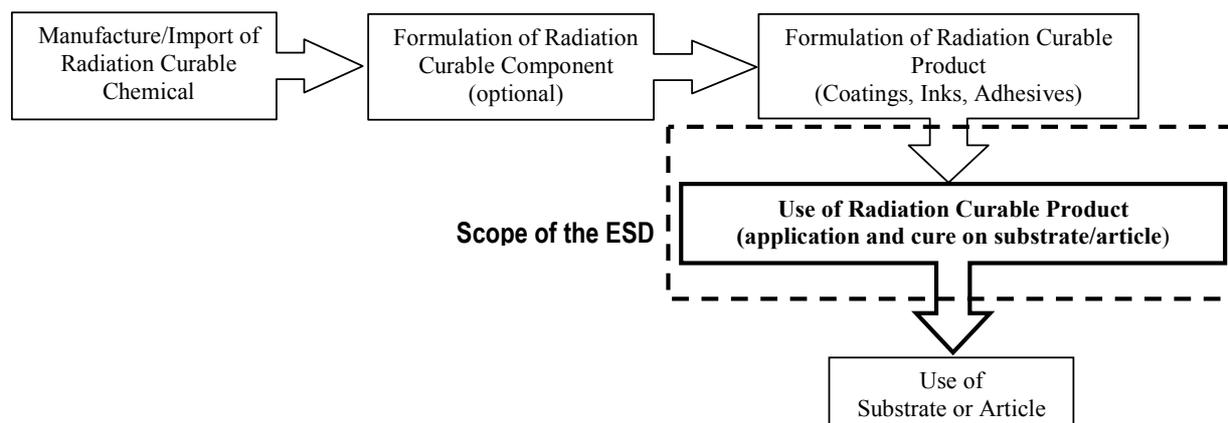
The information in this document is based on U.S. data. Certain aspects of the application process of radiation curable products may differ in other countries; therefore, alternate assumptions and parameters may be necessary in some applications of this emission scenario.

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

Information available for radiation curable products does not differentiate according to the formulated product but distinguishes markets based on the end use of the radiation curable products (APC, 1992). The estimation techniques in this ESD are similar for and therefore, inclusive of all radiation curable coatings, inks, and adhesives. EPA is currently developing a separate ESD on the Use of Adhesives; however, radiation curable adhesives are specifically excluded from the scope of this ESD because they are more appropriately addressed within the context of all radiation curable products.

The ESD covers the application of liquid radiation curable products in a variety of end use markets. Medical and photoresist applications are not covered. Also, since solids and powder formulations represent a small portion of all radiation curable products formulated and the curing processes discussed in this document are mostly applicable to liquid formulations, this document will not cover the application of radiation curable solids or powders. The manufacture or blending of the chemicals into the radiation curable product formulation and the use of the substrate or article coated with the radiation curable product (i.e., end use) are not included in the scope. An illustration of the scope of this ESD within the context of the life cycle of the chemical of interest is provided below.



Note that the formulation and application of radiation curable products are treated separately. This ESD focuses on the application of radiation curable products. The formulation of radiation curable products is discussed in the *Emission Scenario Document on the Formulation of Radiation Curable Coatings, Inks, and Adhesives*, Series on Emission Scenario Documents No. 21 (OECD, 2009).

To estimate environmental releases for the application 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). However, other air releases (e.g., overspray) from process operations may occur.

The methods for estimating the following facility operating parameters and the releases and exposures to chemical used during the application and curing of radiation curable products onto a substrate or an article are discussed in this ESD:

- Number of sites in the United States applying radiation curable formulations containing the chemical of interest onto various substrates and the duration of these activities;
- Releases of volatile chemicals during transfer from the container into the process (storage or mixing vessel);
- Releases during raw material quality sampling;
- Releases from transport container residue (via container cleaning or direct disposal of empty containers);
- Releases during the radiation curable product application process (from spray or mist generation or the application's transfer inefficiencies);
- Releases from equipment cleaning;
- Number of workers that may come into contact with the radiation curable product during the application process;

- Inhalation and dermal exposures during container unloading;
- Inhalation and dermal exposures during raw material quality sampling activities;
- Inhalation and dermal exposures during container cleaning and disposal;
-
- Inhalation and dermal exposures during the application process; and
- Inhalation and dermal exposures during equipment cleaning.

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

EPA, with support from Eastern Research Group, Inc. (ERG), has developed this draft ESD on the application of radiation curable coatings, inks, and adhesives. 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 second part of a set of two ESDs covering the formulation and application of radiation curable coatings, inks, and adhesives. Information on potential environmental releases of and occupational exposures to radiation curable products during formulation can be found in the *Emission Scenario Document on the Formulation of Radiation Curable Coatings, Inks, and Adhesives*, Series on Emission Scenario Documents No. 21 (OECD, 2009).

This ESD supersedes two of EPA's Chemical Engineering Branch (CEB) generic scenarios on the application 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).

A proposal to develop this document as an OECD ESD was approved at the 14th meeting of the Task Force on Environmental Exposure Assessment (TFEEA, to be re-organised to TFEA in 2009) in September 2006. In August 2008, a draft version of this ESD was sent to the TFEEA for review. Comments on the ESD were received from the United Kingdom (UK). Meanwhile in October 2008, industry comments on the draft ESD were received from RadTech. Changes including the description of radiation curable formulation components, curing chemistry, default values for assessing environmental release from overspray, and the potential for releases from equipment cleaning have been made to this version of the ESD to address comments from the UK and RadTech. The final draft ESD was circulated to the TFEA in July 2010 and approved at the final commenting round by the end of January 2011.

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

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Industry Summary and Background

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

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 formulations 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. Other types of oligomers include aliphatic cyclo-epoxies and thiol-ene¹ (RadTech, 2008). UV- and EB-curable formulations may also contain components such as other non-reactive and reactive resins, specialized additives, pigments, and photoinitiators (RadTech, 1995).

Several application methods are used in the radiation curable products industry. Three primary methods discussed in this ESD are spray coating, roll coating, and curtain coating. For three dimensional substrates, spray coating is typically employed. Roll coating and curtain coating methods are used to coat flat substrates.

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).

- **Free Radical Curing** – Free radical curing is predominantly based on formulations that are acrylate-based or thiol-ene-based (RadTech, 2008). UV or EB radiation activates photoinitiators in the formulation that generate free radicals to propagate bulk polymerization and to 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).
- **Cationic Curing** – Cationic UV curing is based predominantly on cycloaliphatic epoxy resins and other epoxy resins, and uses various polyols as reactive monomers and photoinitiators (i.e. “onium” compounds, such as iodonium, sulfonium, phosphonium) for crosslinking. UV radiation activates photoinitiators in the formulation that generate free strong acids to propagate a crosslinking reaction via a ring-opening polymerization mechanism. This mechanism is not subject to oxygen

¹ Aliphatic cyclo-epoxies make up 5-7% and thiol-enes make up 1-2% of the oligomers (RadTech, 2008). Other types of oligomers used in the industry (remaining 6-9%) are not known.

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. The acidic species can also promote corrosion (SpecialChem, 2007). Cationic polymerization accounts for approximately eight percent of the radiation curable products industry (RadTech, 2002).

For both types of polymerization processes, radiation dose affects the degree of cure. Low radiation intensity coupled with longer cure time generally provides a higher degree of cure (more complete cure) than high radiation intensity with short cure time. The degree of cure is an important parameter for end users as it affects the overall characteristics of the end product. A substantial cure of the formulation is typically desired, without over-curing or under-curing, to achieve target characteristics (RadTech, 2008).

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. Line 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).

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).

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 penetrated 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 clear coats on heat-sensitive vinyl sheets (ACS, 1990a).

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).

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 mil)¹.

Market Description

Radiation curable products are a portion of the coatings, inks, and adhesives industries. Table 0-1 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.

Table 0-1. 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

¹ mil = one-thousandth of an inch

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 0-2 presents market data for the radiation curable products industry. Table 1-2 also identifies the North American Industrial Classification System (NAICS) industry sectors associated with each end use market; these industry sectors are used in the facility estimates for applications sites in this document.

In 2005, an estimated 211 million pounds (95.5 million kg) of radiation curable products 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 5-10% of the total radiation curable market (RadTech, 2002). This could be as much as 21 million pounds (9.5 million kg) of EB-curable products produced in the U.S. in 2005.

Table 0-2. 2005 North American Market for Radiation Curable Products by End Use Category

End Use	Production Volume (PV) (million kg)	Radiation Curable Market Share (%) by PV	General End-Use Category (NAICS Industry Sector) ^b
Coatings – Graphic Arts			
Overprint Varnish, Clear – General	22.000	23.0	Paper, Paperboard, Film, and Foil Finishes (NAICS 322221, 322222, 322223, 322226)
Overprint Varnish, Clear - Specialty	3.000	3.1	
Coatings – Wood Finishes			
Fillers	6.100	6.4	Furniture (Wood) (NAICS 337110, 337122, 337211, 321219)
Stains and Sealers	1.150	1.2	
Pigmented Coatings	3.175	3.3	
Clear Finishes	6.600	6.9	Flooring (NAICS 326192, 3219185, 3219187)
Flooring (Prefinished)	2.300	2.4	
Coatings – Plastics			
Vinyl Flooring (Tile & Sheet)	4.500	4.7	Flooring (NAICS 326192, 3219185, 3219187)
Automotive Lens & Reflector	2.000	2.1	Automotive (NAICS 336321, 3363601)
Interior Trim	0.740	0.8	
Flooring (Prefinished)	0.800	0.8	Flooring (NAICS 326192, 3219185, 3219187)
Coatings – Metal Decorating (Can Coating)			
Inks	0.900	0.9	Metal Products and Machinery (NAICS 332431, 332439, 332812, 332996, 3332931)
Overprint Varnishes - Clear	0.875	0.9	
Can End Varnishes	0.425	0.4	
Coatings – Metal, General			
Tubing & Pipe	0.600	0.6	Metal Products and Machinery (NAICS 332431, 332439, 332812, 332996, 3332931)
Name Plates	0.018	0.0	
Wire Coating	0.011	0.0	
Coatings, Miscellaneous			
Optical Fiber - Coating, inks, matrix	3.150	3.3	Optical (NAICS 335921, 3391153, 3391155, 334613)
Printing Plates (Flexographic & Off Set)	7.200	7.5	Metal Products and Machinery (NAICS 332431, 332439, 332812, 332996, 3332931)
Conformal Coatings (Electronics)	0.900	0.9	Electronic Assembly (NAICS 334413, 334418B)

End Use	Production Volume (PV) (million kg)	Radiation Curable Market Share (%) by PV	General End-Use Category (NAICS Industry Sector) ^b
Photoresists ^a	2.000	2.1	NA
Dental Applications ^a	0.021	0.0	NA
Medical Apparatus ^a	0.030	0.0	NA
Miscellaneous			
Stereolithography/Solid Modeling	0.320	0.3	Metal Products and Machinery (NAICS 332431, 332439, 332812, 332996, 3332931)
Inks – Printing			
Off-Set (Lithography)	7.900	8.3	Lithographic Inks (NAICS 323110)
Screen	6.700	7.0	Screen Printing Inks (NAICS 323113)
Flexography	6.000	6.3	Flexographic Inks (NAICS 323112)
Letterpress	0.700	0.7	Letterpress Inks (NAICS 3231193, 3231199, 323119C)
Inkjet	0.350	0.4	Inkjet Inks (NAICS 323114, 323115, 313312)
Adhesives			
Silicone Release Coatings	1.050	1.1	Pressure Sensitive (NAICS 3222226, 3222223, 3222225)
Optical	0.018	0.0	Optical (NAICS 335921, 3391153, 3391155, 334613)
Pressure Sensitive	0.450	0.5	Pressure Sensitive (NAICS 3222226, 3222223, 3222225)
Laminating	3.200	3.3	Laminating (NAICS 322221, 322223, 322225, 3261300)
Electronic Adhesives	0.350	0.4	Electronic Assembly (NAICS 334413, 334418B)
Total	95.533	100.0	

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

^b - These industry sectors are based on NAICS and are used to estimate general facility parameters for each end use. Source: RadTech, 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 products 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;
- 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;
- Elimination of the high costs associated with the handling and disposal of the solvents, or solvent abatement systems;
- Low energy use because heat is not required to cure the coatings, movement of air is not required to drive off water or solvents, and less energy is required to incineration VOC emissions; and
- Reduced greenhouse gas emissions because less fuel must be burned (either to generate electricity or to heat air and the substrate) in the curing process.

PROCESS DESCRIPTION

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

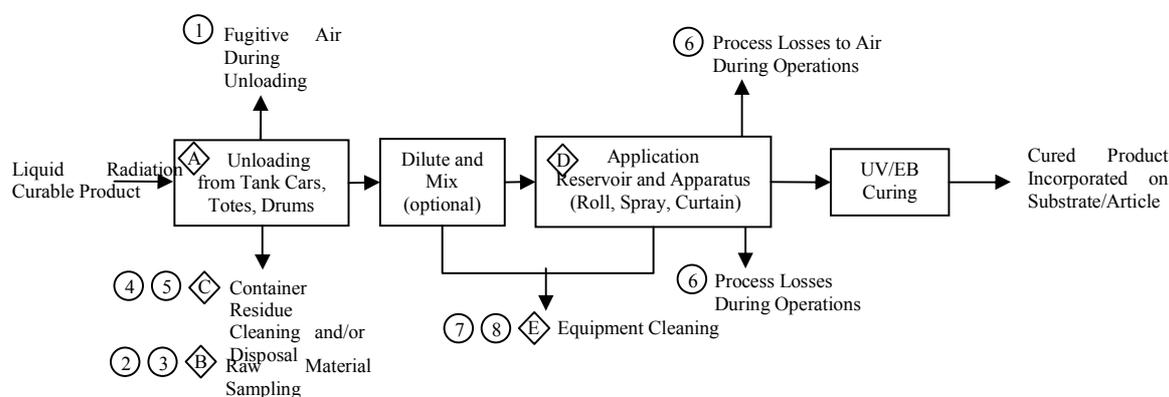
- Section 2.1 presents information on the formulation process;
- Section 2.2 presents an overview on the application process;
- Section 2.3 presents typical formulations of inks, coatings, and adhesives; and
- Section 2.4 presents physical properties of radiation curable chemicals.

Formulation

Radiation curable products are formulated by blending oligomers, monomers, and other functional components in a sealed mixing process. Mixing may occur with or without additional heating. This ESD assumes that the formulation step occurs at a separate site from the application step. Additional information on the formulation of radiation curable products, including methodologies to estimate environmental releases and occupational exposures can be found in the *Emission Scenario Document on the Formulation of Radiation Curable Coatings, Inks, and Adhesives*, Series on Emission Scenario Documents No. 21 (OECD, 2009).

Application

Radiation curable products may be applied using a variety of application techniques including spray, roll, and curtain coating. Figure 0-1 illustrates the general application process for radiation curable products and the associated release sources and worker exposure activities. The releases and exposure associated with each specific application method are discussed in greater detail in the following subsections.



○ = Environmental Releases:

1. Transfer operation losses of volatile chemicals to air from unloading the radiation curable product.
2. Raw material sampling losses to water, incineration, or landfill (not quantified in this ESD).
3. Open surface losses of volatile chemicals to air during raw material sampling.
4. Container residue losses to water, incineration, or landfill from radiation curable product transport containers.
5. Open surface losses of volatile chemicals to air during container cleaning.
6. Process losses to air from vented or captured overspray during spray coating operations. Process losses to water, land, or incineration from disposal of spent coating during roll, spray, or curtain coating.
7. Equipment cleaning losses to incineration or landfill.
8. Open surface losses of volatile chemicals to air during equipment cleaning.

◇ = Occupational Exposures:

- A. Inhalation and dermal exposure to liquid radiation curable product during unloading.
- B. Inhalation and dermal exposure to liquid radiation curable product during sampling activities.
- C. Inhalation and dermal exposure to liquid radiation curable product during container cleaning.
- D. Inhalation and dermal exposure to liquid radiation curable product during coating application.
- E. Inhalation and dermal exposure to liquid radiation curable product during equipment cleaning.

Figure 0-1. General Radiation Curable Application Process

Liquid formulations are typically unloaded from transport containers (e.g., tank trucks, totes, drums) directly into the coating reservoir. 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 0-1 summarizes shipping containers for radiation curable components and products. The radiation curable products are usually supplied using feed lines but may be manually poured in some smaller operations (Release 1, Exposure A) (Schaefer, 1994).

Table 0-1. Shipping Containers for Radiation Curable Components and Products

Type of Material	Type of Containers
Acrylate Raw Materials (e.g. oligomers, monomers, blends, cycloaliphatic epoxy resins, polyols)	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

Source: RadTech, 2007.

Quality assurance samples may be drawn from the liquid formulations prior to use in the application process. Dilutions or additions to the formulation may be made; however, the received formulation is typically used as received (RadTech, 2007). Although no industry-specific data were found regarding raw material sampling practices for radiation curable applicators, it is generally assumed that some amount of raw material quality assurance/quality control (QA/QC) sampling is performed as part of the application process (engineering judgment). Releases and associate exposures are expected to occur as a result of sampling activities (Release 2, Release 3, Exposure B).

Industry-specific information was provided on residuals in transport containers. Container residual losses are typically minimized by leaving the empty container in an inverted position to drain and recover as much residual as possible (RadTech, 2007). Containers are neutralized with alkaline soapy water wash treatments and rinsed with water and are disposed to water, incineration, or landfill (RadTech, 1995; RadTech, 2007). While transport containers may be cleaned off site by a third party, this ESD assumes that the container residues are disposed by the receiving application facility, either by being rinsed from the container or the empty container being discarded directly into an off-site landfill (Release 4, Release 5, Exposure C).

The application process is typically a continuous process and involves applying the coating to a flat or three-dimensional substrate and exposing the substrate to radiation. Once curing takes place, the chemical of interest is incorporated onto the substrate or article and is no longer a concern for release or exposure. Many methods are used to apply coatings. Each method has a working viscosity range that will produce a quality cure. Table 0-2 lists examples of coating methods used in the radiation curable products industry. Three coating applications represent the majority of the radiation curable products industry and are discussed in this ESD: spray coating, roll coating, and curtain coating (RadTech, 2007; RadTech 1995).

Table 0-2. Application Methods in the Radiation curable products industry

Examples of Application Methods	
Air-knife or Rigid-knife	Roll Coating
Metering Rod (Mayer rod)	Vacuum Coating
Puddle (Flexible-knife)	Flexographic Printing
Electrostatic Spray	Gravure Printing
Curtain Coating	Letterpress
Flow Coating	Lithographic Printing
Spray Coating	News Ink Printing
Dip Coating	Screen Printing

Source: RadTech, 1995.

Spray Coating

Figure 0-2 illustrates a spray coating process. This application method is commonly used for irregularly-shaped objects (e.g., metal cans, furniture, and car parts) that cannot be coated using roll or curtain coating methods. Transfer efficiencies for spray coating applications range from 20 to 90 percent

and is dependent on the type of spray gun used (P2Pays, 1997; CEB, 1996). Automated or totally enclosed spray systems are typical for a major portion of the industry; however, some facilities may still use hand-held spray guns to manually apply liquid formulations. The ESD assumes releases to water, air, incineration, or landfill (Release 6) for spray applications (CEB, 1996).

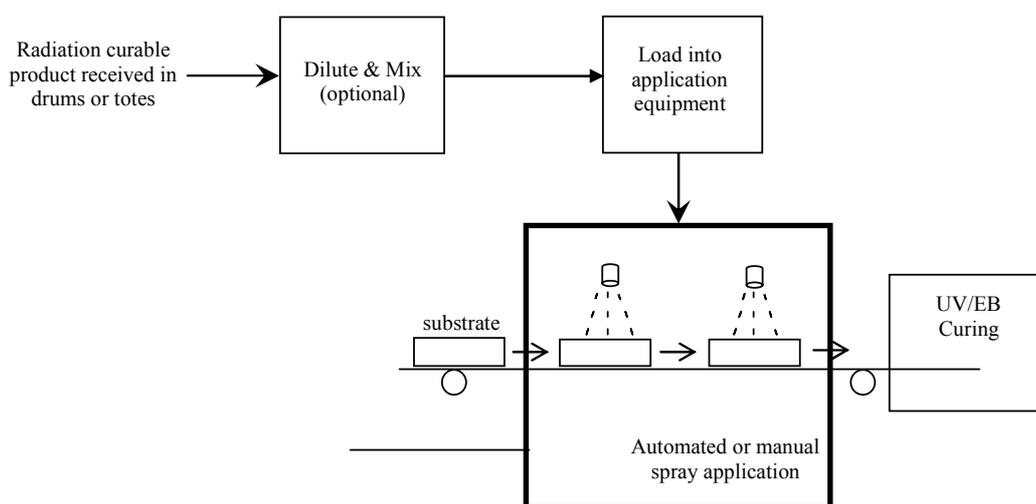


Figure 0-2. Spray Coating Application Process

In the coating process, the formulation is loaded into a pressurized vessel and pumped through the spray gun using compressed air. Overspray is generated during application. Spray coating operations typically occur in spray booths or totally enclosed cabinets, as radiation curable coatings may be sensitive to ambient conditions (Release 6, Exposure D).

The quality of the finish generally improves as the size of spray particles is reduced. Unfortunately, as the size of spray particles decreases, transfer efficiency also decreases and overspray increases. Some of the finest particle sizes are achieved with conventional LVHP air spray; however, this is the least efficient means of applying paint (P2Pays, no date).

Roll Coating

Roll coaters have two main methods of application, direct roll and reverse roll (RadTech, 1995; EPA, 1992). In direct roll-coating, the substrate is fed between two rollers and is coated using an applicator roll rotating in the same direction (FSCT, 1988). Reverse roll-coating can be used to coat less rigid materials such as sheet metal or paper. In this process, the applicator roll runs in a direction opposite the feedstock, which is fed directly from a coil of uncoated material. This coating method is the faster and more economical than direct roll-coating. Figure 0-3 illustrates a simple direct roll coating system. Note that while Figure 2-3 only contains one roller, most roll coaters contain multiple rollers including a pick-up roller to transfer the coating from the reservoir to the supply roller, a supply roller to transfer the coating from the pick-up roller to the application roller, and an applicator roll to apply the coating to the substrate (FSCT, 1988). Other forms of roll coating include knife-over roll coating, kiss-roll coating, squeeze-roll coating, and engrave-roll coating. Coatings can be applied to both sides of a flat

substrate during one pass if an additional set of applicator rolls is used. Roll coating can generate mist and splatter from the high line speeds associated with the process (Exposure D).

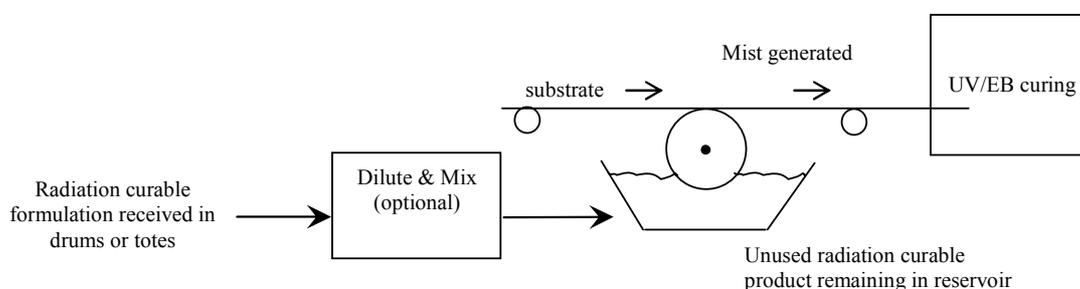


Figure 0-3. Simple Direct Roll Coating Application Process

Roll coating is very similar to printing in that an elastomeric-covered steel roller is used to transfer the coating to a flat substrate moving past the roller (FSCT, 1988). Coating thickness of 5 to 13 μm (0.2 to 0.5 mil¹) can be obtained using this method. The coating thickness is determined as the minimum thickness necessary to obtain a continuous film on the substrate (Mahon, no date). One gallon of UV coating covers approximately 4,000 square feet using roll coating, compared with 1,500 to 1,800 square feet per gallon for solvent-based paints (RadTech, 2000).

New coating material is supplied to the feed trough only when required to maintain a continuous coating process. Excess coating material not adhering to the feedstock is redirected to the feed trough for recycling. The transfer efficiency of coating to substrate ranges from 90 to 98 percent (P2Pays, 1997). After a run is completed, unused coating in the reservoir may be collected for disposal. Limited information was found on the disposal of unused coating. The ESD assumes disposal to incineration or landfill (Release 6). This ESD assumes that the feed trough is disposed and recharged with new coating material daily as a conservative estimate.

Curtain Coating

Curtain coating derives its name from the fact that a sheet of liquid is formed at a die and allowed to fall freely to a substrate passing underneath (Converting Magazine, 2002). Figure 0-4 illustrates a typical curtain coating system.

¹ mil = one thousandth of an inch

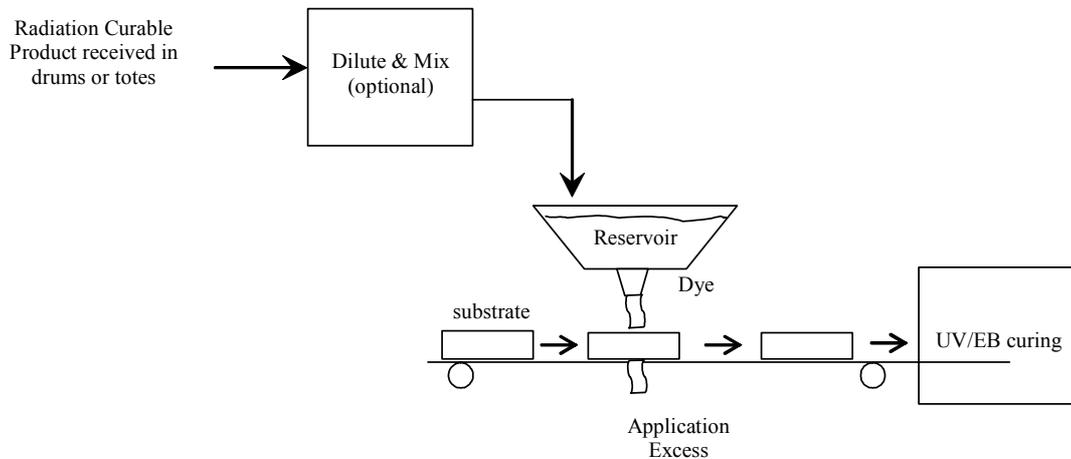


Figure 0-4. Curtain Coating Application Process

Curtain coating requires low viscosity formulations that are clear or have low filler concentrations (RadTech, 1995). The curtain is formed by the coating fluid issued from a precision die, typically from a height of 10-30 cm above the substrate. The edges of the curtain are pinned to prevent “necking” or narrowing of the curtain near the substrate. The coating solution wets and spreads on the substrate through a combination of surface energy and the momentum of the falling liquid (Converting Magazine, 2002). No mists and corresponding occupational exposures are expected from this coating operation. Figure 0-5 shows the general flow of the liquid as it exits the precision die and contacts the substrate.

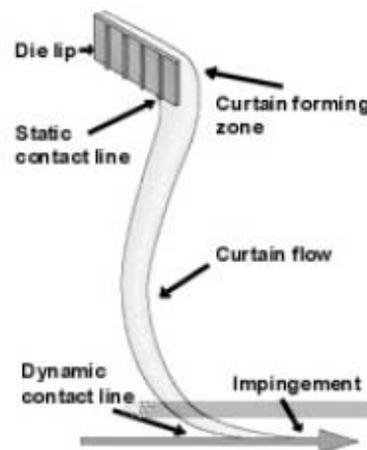


Figure 0-5. Curtain Flow during Coating Process

Source: Converting Magazine, 2002.

The transfer efficiency of coating to substrate also ranges from 90 to 98 percent for curtain coating methods and fits well with higher film builds and finishing flat stock (P2Pays, 1997). Excess coating material that did not adhere to the substrate may be collected and recycled to the feed reservoir.

Limited information was found on the disposal of spent coating material. EPA assumes disposal to incineration or landfill (Release 6). This ESD assumes that the feed trough is disposed and recharged with new coating material daily as a conservative estimate.

Curing

Once the formulation is applied, the coated substrate is transported to the UV or EB unit for curing. Curing typically occurs immediately after the application process and employs UV or EB radiation to initiate polymerization. Free-radical polymerization is the most common crosslinking mechanism; although, cationic polymerization may be utilized. Curing substantially converts the liquid formulation to a polymeric matrix on the substrate or into an article, which results in no further releases or exposures.

In UV curing, the cure speed is on the order of a few seconds, but is limited to line-of-sight curing. Production rates are slower than with EB curing technologies. Figure 0-6 shows a mercury vapor UV curing unit. A 400-watt/inch UV lamp can cure clear liquid formulations on plastic at a rate of 300 ft/min, on metal at 200 ft/min, and on wood at 25 ft/min (RadTech, 1999). The rate of reaction is affected by the light intensity, type of photoinitiator, and type and concentration of reactive monomers. A medium pressure mercury lamp is the most common source of UV radiation. Roll or web products are ideal configurations for UV curing, but intricate shapes are difficult to cure by UV (RadTech, no date).

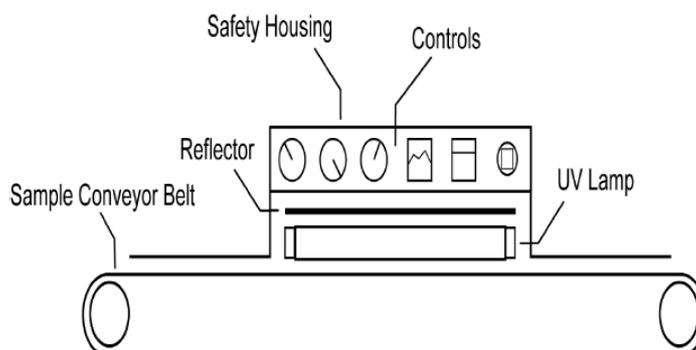


Figure 0-6. Mercury Vapor UV Curing Unit

Source: Schrantz, 1992

EB curing is a more rapid process that occurs within fractions of a second (ACS, 1990a). The polymerization is carried out in a nitrogen atmosphere to prevent oxygen from inhibiting the reaction. EB curing stations must be properly shielded to protect workers from ionizing radiation products (RadTech, 1992). Figure 0-7 shows an EB-curing unit used for commercial printing. Potentials in the range of 150,000 to 300,000 volts are typically used. Well-designed EB-curing units transform approximately 90 percent of the incoming kilowatts of line power to electron beam energy (ACS, 1990b; Berejka, 1992).

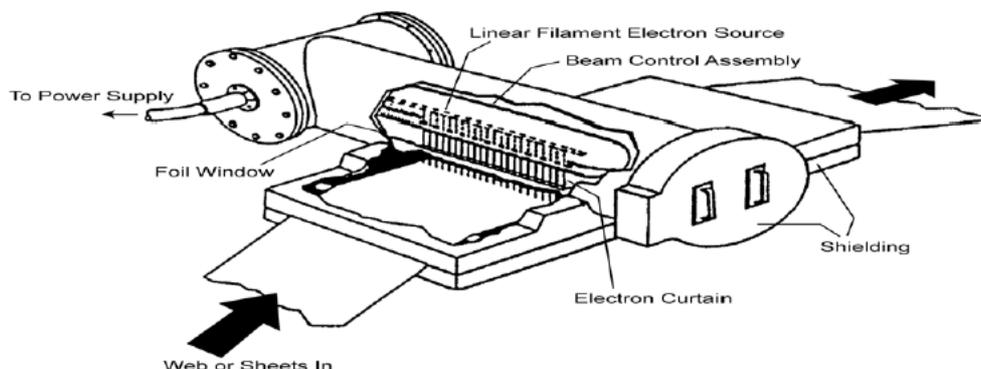


Figure 0-7. Linear Filament Electron Beam Printing Installation

Equipment Cleaning

Limited information was found regarding standard equipment cleaning practices within the radiation curable products industry. Equipment is typically cleaned with the organic solvents followed by soapy water wastes and water rinses (RadTech, 1995). The application process equipment is expected to be routinely cleaned and the residues disposed to incineration or landfill (RadTech, 2007). Since UV and EB formulations generally do not depend on solvents or water to prevent drying out, and cure only if exposed to UV or EB radiation, they may allow greater flexibility in cleaning schedules and may require less aggressive cleaning measures (RadTech, 2008). While some facilities may clean process equipment after a campaign, this ESD assumes that the residues are removed daily as a conservative estimate (Release 7, Release 8, Exposure E).

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 0-3 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 2-4 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 2-4 only covers additives and specifically excludes base resins.

Table 0-3. Formulation Compositions of Radiation Curable Products

Component	Concentration (%)		
	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 ^a	-	1-20	-
Photoinitiator	0-4	0-10	0-4

Source: RadTech, 2007.

a – Pigment concentrations are not available in this source for coatings and adhesives. See Table 2-3 for alternative concentrations.

Formulators measure the composition of components in parts per hundred parts of resin (PHR) as presented in

Table 0-4. In practice, the difference between PHR and weight fractions can significantly change the properties in the final formulation (RadTech, 1995). To determine the weight percentage of the component in formulation, this ESD conservatively assumes that the density of a formulation is 1.0 kilogram per liter and that the conversion of PHR to weight percentage is 1:1. The estimated weight percentage will always be a more conservative estimate of the formulation composition since the density of a formulation is typically 1.0 kilogram per liter or greater and therefore, the ratio of PHR to weight percentage is greater than 1:1. Note that some component types are not used in every radiation curable formulation.

Table 0-4. Summary of Formulation Compositions of Radiation Curable Products

Component	Parts per Hundred Parts (PHR)	Estimated Weight Percent % (kg component per 100 kg formulation)	Function
Oligomers			
Hard resins, such as epoxy acrylates	0-100	0-100%	Results in stiff, hard, low extension cured polymeric matrix
Soft resins, such as urethane acrylates	0-100	0-100%	Results in flexible, soft, high extension cured polymeric matrix
Blend of hard/soft oligomers	5/95-95/5	5/95-95/5%	Intermediate
All low molecular weight	0-100	0-100%	Results in stiff, brittle, low extension cured polymeric matrix
All high molecular weight	0-100	0-100%	Results in flexible, more extension cured polymeric matrix
Monofunctional	0-3	0-3%	Results in softer cured polymeric matrix
Difunctional	100-90	100-90%	Most are difunctional
Multifunctional	0-10	0-10%	Results in hard, stiff, low extension cured polymeric matrix
Monomers			
Single double bond	0-80	0-80%	Lower viscosity
Multiple double bonds	0-45	0-45%	Increase crosslink density, stiff tough
Mixed functionality	0-10	0-10%	Adhesion, modify properties
Other resins			
Nonreactive	0-15	0-15%	Plasticize
Reactive	0-15	0-15%	Adhesion, modify properties
Photoinitiator			
Free radical	0.25-5	0.25-5%	Cure speed, shelf life
Cationic type	2-5	2-5%	Cure speed, shelf life
Photosensitizer	0-5	0-5%	Cure speed, shelf life
Chain transfer	0-0.5	0-0.5%	Controls MW
Stabilizer			
For raw materials	0.002-0.02	0.002-0.02%	Shelf life
For formulation	As required	As required	Inhibits pre-cure
Light stabilizer	As required	As required	Color change, properties
Heat, hydrolytic, etc.	As required	As required	Prevent property loss
Antioxidants	As required	As required	Inhibit oxidation
Surfactants			
Dispersants	0-1	0-1%	Disperse pigments and fillers
Flow Modifiers	0-5	0-5%	Flow out leveling
Emulsifiers	0-1	0-1%	Disperse oligomers in water, monomers
Defoamers	0-0.15	0-0.15%	Reduce foam, air bubbles
Other	0-1	0-1%	Wetting, prevent phase separation
Pigments, fillers, flattening agents	0-45	0-45%	Viscosity, color, cure
Dyes	0-5	0-5%	Color cure

Component	Parts per Hundred Parts (PHR)	Estimated Weight Percent % (kg component per 100 kg formulation)	Function
Adhesion promoter	0-5	0-5%	Adhesion
Coupling agents	0-0.5	0-0.5%	Adhesion, aid in pigment binding
Viscosity stabilizer	0-1	0-1%	Viscosity
Dual cure additive	0-3	0-3%	Shelf life, second cure

Source: RadTech, 1995.

Note: The reactive components (oligomers, monomers, and photoinitiators) differ for cationic formulations and free radical formulations. However, there is insufficient information in the reference source to differentiate the oligomer and monomer compositions between these types of formulations.

Physical Properties of Radiation Curable Chemicals

Table 0-5 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 0-5 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 0-5);
- Physical property data were found to be relatively consistent among multiple sources; and
- A complete "set" of Table 0-5 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 0-5. 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	Free Radical Formulation: urethane acrylates; epoxy acrylates; polyester acrylates; silicone acrylates Cationic Formulation: 3,4- epoxy cyclohexyl methyl-3,4 epoxy cyclohexane carboxylate	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. Radiation curable polymers are generally expected to be of high, variable molecular weight and have a negligible vapor pressure. 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. Free radical formulations are generally based on acrylates while cationic formulations are based on cycloaliphatic epoxy and epoxy resins.						
Monofunctional Monomer	Free Radical Formulation (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)
	Free Radical Formulation (multifunctional monomer): 2-Propenoic acid, 2-ethyl-2-[[[(1-oxo-2-propenyl)oxy]methyl]-1,3-propanediyl ester (CAS# 15625-89-5)	NA	296.32 ^(e)	NA	>200 ^(f)	-66 ^(f)	NA	1.10 ^(e)
Multifunctional Monomer	Cationic Formulation: Trimethylolpropane oxetane (CAS# 3047-32-3)	Liquid ^(g)	NA	0.02 (at 20°C) _(g)	84 ^(g)	<0 ^(g)	NA	1.02 ^(g)
Photoinitiator Photosensitizer	Free Radical Formulation: 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)

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}
	Cationic Formulation: Salts of aryldiazonium, triarylsulfonium, and diaryliodonium	NA	NA	NA	NA	NA	NA	NA
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
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

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}
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.

e – Source: ChemLink, 2010.

f – Source: LookChem, 2008.

g – Source: Perstorp, 2008.

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

This ESD presents EPA's standard approach for estimating environmental releases of and worker exposures to components in radiation curable products during the application and curing of the product onto an article or substrate.

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 8 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 application sites, which estimate daily use rates of radiation curable products, the number of application sites using the chemical of interest, and the number of days the chemical is expected to be used in the application process.

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

Section 5 of the ESD presents the occupational exposure assessments of several application methods, 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.

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 daily use rate of the chemical of interest for an application site. The daily use rate can be estimated using several facility parameters, including the annual facility production use rate ($Q_{app_site_yr}$); the number of application sites that may use a particular product containing the chemical of interest (N_{app_sites}); and the days of operation ($TIME_{app_working_days}$). Industry provided 2005 production data for coatings, inks, and adhesives (see Table 1-2). Additional information on the number of application sites was obtained from the Economic Census data (USCB, 2004).

Combined with available formulation data presented in Table 2-3, market production data and census data can be used to calculate the annual facility production use rate and daily use rate of the chemical of interest. The number of shipping containers that are transferred into the operation annually can also be 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.

Parameter	Description	ESD Section
$Q_{app_site_yr}$	Annual facility use rate of formulations containing the chemical of interest (kg formulation/site-yr)	3.2
F_{chem_comp}	Mass fraction of the chemical of interest in the radiation curable component (kg chemical/kg component)	3.3
F_{comp_form}	Mass fraction of the component used in the formulated radiation curable product (kg component/kg product)	3.4
F_{chem_form}	Mass fraction of the chemical of interest in the radiation curable product (kg chemical/kg product)	3.5
N_{app_sites}	Number of facilities using the chemical of interest in application processes (sites)	3.6
$TIME_{app_working_days}$	Annual number of days the formulation product is applied at each facility (days/yr)	3.7
$Q_{app_chem_site_day}$	Daily use rate for the chemical of interest at each facility (kg of chemical/site-day)	3.8
$N_{form_cont_empty_site_yr}$	Annual number of chemical-containing radiation curable product containers emptied per facility (container/site-yr).	3.9

Table 0-1. Summary of General Facility Parameters for Application Sites

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.

Annual Facility Radiation Curable Product Use Rate ($Q_{app_site_yr}$)

Annual facility use rates are estimated using available 2005 production rates for the radiation curable products industry and the number of application sites found to date. Application sites are determined by end-use markets. Table 3-2 summarizes the radiation curable products industry use rate for each type of end-use market. Appendix C presents the general methodology used to derive the annual facility use rates shown in Table 3-2 based on a “top-down” approach (e.g., national use rate data divided by the number of sites). The approach references available data sources for production and facility information and identifies general assumptions and limitations in the derived facility use rates. The recommended default value for the annual facility use rate ($Q_{app_site_use_rate}$) depends on the type of radiation curable product (i.e., coatings, inks, or adhesives) and the end-use market. Figure 3-1 presents a logic diagram that can be used to determine the appropriate defaults.

The 1994 generic scenarios for roll-coating of UV and EB curable coatings estimated an annual facility use rate of 140,000 kg product/site-yr based on an audit of five roll coating facilities. This “bottom-up” approach, which is presented in Appendix C, assumed several facility parameters, was non-specific, and applied across all industries (CEB, 1994a; CEB, 1994b). The annual facility use rates estimated in Table 3-2 may be more or less conservative for estimating the releases and exposures for the site. If the operation parameters are comparable to the assumptions made in this alternative approach, the facility use rate of 140,000 kg product/site-yr may be an appropriate estimate for roll coating application sites. If the operation parameters are available for facilities using other application methods, this “bottom-up” approach may be used to determine the facility use rate, as discussed in Appendix C.

Table 0-2. Annual Facility Production Rate of Radiation Curable Products for Application Sites

End Use Markets	Total U.S. Radiation Curable Production Volume (million kg/yr)^a	Annual Facility Product Use Rate ($Q_{\text{app site use rate}}$) (kg/site-yr)^b
Automotive (Default for Coatings)	2.74	137,000
Optical	3.17	29,083
Furniture (Wood)	19.33	12,684
Flooring	5.30	265,000
Metal Products and Machinery	10.35	34,158
Paper, Paperboard, Film, and Foil Finishes	25	70,822
Letterpress Inks	0.70	233,333
Screen Printing Inks	6.70	2,694
Lithographic Inks (Default for Inks)	7.90	24,085
Flexographic Inks	6.00	157,895
Inkjet Inks	0.35	18,421
Laminating Adhesives (Default for Adhesives)	3.20	457,143
Pressure Sensitive Adhesives	1.50	1,500,000
Electronic Adhesives	1.25	21,930

a – Total U.S. production volumes on radiation curable coatings were previously discussed and summarized in Tables 1-2.

b – See Appendix C for the source of these estimates. Please note that these values are based on several key assumptions, as discussed in Appendix C. It should also be noted that no facility-specific production rates were found; therefore, no ranges in the production rates are available to demonstrate their variability.

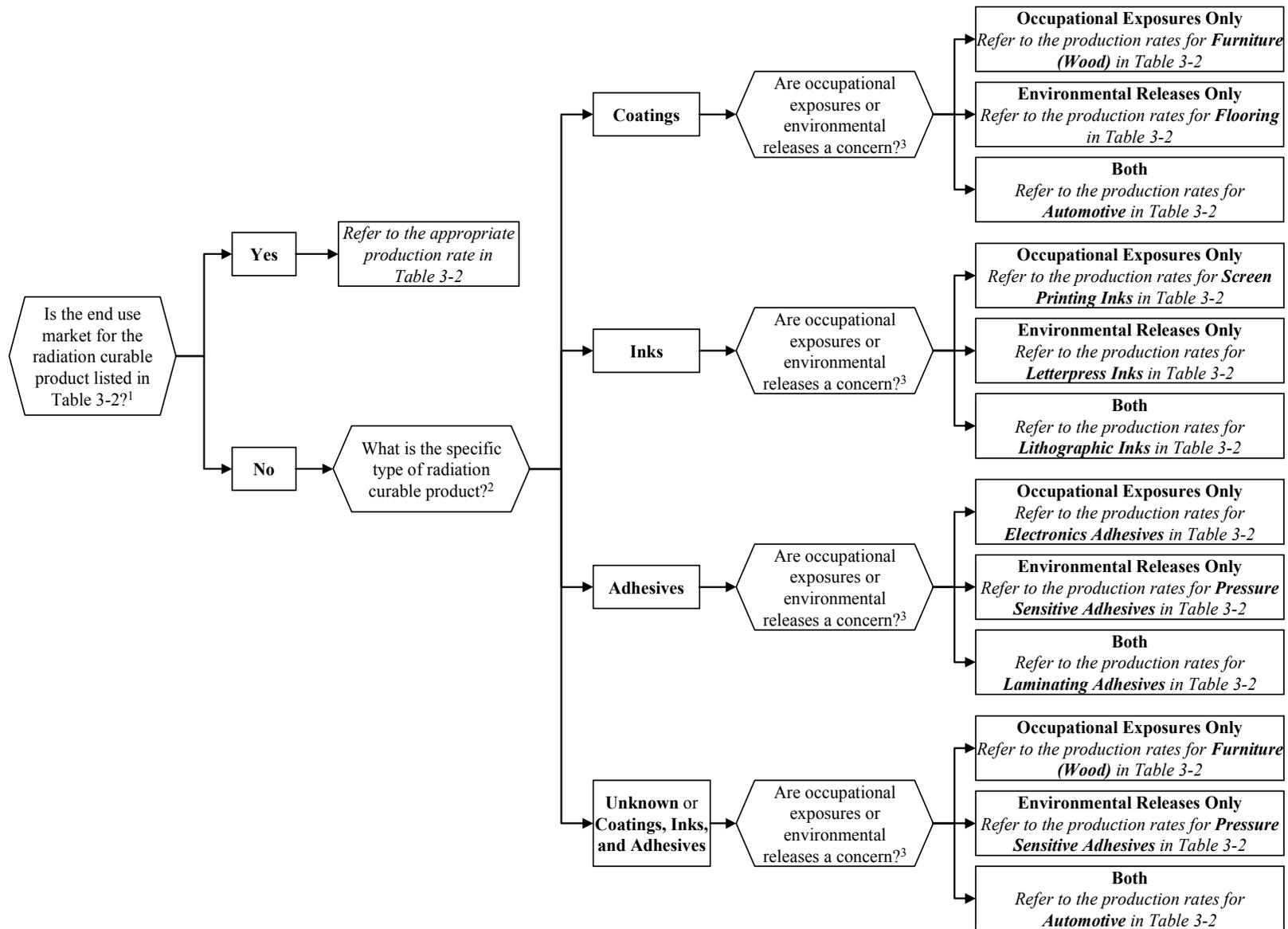


Figure 0-1. Logic Diagram to Determine Appropriate Defaults for Assessments

Footnotes to Figure 3-1

- 1) If the specific end use market (e.g., automotive, optical) for the radiation curable product is listed in Table 3-2, the appropriate annual facility use rate should be utilized. However, if the specific end use market is unknown, then the type of radiation curable product (e.g., coatings, inks, adhesives) should be considered when selecting the appropriate default for the annual facility use rate.
- 2) If the specific type of radiation curable product (e.g., coatings, inks, adhesives) is known, but the end use market is unknown, data specific for coatings, inks, or adhesives should be utilized. If the type of radiation curable product is unknown, or if the chemical of interest could be used in multiple products (i.e., coatings, inks, and adhesives), utilize the methodology for “unknown”.
- 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, median values are typically utilized. This methodology was utilized to select the defaults in Figure 3-1, with one exception. For occupational exposure concerns only for the “unknown” radiation curable product type, “Furniture (Wood) Coatings” was selected even though “Screen Printing Inks” has the lowest annual facility use rate. Furniture coatings are typically spray applied, resulting in a greater exposure dose than roll application used for screen printing inks.

In lieu of site-specific information, it is assumed that the chemical of interest is in all radiation curable products used at an application site ($F_{app_radcur} = 1$ kg product incorporating chemical/kg total product applied). The following calculation may be used to determine the annual facility production rate for the radiation curable product containing the chemical of interest ($Q_{app_site_yr}$):

$$Q_{app_site_yr} = Q_{app_site_use_rate} \times F_{app_radcur} \quad (3-1)$$

Where:

$Q_{app_site_yr}$	=	Annual facility radiation curable product use rate containing the chemical of interest (kg product used/site-yr)
$Q_{app_site_use_rate}$	=	Total annual facility radiation curable product use rate (kg/site-yr) (See Figure 3-1 for default production use rates.)
F_{app_radcur}	=	Fraction of the total radiation curable product type used that contains the chemical of interest (Default: 1 kg material containing the chemical/kg total product used)

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

The chemical of interest may only be a fraction of the radiation curable product component (e.g., oligomers, monomers, stabilizers, pigments). 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:

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

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

Available data for the general composition of a radiation curable formulation are presented in Tables 2-3 and 2-4. If the component type containing the chemical of interest is known, the mass fraction of the component in the formulated product may be estimated using the data presented in these tables. 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 2-3, as a default. If a range in concentration is presented, EPA suggests using the upper bound concentration¹.

$$F_{comp_form} = \text{Mass fraction of the component used in the formulated radiation curable product (Default: 0.7 kg component/kg material for an oligomer. See Tables 2-3 and 2-4 for alternative fractions, as appropriate.)}$$

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 of workers will be minimized).

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 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, see Section 3.3)
$F_{\text{comp_form}}$	=	Mass fraction of the component used in the formulated radiation curable product (Default: 0.7 kg component/kg material for an oligomer. See Tables 2-3 and 2-4 for alternative fractions, as appropriate.) (See Section 3.4)

Number of Application Sites ($N_{\text{app_sites}}$)

The following calculation combines the annual use volume of radiation curable formulations for applicators ($Q_{\text{app_site_yr}}$) and the fraction of the chemical of interest in the radiation curable material ($F_{\text{chem_form}}$) to estimate the number of applicator sites expected to utilize the amount of chemical of interest:

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

Where:

$N_{\text{app_sites}}^1$	=	Number of applicators using the formulation containing the chemical of interest (sites)
$Q_{\text{chem_yr}}$	=	Annual production volume of the chemical of interest (kg chemical/yr)
$Q_{\text{app_site_yr}}$	=	Annual facility radiation curable product use rate (kg product/site-yr) (See Section 3.2)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (kg chemical/kg product) (See Section 3.5)

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

$$Q_{\text{app_site_yr}} = \frac{Q_{\text{chem_yr}}}{N_{\text{app_sites}} \times F_{\text{chem_form}}}$$

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

The number of sites that apply the formulation onto substrates is estimated based on the total amount of the chemical-containing component produced (kg/yr) and the annual facility use rate of the radiation curable product (kg/site-yr). The maximum number of sites should not exceed the total number of sites listed in Table 3-2 for each end-use market, per U.S. Census data (USCB, 2004).

Days of Operation ($TIME_{app_working_days}$)

Typical application methods for radiation curable products employ a continuous process. 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 holidays and an operating schedule of 50 weeks per year.

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

The daily use rate of the chemical of interest during application of radiation curable products onto various substrates is estimated using the following equation, based on the annual product use volume, the concentration of the chemical of interest, and the number of operating days.

$$Q_{app_chem_site_day} = \frac{Q_{app_site_yr} \times F_{chem_form}}{TIME_{app_working_days}} \quad (3-4)$$

Where:

$Q_{app_chem_site_day}$	=	Daily use rate of the chemical of interest contained in formulations to apply onto substrate (kg chemical used/site-day)
$Q_{app_site_yr}$	=	Annual use volume of radiation curable products containing the chemical per site (kg product used/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)
$TIME_{app_working_days}$	=	Annual number of days the radiation curable product is applied (days/yr) (Default: 250 days/yr, See Section 3.7)

Annual Number of Radiation Curable Product Containers Emptied per Facility

The number of radiation curable product 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 formulation (F_{chem_form}). EPA suggests that a default transportation container size of a 55-gallon drum could be used in the absence of site-specific information. Industry-specific data suggests that radiation curable formulations are typically stored in drums, which is consistent with EPA's assumptions (RadTech, 2007). Engineering judgment should be used to determine if another container type or size is more appropriate. If the density of a liquid formulation is not known, the density for water can be used as a default (1 kg/L).

$$N_{form_cont_empty_site_yr} = \frac{Q_{app_chem_site_day} \times TIME_{app_working_days}}{F_{chem_form} \times Q_{cont_empty}} \quad (3-5)$$

Where:

$N_{form_cont_empty_site_yr}$	=	Annual number of containers emptied containing chemical of interest per site (containers/site-yr)
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$Q_{app_chem_site_day}$	=	Daily use rate of the chemical of interest used in formulation to apply the radiation curable product onto substrate (kg chemical/site-day) (See Equation 3-4)
$TIME_{app_working_days}$	=	Annual number of days the radiation curable product is applied (Default: 250 days/yr) (See Section 3.7)
F_{chem_form}	=	Mass fraction of the chemical of interest in the radiation curable product (kg chemical/kg product) (See Section 3.5)
$Q_{cont_empty}^1$	=	Mass of the radiation curable formulation in the container (kg product/container)

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

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

Where:

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

ENVIRONMENTAL RELEASE ASSESSMENTS FOR THE APPLICATION OF RADIATION CURABLE PRODUCTS

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

The methodology presented in this section for estimating the releases of the chemical of interest from the application 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 are appropriate for conservative, screening-level assessments and 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 radiation curing application sites using the chemical of interest (N_{app_sites}) (See Equation 3-3).

Some of the 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.

Many of the environmental release estimates presented in this document are based on standard EPA release models, with the exception of the methodology described in Section 4.8 for estimating the amount of the chemical of interest released from the application process. This release estimate is based on a transfer efficiency of the application method used. 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 0-1. Summary of Radiation Curable Application 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	Raw material sampling losses to non-air media	No methodology for quantifying the release from this source has been developed	
3	Open surface losses of volatile chemical to air during raw material sampling	EPA/OPPT Penetration Model	✓
4	Container residue losses to non-air media	Specific model used is based on the type and size of the containers, and on the physical state of the formulation: <ul style="list-style-type: none"> • EPA/OPPT Bulk Transport Residual Model • EPA/OPPT Drum Residual Model • EPA/OPPT Small Container Residual Model 	✓
5	Open surface losses of volatile chemical to air during container cleaning	EPA/OPPT Penetration Model	✓
6	Process releases during operations	Specific model used is based on the application method selected: <ul style="list-style-type: none"> • EPA/OPPT Automobile OEM Overspray Loss Model • EPA/OPPT Automobile Refinish Spray Overspray Loss Model • EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations 	✓
7	Equipment cleaning losses to non-air media	EPA/OPPT Multiple Process Vessel Residual Model	✓
8	Open surface losses of volatile chemical to air during equipment cleaning	EPA/OPPT Penetration Model	✓

Control Technologies

Industry-specific information indicates that less than one percent of all waste generated at radiation curable product application 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 will likely collect and dispose of liquid and solid process wastes in hazardous waste incinerators or landfills (RadTech, 2007). 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.

According to RadTech, spraying operations typically occur in spray booths or totally enclosed cabinets. In flat-line applications (i.e., roll and curtain coating), canopy hoods are often used to minimize acrylate odor and remove mist generated during application (RadTech, 1995). Additional information on the specific type of mist capture devices (e.g., water curtain, dry filter) was not available.

Transfer operations Losses to Air from Unloading the Radiation Curable Formulation (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 ($E_{local_{app_air_transfers}}$). 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 0-2. 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 $N_{\text{form_cont_empty_site_yr}}$ or $\text{TIME}_{\text{app_working_days}}$, See Sections 3.7 and 3.9.
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 4.5) 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) (consistent with Section 3.9)
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

Raw Material Sampling Wastes Disposed to Water, Incineration or Landfill (Release 2)

EPA generally assumes raw material sampling activities occur at application sites 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). If additional site-specific information is not available, the entirety of this release is conservatively assessed to all three media. 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 raw material sampling activities to be relatively low in comparison to the other sources of release in the application process.

Open Surface Losses to Air During Raw Material Sampling (Release 3)

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 QA/QC sampling activities ($E_{\text{local_app_air_sample}}$). 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 sampling activities to be relatively low in comparison to the other sources of release in the process; however, this release estimate is required to calculate a vapor generation rate to estimate the corresponding inhalation exposure to vapors for volatile chemicals.

The model inputs and default values are listed in Table 4-3. 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 0-3. EPA/OPPT Penetration Model Parameter Default Values During Raw Material 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 _{app} 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	Standard EPA default of 298 K (CEB, 1991)
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.

Radiation Curable Formulation Container Residue Released to Water, Incineration, or Landfill (Release 4)

Radiation curable coatings and adhesives may be received in tank trucks (only for the highest volume products), totes, drums, pails, and smaller containers, and radiation curable inks may be received in pails and smaller containers (RadTech, 2007). EPA suggests that a default transportation container size of a 55-gallon drum should be used in the absence of site-specific information.

Radiation curable formulations are most commonly received as liquids. This ESD does not cover the application of powder formulations. The amount of radiation curable formulation remaining in transportation containers depends on the size of the transport container. In the absence of industry-specific data, 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

Industry-specific information indicates that approximately 1 percent of the raw material received may be lost as container residue (RadTech, 2007). Note that the EPA models estimate between 0.2 (bulk containers) and 3 percent (drums) of the received product may be released to the environment, which is consistent with industry estimates. The rationale, defaults, and limitations of the EPA 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.

Container cleaning may involve an organic and water wash, which could be released to water, incineration, or landfill (RadTech, 1995). If additional site-specific information is not available, the entirety of this release is conservatively assessed to all three media. The annual number of containers emptied ($N_{\text{form_cont_empty_site_yr}}$) is estimated based on the daily use rate of the formulation and the container size (see Section 3.9). EPA assumes 55-gallon (208 L) drums and density of 1 kg/L (density of water) as defaults.

If the $N_{\text{form_cont_empty_site_yr}}$ value is fewer than the days of operation ($\text{TIME}_{\text{app_working_days}}$), the days of release equal $N_{\text{form_cont_empty_site_yr}}$ (as calculated in Equation 3-5) and the daily release is calculated based on the following equation:

$$\text{Elocal}_{\text{app_container_residue_disp}} = Q_{\text{cont_empty}} \times F_{\text{chem_form}} \times F_{\text{container_residue}} \times N_{\text{form_cont_empty_site_day}} \quad (4-1a)$$

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

Where:

$\text{Elocal}_{\text{app_container_residue_disp}}$	=	Daily release of chemical of interest from radiation curable product container residue (kg chemical/site-day)
$Q_{\text{cont_empty}}$	=	Mass of the radiation curable formulation in the container (kg product/container) (Default: use the same value used to estimate $N_{\text{cont_empty_site_yr}}$ in Section 3.9)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (kg chemical/kg product) (See Section 3.5)
$F_{\text{container_residue}}$	=	Fraction of radiation curable formulation remaining in the container as residue (Default: 0.03 kg formulation/kg shipped for drums (CEB, 2002a); See Appendix B for defaults used for other container types)
$N_{\text{form_cont_empty_site_day}}^1$	=	Number of containers unloaded per site, per day (Default: 1 container/site-day)

¹ The daily number of containers unloaded per site may be estimated as (consistent with Section 3.9):

$$N_{\text{form_cont_empty_site_day}} = \frac{N_{\text{form_cont_empty_site_yr}}}{\text{TIME}_{\text{app_working_days}}}$$

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

Where:

$N_{\text{form_cont_empty_site_yr}}$	=	Annual number of containers emptied containing chemical of interest per site (containers/site-yr) (See Equation 3-5)
$\text{TIME}_{\text{app_working_days}}$	=	Annual number of days the radiation curable material is formulated (days/yr) (See Section 3.7)

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

$$\text{Elocal}_{\text{app-container_residue_disp}} = Q_{\text{app_chem_site_day}} \times F_{\text{container_residue}} \quad (4-1b)$$

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

Where:

$\text{Elocal}_{\text{app_container_residue_disp}}$	=	Daily release of chemical of interest from container residue (kg chemical/site-day)
$Q_{\text{app_chem_site_day}}$	=	Daily use rate of the chemical of interest in the formulation for application (kg chemical/site-day) (See Equation 3-4)
$F_{\text{container_residue}}$	=	Fraction of radiation curable formulation 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 3-5 and 4-1a, and $N_{\text{form_cont_empty_site_yr}}$ is unknown.

Open Surface Losses to Air During Container Cleaning (Release 5)

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 ($\text{Elocal}_{\text{app_air_cleaning}}$). 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 0-4. 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 $N_{\text{form_cont_empty_site_yr}}$ or $\text{TIME}_{\text{app_working_days}}$, consistent with Section 4.5
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 ($N_{\text{form_cont_empty_site_day}}$, consistent with Release 4) 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.

Process Releases During Operations (Release 6)

The releases generated during the application process are dependent on the type of application method used. Different default values are used to determine the amount of release from spray, roll, and curtain coating. Figure 4-1 presents a logic diagram to help determine the appropriate default application method. If the application method is unknown or multiple application methods are identified, utilize the methodology for “unknown.”

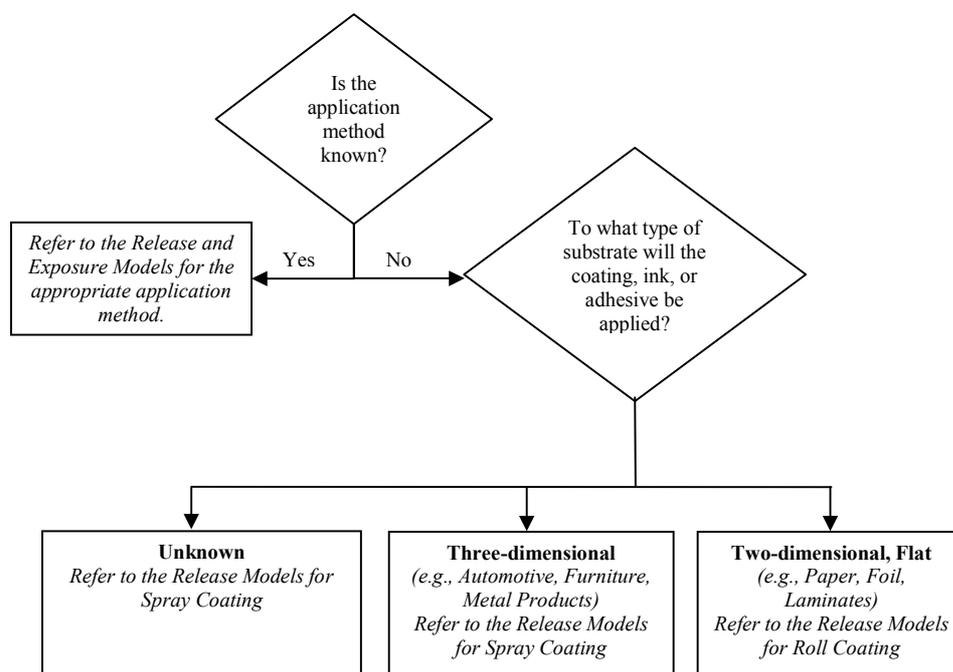


Figure 0-1. Logic Diagram for the Determination of Application Methods

Spray Coating

Spray coating applications are typically used for coating oddly shaped substrates. The ESD assumes that the primary end-use markets using this type of application method may include furniture manufacturing, automobile manufacturing, and metal products and machinery manufacturing. In lieu of industry-specific information, spray application is assumed the default application method for these markets.

In spray applications, the formulation is loaded into a pressurized vessel and pumped through the spray gun using compressed air. The formulation is applied to the substrate as a mist generating overspray. Spray coating operations typically occur in spray booths or totally enclosed systems, as radiation curable coatings are of high value and minimal product wastes are desired. The use of a conventional control technology, such as a dry filter spray booth, is anticipated at sites that apply these coatings (RadTech, 2008). It is also possible that spray booths equipped with water curtains are used to capture particulates.

Table 4-5 presents efficiencies from various sources that can be used to estimate losses of spent coating. These values are based on:

- A laboratory-scale experiment investigating transfer efficiencies, overspray, and inhalation exposures from a variety of spray guns (CEB, 1996);
- A pollution prevention bulletin providing heuristic transfer efficiency information for typical application methods for the paint and coatings industry (P2Pays, 1997); and

- Information provided by RadTech in support of the development of this document providing heuristic transfer efficiency information for the radiation curable products industry (RadTech, 2007).

If the type of spray application process is unknown assume a conventional air-atomized spray coating process and a transfer efficiency of 25% as the conservative default.

Table 0-5. Transfer Efficiencies of Spray Coating Application Processes

Spray Coating Process	Transfer Efficiency in CEB, 1996 (%)	Transfer Efficiency in P2Pays, 1997 (%)	Transfer Efficiency in RadTech, 2007 (%)	Default Value (%)
High Volume, Low Pressure (HVLP)	>65	67-70	NA	65
Low Volume, Low Pressure (LVLP)	>65	NA	NA	65
Air-atomized (Conventional) (Default)	20-40 (25, midpoint default)	30-60	<50	25
Airless/Air-assisted	NA	NA	65	65
Electrostatic Airless/Rotary Bell	60-90	NA	80	60

NA – Not available.

Source: P2Pays, 1997; CEB, 1996; RadTech, 2007.

The EPA standard model for estimating releases from spray coating may be used (*EPA/OPPT Automobile OEM Overspray Loss Model*)¹. The user should assume the use of a conventional spray gun within a spray booth equipped with dry filter as default². This operation will assume the use of a conventional spray gun within a spray booth having a water curtain to capture overspray. The model assumes a spray booth capture efficiency of 90 percent ($F_{capture_eff} = 0.90$) and a solid removal efficiency of 100 percent ($F_{solidrem_eff} = 100$).

Based on the daily use rate and transfer efficiency of the technology used, the daily releases from spray coating operations are calculated using the following equation:

$$E_{local_application_losses} = Q_{app_chem_site_day} \times (1 - F_{transfer_eff}) \tag{4-2}$$

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

Where:

- $E_{local_application_losses}$ = Daily release of chemical of interest from application (kg chemical/site-day)
- $Q_{app_chem_site_day}$ = Daily use rate of the chemical of interest contained in the radiation curable product (kg chemical/site-day)

¹ This EPA model assumes the use of water curtains during spray application. However, if a facility’s use of a spray booth with dry filters is known, the *EPA/OPPT Automobile Refinish Spray Overspray Loss Model* may be more appropriate to estimate environmental releases from overspray (CEB, 1996).

² This default for this model assumes the use of a conventional spray gun within a spray booth having a water curtain to capture overspray, with a spray booth capture efficiency of 96 percent ($F_{capture_eff} = 0.96$) and a solid removal efficiency of 90 percent ($F_{solidrem_eff} = 0.90$).

$F_{\text{transfer_eff}}$ = Fraction of radiation curable product adhered (Based on transfer efficiency of application methods; Default = 0.65 kg product adhered/kg applied, see Table 4-5 for alternative values)

For spray applications, spray booths are typically implemented to provide makeup air, capture overspray, and exhaust emissions. As previously discussed, as default, paint overspray is collected in the dry filter with a capture efficiency of 90 percent ($F_{\text{capture_eff}} = 0.90$) and a solid removal efficiency of 100 percent ($F_{\text{solidrem_eff}} = 1.0$) (CEB, 1996). If it is known that paint overspray is collected as sludge in a water-controlled spray booth, a spray booth capture efficiency of 96 percent ($F_{\text{capture_eff}} = 0.96$) with a solid removal efficiency of 90 percent ($F_{\text{solidrem}} = 0.9$) can be used (CEB, 1996). The following equations can be used to partition the individual releases to water, air, and incineration or landfill from the spray application process.

$$\text{Water Releases} \quad \%_{\text{water}} = F_{\text{capture_eff}} \times (1 - F_{\text{solidrem_eff}}) \times 100 \quad (4-3a)$$

$$\text{Air Releases:} \quad \%_{\text{air}} = (1 - F_{\text{capture_eff}}) \times 100 \quad (4-3b)$$

$$\text{Incineration or Landfill Releases:} \quad \%_{\text{land_inc}} = F_{\text{capture_eff}} \times F_{\text{solidrem_eff}} \times 100 \quad (4-3c)$$

Where:

$\%_{\text{water}}$ = Percentage of releases to water from spray coating (%)
 $\%_{\text{air}}$ = Percentage of releases to air from spray coating (%)
 $\%_{\text{land_inc}}$ = Percentage of releases to land or incineration from spray coating (%)
 $F_{\text{capture_eff}}$ = Fraction of mist captured in spray booth technology (Default: 0.90 kg mist captured /kg released for water curtain)
 $F_{\text{solidrem_eff}}$ = Fraction of solid removed in the spray mist (Default: 1.0 kg solid removed/kg mist captured)

Roll Coating

Roll coating applications are typically used to apply coatings to various flat substrates. Roll coating may apply clear and pigmented coatings. Roll coating processes may involve high line speeds that have a potential for splatter and mist generation during application that is disposed to water, incineration, or land. Disposal of the coating in the reservoir may also be sent to incineration, or land. If additional site-specific information is not available, the entirety of this release is conservatively assessed to each of water, incineration, and land.

The EPA standard model for estimating releases from roll coating and curtain coating may be used (*EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations*). The model estimates a transfer efficiency range of 90-98 percent during application. This is based on a pollution prevention bulletin providing heuristic transfer efficiency information for typical application methods for the paint and coatings industry (P2Pays, 1997). If the transfer efficiency of roll coating or curtain coating is not known, a 90 percent transfer efficiency ($F_{\text{transfer_eff}} = 0.90$) can be used as a conservative default to estimate an overall application loss (CEB, 2008).

Releases for these application methods can be estimated using the following equations, based on the daily use rate and transfer efficiency of the technology used:

$$E_{\text{local}}_{\text{application_losses}} = Q_{\text{app_chem_site_day}} \times (1 - F_{\text{transfer_eff}}) \quad (4-4)$$

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

Where:

$E_{\text{local}_{\text{application_losses}}}$	=	Daily release of chemical of interest from application (kg chemical/site-day)
$Q_{\text{app_chem_site_day}}$	=	Daily use rate of the chemical of interest contained in the radiation curable product (kg chemical/site-day)
$F_{\text{transfer_eff}}$	=	Loss fraction of radiation curable product released (Based on transfer efficiency of application methods; Default = 0.90 kg product adhered/kg applied for roll coating or curtain coating)

Curtain Coating

Similar to roll coating, curtain coating applications are typically used to apply clear coatings to flat stock, including metal, wood, paper, and plastic substrates. In curtain coating, a stream of coating flows at a controlled rate as the substrate is conveyed across the stream. The amount of coating that is not transferred to the substrate drips down collection tunnels and may be recycled to the feed reservoir or disposed to water, incineration, or landfill. No additional industry-specific information is provided to determine the amounts released to air, water, incineration or land. As a conservative estimate, the entirety of this release is assessed to each of air, water, incineration, and land. The *EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations*, as discussed above, may also be applied to estimate releases during curtain coating to account for losses of spent coating.

Other Process Releases

Volatile components may also evaporate during the application process. However, the semi-volatile components (e.g., some monomers) in radiation curable products are vital for the product to cure and are not anticipated to volatilize in significant quantities. No additional releases are anticipated for volatile components.

Equipment Cleaning Releases to Incineration or Landfill (Release 7)

UV/EB coating application equipment requires little solvent for cleaning. Based on extraction studies performed by RadTech, UV/EB materials are present in the parts per million (ppm) range in the cleaning solution, resulting in minimal releases to the environment (RadTech, 2008). Industry-specific information estimates approximately one percent of used radiation curable product is lost during equipment cleaning at the application site. These releases are typically sent to incineration or land (RadTech, 2007). If additional site-specific information is not available, the entirety of this release is conservatively assessed to both media. EPA recommends that the *EPA/OPPT Multiple Process Vessel Residual Model* is utilized to estimate process losses from equipment cleaning at the application sites. The model assumes that no more than two percent of the batch size or capacity of the process remains in the equipment as residue that is released as equipment cleaning waste. The multiple vessel model is recommended as the default because application equipment may include applicators (e.g., spray gun, rollers, die), conveyors, dryers, and curing systems.

Cleaning frequencies may vary significantly across the industry. One source indicates that cleaning operations typically occur twice a month (RadTech, 2007); however, because product lines may be changed frequently, EPA assumes daily equipment cleaning as a conservative estimate.

The daily release of chemical residue in the process equipment is calculated using the following equation:

$$E_{\text{local_app_equip_cleaning}} = Q_{\text{app_chem_site_day}} \times F_{\text{equipment_cleaning}} \quad (4-5)$$

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

Where:

$E_{\text{local_app_equip_cleaning}}$	=	Daily release of chemical of interest from equipment cleaning at application site (kg chemical/site-day)
$Q_{\text{app_chem_site_day}}$	=	Daily use rate of the chemical of interest used in the radiation curable product (kg chemical/site-day) (See Equation 3-4)
$F_{\text{equipment_cleaning}}$	=	Fraction of radiation curable product released as residual in process equipment (Default: 0.02 kg product released/kg batch holding capacity (CEB, 1992a))

Open Surface Losses to Air During Equipment Cleaning (Release 8)

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 ($E_{\text{local_air_eqpt_cleaning}}$). 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 4-6.

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 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 0-6. 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	Equal to the number of cleanings per year, as determined in Section 4.8
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Operating Hours for the Activity	EPA default 4 hrs/day (CEB, 2002b)
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 operating hours for this activity is based on the EPA default of four hours for cleaning multiple vessels. EPA suggests that the default of four hours per cleaning be used in lieu of site-specific information (CEB, 2002b).

OCCUPATIONAL EXPOSURE ASSESSMENTS FOR THE APPLICATION OF RADIATION CURABLE PRODUCTS

The following section presents estimation methods for worker exposures to the chemical of interest during the application process. Figure 2-1 illustrates the occupational activities performed within the application 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 coatings, inks, and adhesives industries 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 0-1. Summary of Radiation Curable Application Scenario Exposure Models

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description ^a	Standard EPA Model (✓)
A	Exposure to liquid curable radiation formulation during unloading or transferring.	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	✓
B	Exposure to liquid formulation during raw material 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	✓
C	Exposure to liquid curable radiation formulation during container 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 (✓)
D	Exposure to liquid radiation curable product during application	Inhalation of volatile liquid chemical vapors	EPA/OPPT Mass Balance Model	✓
		Inhalation of overspray during spray coating	EPA/OPPT Automobile OEM Spray Coating Inhalation Model	✓
		Inhalation of mist from roll or curtain coating	EPA/OPPT UV/EB Roll Coating Inhalation Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
E	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	✓

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

Personal Protective Equipment

Industry information indicates that workers who handle radiation curable 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. Respiratory protection is used when necessary, especially when escape of spray particles into the work environment is unavoidable (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.

Number of Workers Exposed Per Site

Industry-specific data on the number of workers potentially exposed while performing each of the application activities were not found in the references reviewed for this ESD (refer to Section 8).

Table 5-2 summarizes data collected from the 2002 Economic Census for the coatings, inks, and adhesives application industries. In the absence of site-specific data, the default number of workers should be consistent with the end-use market selected based on the decision logic in Section 0 (Figure 0-1. Logic Diagram to Determine Appropriate Defaults for Assessments).

In combination with use rate information provided in Table 3-2, the total number of workers can be estimated by end-use market; however, not all workers are expected to work in the production areas. The 2002 Economic Census also provides estimates for *production workers* (USCB, 2004), 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, 2004).

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, 2004).

The 1996 Generic Scenario on *Automobile Spray Coating* provides estimates on the number of workers potentially exposed to general automotive coating, which may include UV/EV curable coating, during original equipment manufacture (OEM). No information was found that would provide bases for estimating the specific numbers of production workers potentially exposed to UV/EV curable coatings in other end use markets. In the absence of data, Census data are used to estimate the average number of production workers per site. The number of workers potentially exposed to the chemical of interest during each activity should be conservatively estimated as the number of workers per site indicated by end-use market; however, the total number of workers per site does not equal the sum of the number of workers assumed to be exposed during each activity.

Table 0-2. Number of Workers Potentially Exposed During the Application Process

End Use Market	Average Number of Production Workers per Facility ^a
Automotive	17 ^b
Optical	51
Furniture (Wood)	16
Flooring	50
Metal Products and Machinery	24
Paper, Paperboard, Film, and Foil Finishes	43
Letterpress	21
Screen Printing	11
Lithographic	17
Flexographic	22
Inkjet	7
Laminating	37
Pressure Sensitive	85
Electronic	83

a – Average number of workers per facility is based on the end-use market NAICS codes presented in Appendix C of this ESD.

^b – Based on the number of workers associated with automobile OEM presented in the 1996 Generic Scenario on *Automobile Spray Coating* (note the estimate for OEM is used because it is more conservative than the estimated number of workers associated with automobile refinishing). The estimate is based on industry-specific data on the number of car assembled; this estimate appears more realistic than Census data of 168 production workers/site for the automotive industry (NAICS 336321 and 3363601). Census data for other end use markets appear reasonable when compared to estimates provided in recent Pre-Manufacture Notice (PMN) submissions related to UV/EV curable coatings.

Exposure from Unloading Liquid Formulations (Exposure A)

Workers may connect transfer lines or manually unload formulations from transport containers into the application equipment. If the concentration of the chemical in the formulation ($F_{\text{chem_form}}$) is unknown, 70 percent concentration may be assumed as a conservative default, as previously discussed in Section 3.5. To determine the maximum number of workers exposed during this activity, please reference Table 0-2, according to the end-use market previously identified from the decision logic in Section 3.2 (Figure 0-1. Logic Diagram to Determine Appropriate Defaults for Assessments).

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).

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 5-3 lists the model inputs and default values. Note that the exposure hours per day is equivalent to the operating hours per day for this activity (consistent with Section 4.2 calculations), but EPA assumes an exposure duration of eight hours per day for a given worker if the actual exposure duration or work shift duration is not known. Similarly, EPA assumes that the number of exposure days per year is the same as the number of days of transfer, although EPA often assumes 250 exposure days per year if the number of days of transfer significantly exceeds 250 days per year. These exposure duration maximum defaults are based on full-time employment and considers an individual worker's vacation, sick, and weekend time (i.e., a 40-hour work week over 50 weeks per year).

Table 0-3. EPA/OPPT Mass Balance Model Parameter Default Values During Transfers

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m ³ /hr (CEB, 1991)
Exposure Days	Consistent with the Frequency of Release determined in Section 4.2, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OAQPS AP-42 Loading Model</i> (Section 4.2)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.2, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (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.

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 into the application equipment. Workers may manually pour liquid radiation curable formulations 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. The rationale, defaults, and limitations of these models are further explained in Appendix B.

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

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

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

Where:

EXP_{dermal} = Potential dermal exposure to the chemical of interest per day (mg chemical/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))
$N_{\text{exp_incident}}^1$	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

Exposure to Liquids from Sampling Raw Material (Exposure B)

Workers may collect samples of the radiation curable product that were shipped to the site for quality analysis/quality control (QA/QC). To determine the maximum number of workers exposed during this activity, please reference Table 0-2, according to the end-use market previously identified from the decision logic in Section 3.2 (Figure 0-1. Logic Diagram to Determine Appropriate Defaults for Assessments).

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. 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 assumes that fugitive emission of volatile chemicals may occur during raw material sampling and estimating the associated worker inhalation exposure as a worst-case.

Using the vapor generation rate calculated in Release 3 (Section 4.4), 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 5-4 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

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 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.

packaging/loading activities. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 0-4. 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 4.4, 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 (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 4.4
Vapor Pressure	Consistent with the Vapor Pressure used in Section 4.4
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 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 during sampling, EPA recommends using the following equation:

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

This exposure will occur over [TIME_{app_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 _{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 the footnote to Equation 5-1)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

Exposure to Liquids from Container Cleaning (Exposure C)

Workers may be exposed while rinsing containers used to transport the radiation curable formulation. If the concentration of the chemical in the formulation ($F_{\text{chem_form}}$) is unknown, 70 percent concentration may be assumed as a conservative default, as previously discussed in Sections 3.5. To determine the maximum number of workers exposed during this activity, please reference Table 0-2, according to the end-use market previously identified from the decision logic in Section 3.2 (Figure 0-1. Logic Diagram to Determine Appropriate Defaults for Assessments).

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 5, 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 5-5 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 4.6 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 0-5. 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 4.6, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OPPT Penetration Model</i> (Section 4.6)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.6, 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.

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. The rationale, defaults, and limitations of these models are explained in Appendix B.

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

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

This exposure will occur over [the lesser of $N_{\text{form_cont_empty_site_yr}}$ or $TIME_{\text{app_working_days}}$ (consistent with Section 4.6), 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 formulation 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 the footnote to Equation 5-1)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

Exposure during Coating Operations (Exposure D)

Worker exposure to the chemical contained in radiation curable formulations may vary according to the coating operations used. Figure 3-1 presents a logic diagram that can be used to determine the appropriate application method to use for the chemical of interest. This assumption considers the fraction of the chemical of interest in the formulation.

Inhalation exposures are estimated below for mists or overspray generated from the coating processes by nonvolatile chemicals in formulation. Standard EPA models are used to estimate the dermal exposures from the processes. To determine the maximum number of workers exposed during this activity, please reference Table 0-2, according to the end-use market previously identified from the decision logic in Section 3.2 (Figure 0-1. Logic Diagram to Determine Appropriate Defaults for Assessments). 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.

Inhalation Exposure:

Spray Application

Spray application in the radiation curable products industry is a typically controlled process conducted in a spray booth or an enclosed system. If chemical-specific information indicates spray application in a fully enclosed, automated system, negligible inhalation exposure to the chemical is expected from the spray application process.

However, no data on the prevalence of fully-enclosed spray application systems in the radiation curable products industry were available. While some facilities may utilize automated systems that do not require workers to manually spray-apply the radiation curable product, workers may still be exposed during loading/unloading, equipment maintenance activities, and if the system is not fully enclosed. Therefore, if the process enclosure is unknown, assume the default system to be a manual or unenclosed application. Due to the lack of specific exposure data, this ESD conservatively estimates exposures during spray coating using the *EPA/OPPT Automobile OEM Spray Coating Inhalation Exposure Model*. This model is the default for calculating worker exposures to a non-volatile chemical during the spray coating and can be used to estimate the amount of non-volatile chemical in mist inhaled by a worker spray painting original equipment manufactured (OEM) in coating operations. Table 5-6 lists concentrations for using conventional air-atomized and high volume-low pressure (HVLP) spray guns during the

application step. The mass concentration of particulate in air is further used to estimate the inhalation exposure and average and lifetime dosages.

Table 5-6. Mass Concentration of Total Particulate in Air, $C_{\text{part_air}}$, by Spray Gun Type

Spray Gun type ^a	$C_{\text{part_air}}$ (mg/m ³)
Conventional	2.3 mg/m ³ (Downdraft) (Default) ^b
	15 mg/m ³ (Crossdraft)
HVLP	1.9 mg/m ³ (Downdraft)
	15 mg/m ³ (Crossdraft)

a – If an alternate spray gun type is used, $C_{\text{part_air}}$ values for conventional spray guns (downdraft) may be used.

b – This default was selected based on an internal CEB policy decision in July 2003 to use conventional spray guns (downdraft) as a default for all OEM spray coating operations, including applications outside the automotive industry.

To estimate the potential worker inhalation exposure to the chemical during coating operations, EPA recommends using the following equation:

$$\text{EXP}_{\text{inhalation}} = C_{\text{part_air}} \times \text{TIME}_{\text{exposure}} \times \text{RATE}_{\text{breathing}} \times F_{\text{chem_particulate}} \quad (5-4)$$

This exposure will occur over [$\text{TIME}_{\text{app_working_days}}$ (consistent with Section 4.7), up to 250] days per year.

Where:

$\text{EXP}_{\text{inhalation}}$	=	Inhalation potential dose rate of chemical during spray coating (mg chemical/day)
$C_{\text{part_air}}$	=	Mass concentration of total particulate in air (Default: 2.3 mg particulate/m ³ of air) (See Table 5-6)
$\text{TIME}_{\text{exposure}}$	=	Duration of exposure to the chemical during the coating process (Default: 8 hours/day)
$\text{RATE}_{\text{breathing}}$	=	Inhalation rate (CEB default: 1.25 m ³ /hr) (CEB, 1991)
$F_{\text{chem_particulate}}$	=	The lesser of $F_{\text{chem_form}}/F_{\text{particulate_prod}}$ or 1.
$F_{\text{chem_form}}$	=	Mass fraction of chemical in the radiation curable product (Default: 0.7 mg chemical/mg product) (See Section 3.5)
$F_{\text{particulate_prod}}$	=	Mass fraction of particulate in the radiation curable product (Default: 0.25 mg particulate/mg product)

The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to spray coating activities. The *Generic Scenario for Automobile Spray Coating* (CEB, 1996) provides additional information about this model.

Roll Coating

The *EPA/OPPT UV Roll Coating Inhalation Model* is the default model for calculating worker inhalation exposures to the mist that may be generated by roll coating. This model estimates the amount of chemical inhaled by a worker who conducts activities near roll coater(s) using coatings, inks, or adhesives containing the chemical.

The equation for the *EPA/OPPT UV Roll Coating Inhalation Model* is the same as Equation 5-4 but uses a different set of default values for mass concentrations of total particulate air. For this model, the default low- and high-end mass concentrations of total particulate in air, $C_{\text{part_air}}$, are 0.04 mg/m^3 and 0.26 mg/m^3 , respectively. Details on the *EPA/OPPT UV Roll Coating Inhalation Model* are provided in Appendix B.6.3.

Curtain Coating

In curtain coating, a stream of coating flows at a controlled rate as the substrate is conveyed across the stream. Unlike roll coating processes, which involve high line speeds that can cause splatter and generate mist, curtain coating is not expected to create mist or overspray; therefore, inhalation exposures are assumed negligible in this ESD.

Dermal Exposure:

Dermal exposure is expected during the application of radiation curable formulations by spray, roll, or curtain coating. ERG believes that dermal exposure may still occur during maintenance operations on the application system. Workers may be required to perform activities that involve potential contact with the radiation curable products, such as checking reservoir depth, adjusting applicators, and ensuring normal system operations. Although exposures may be overly conservative for automated systems, ERG believes these activities justify the inclusion of a dermal exposure assessment.

Spray Application

While spray coating operations may be automated minimizing dermal exposure, manual coating may still occur. Therefore, dermal exposure will be assumed for spray application as well. For spray applications, the *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these application activities.

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

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

This exposure will occur over $[TIME_{\text{app_working_days}}$ (consistent with Section 4.7), 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 formulation remaining on skin (Defaults: $10.3 \text{ mg component/cm}^2$ -incident (high-

		end) and 1.3 mg component/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 the footnote to Equation 5-1)
F _{chem_form}	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

Roll Coating or Curtain Coating

Dermal exposure is also expected during the application of radiation curable formulations by roll and curtain coating. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* uses the same equation as Equation 5-5 but with a different set of default values for the quantity of liquid remaining on the skin. For this model, the default low- and high-end values for Q_{liquid_skin} are 0.7 mg/cm²-incident and 2.1 mg/cm²-incident, respectively. These values may be substituted in Equation 5-5 to estimate dermal exposure to the chemical of interest in a liquid formulation during roll or curtain coating application activities

Exposure to Liquids from Equipment Cleaning of Applicators and other Process Equipment (Exposure E)

Workers may be exposed while cleaning the application process equipment with water or organic solvents. Because some equipment cleaning may be performed manually, exposures during equipment cleaning should be assessed. To determine the maximum number of workers exposed during this activity, please reference Table 0-2, according to the end-use market previously identified from the decision logic in Section 3.2 (Figure 0-1. Logic Diagram to Determine Appropriate Defaults for Assessments).

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).

Using the vapor generation rate calculated in Release 8, 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 5-7 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 4.9 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.

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 equipment cleaning. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 0-6. 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 4.9, up to 250 days per year
Vapor Generation Rate	Calculated by the <i>EPA/OPPT Penetration Model</i> (Section 4.9)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.9, 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)
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 formulation for this activity, use the following equation:

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

This exposure will occur over [the number of cleanings per year (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: 840 cm ² for 2 hands (CEB, 2000a))

$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day) (See footnote to Equation 5-1)
$F_{\text{chem_form}}$	=	Mass fraction of the chemical of interest in the radiation curable product (mg chemical/mg product) (See Section 3.5)

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 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 *10,000 kg chemical/yr* and is an oligomer in 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 @ 25°C (i.e., the chemical is volatile for the purposes of the assessment).
3. The unknown radiation curable product containing 70% of the chemical in formulation is received in liquid form to be spray applied to metal substrates.

General Facility Information for Application of Radiation Curable Products

Annual Radiation Curable Product Use Rate ($Q_{\text{app_site_yr}}$)

It is only known that the radiation curable product is used for metal coatings. Additional site-specific information is not known for the Equation 3-3 parameters (i.e., $Q_{\text{app_site_yr}}$ and $F_{\text{app_radcur}}$). The use of default assumptions is appropriate. Using Table 3-2, the following assumptions can be made about the applicator site:

Type of End-Use Market: *Metal Products and Machinery Manufacturing*

The resulting product use rate ($Q_{\text{app_site_use_rate}}$) from Table 3-2 is *34,158 kg metal coating/site-yr*:

$$Q_{\text{app_site_yr}} = Q_{\text{app_site_use_rate}} \times F_{\text{app_radcur}} \quad [\text{Eqn. 3-1}]$$

$$Q_{\text{app_site_yr}} = 34,158 \text{ kg total metal coating/site - yr} \times 1 \text{ kg coating with chem./kg total coating}$$

$$Q_{\text{app_site_yr}} = 34,158 \text{ kg total coating/site - yr}$$

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

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

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

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 2-3 is assumed. The high-end concentration for oligomers used in radiation curable coatings ($F_{\text{comp_form}}$) is *0.70 kg component/kg coating*.

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.

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

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

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

Number of Application Sites (N_{app_sites})

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

$$N_{app_sites} = \frac{10,000 \text{ kg chem./yr}}{34,158 \text{ kg coating/ site - yr} \times 0.7 \text{ kg chem./kg product}}$$

$$N_{app_sites} = 0.42 \text{ sites}$$

Round N_{sites} up to next integer (1 *application sites*) and recalculate $Q_{app_site_yr}$:

$$Q_{app_site_yr} = \frac{10,000 \text{ kg chem./yr}}{1 \text{ site} \times 0.7 \text{ kg chem/kg product}}$$

$$Q_{app_site_yr} = 14,286 \text{ kg product/site - yr}$$

Days of Operation ($TIME_{app_working_days}$)

For a continuous application line, the default number of operating days is 250 days per year. Because the number of sites is less than one, the number of operating days should be adjusted by a factor of 0.42, resulting in 105 days per year.

Daily Use rate of the Chemical of Interest ($Q_{app_chem_site_day}$)

$$Q_{app_chem_site_day} = \frac{Q_{app_site_yr} \times F_{chem_form}}{TIME_{app_working_days}} \quad [\text{Eqn. 3-4}]$$

$$Q_{app_chem_site_day} = \frac{14,286 \text{ kg prod.} \times 0.7 \text{ kg chem.}}{\text{site - yr} \times \text{kg prod.}}$$

$$Q_{app_chem_site_day} = \frac{95 \text{ kg chem.}}{105 \text{ days/yr}}$$

$$Q_{app_chem_site_day} = \frac{95 \text{ kg chem.}}{\text{site - day}}$$

Annual Number of Product Containers Emptied per Site ($N_{form_cont_empty_site_yr}$, container/site-year)

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

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

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

$$N_{form_cont_empty_site_yr} = \frac{Q_{app_chem_site_day} \times TIME_{app_working_days}}{F_{chem_form} \times Q_{cont_empty}} \quad [\text{Eqn. 3-5}]$$

$$N_{form_cont_empty_site_yr} = \frac{95 \text{ kg chem./site - day} \times 105 \text{ days/yr}}{0.7 \text{ kg chem./kg prod.} \times 208 \text{ kg prod./container}}$$

$$N_{comp_cont_empty_site_yr} = 69 \text{ containers/site - yr}$$

Release Assessments for Application of Radiation Curable Products**Transfer Operation Losses to Air from Unloading the Radiation Curable Product (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:

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

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

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	MW _{chem}	g/mol	100
Saturation Factor	F _{saturation_factor}	Dimensionless	Typical = 0.5 Worst Case = 1
Vapor Pressure	VP _{chem}	Torr	0.1
Container Volume	V _{cont_empty}	Gal	55
Fill Rate	RATE _{fill}	containers/hour	20
Temperature	TEMP _{ambient}	K	298
Vapor Correction Factor	F _{correction_factor}	Dimensionless	1
Gas Constant	R	Atm·cm ³ /K·mol	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 4-2 for container unloading, the model then estimates the daily release to air using the following equation:

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

$$E_{\text{local_app_air_transfers}} = (3.1 \times 10^{-4} \text{ to } 6.2 \times 10^{-4}) \text{ g chem./sec} \times \left(\frac{69 \text{ containers/site - yr}}{105 \text{ days/yr} \times 20 \text{ containers/hr}} \right) \times \frac{3600 \text{ sec/hr}}{1000 \text{ g/kg}}$$

$$E_{\text{local_app_air_transfers}} = 3.7 \times 10^{-5} - 7.3 \times 10^{-5} \text{ kg chem. emitted/site-day}$$

...over 105 days/year from 1 site.

Raw Material Sampling Wastes Disposed to Non-air Media (Release 2)

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

Open Surface Losses to Air During Raw Material Sampling (Release 3)

Since the chemical of interest is volatile, it will be emitted from the process during raw material 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]

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

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

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	MW _{chem.}	g/mol	100
Vapor Correction Factor	F _{correction_factor}	Dimensionless	1
Vapor Pressure	VP _{chem.}	Torr	0.1
Air Speed	RATE _{air_speed}	ft/min	100
Surface Area of Pool Opening	AREA _{opening}	cm ²	Typical = 4.9 Worst case = 78.5
Temperature	TEMP _{ambient}	K	298
Diameter of Pool Opening	D _{opening}	Cm	Typical = 2.5 Worst case = 10
Pressure	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 4-3 for raw material sampling, the model then estimates the daily release to air using the following equation:

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

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

$$\text{Elocal}_{\text{app_air_sample}} = 1.5 \times 10^{-5} - 1.2 \times 10^{-4} \text{ kg chem. emitted/ site - day}$$

...over 105 days/year from 1 site.

Radiation Curable Product Container Residue Released to Water, Incineration, or Landfill (Release 4)

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

$$\text{Elocal}_{\text{app_container_residue_disp}} = Q_{\text{app_chem_site_day}} \times F_{\text{container_residue}} \quad [\text{Eqn. 4-1b}]$$

Since it is known that the radiation curable component is in a liquid form when shipped to the application 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):

$$\text{Elocal}_{\text{app_container_residue_disp}} = \frac{95 \text{ kg chem.}}{\text{site - day}} \times \frac{0.03 \text{ kg chem. remain}}{\text{kg chem. full}}$$

$$\text{Elocal}_{\text{app_container_residue_disp}} = \frac{2.85 \text{ kg chem. released}}{\text{site - day}}$$

...over 105 days/year from 1 site.

Open Surface Losses to Air During Container Cleaning (Release 5)

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

[Eqn. B-1]

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

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

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	MW _{chem.}	g/mol	100
Vapor Correction Factor	F _{correction factor}	Dimensionless	1
Vapor Pressure	VP _{chem.}	Torr	0.1
Air Speed	RATE _{air speed}	ft/min	100
Surface Area of Pool Opening	AREA _{opening}	cm ²	20.3
Temperature	TEMP _{ambient}	K	298
Diameter of Pool Opening	D _{opening}	Cm	5.08
Pressure	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 4-4 for container cleaning, the model then estimates the daily release to air using the following equation:

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

$$E_{\text{local_air_cleaning}} = 1.2 \times 10^{-5} \text{ g chem./sec} \times \left(\frac{69 \text{ containers/site-yr}}{105 \text{ days/yr} \times 20 \text{ containers/hr}} \right) \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}}$$

$$E_{\text{local_air_cleaning}} = 1.4 \times 10^{-6} \text{ kg chem. emitted/ site - day}$$

...over 105 days/year from 1 site.

Process Releases During Application Process (Release 6)

It is known that the chemical is spray-applied onto metal substrates at the application sites; however, spray technologies are not known. Therefore, default assumption can be made to estimate the releases to spray coating. From Table 4-5, the following information is obtained:

Coating process: *Air-atomized (Conventional) Spray Coating*

The transfer efficiency of the resulting process: 25-90% (*conservative: 25%*)

$$E_{\text{local_application_losses}} = Q_{\text{app_chem_site_day}} \times (1 - F_{\text{transfer_eff}}) \quad [\text{Eqn. 4-2}]$$

$$E_{\text{local_application_losses}} = 95 \text{ kg / site - day} \times (1 - 0.25 \text{ kg coating transferred/kg sprayed})$$

$$E_{\text{local_application_losses}} = 71 \text{ kg/site - day}$$

...over 105 days/yr from 1 site

The partitioning of the releases can be calculated based on assumptions that the spray booth technology has 96% capture efficiency with a water curtain.

$$\text{Water Releases: } \%_{\text{water}} = F_{\text{capture_eff}} \times (1 - F_{\text{solidrem_eff}}) \times 100 \quad [\text{Eqn. 4-3a}]$$

$$\%_{\text{water}} = (0.96 \text{ kg captured/kg released}) \times (1 - 0.90 \text{ kg removed/kg captured}) \times 100$$

$$\%_{\text{water}} = 9.6\%$$

$$\text{Elocal}_{\text{application_losses}} \times \%_{\text{water}} = (71 \text{ kg/site - day}) \times 0.096 = 6.8 \text{ kg/site - day to water}$$

$$\text{Air Releases: } \%_{\text{air}} = (1 - F_{\text{capture_eff}}) \times 100 \quad [\text{Eqn. 4-3b}]$$

$$\%_{\text{air}} = (1 - 0.96 \text{ kg captured/kg released}) \times 100$$

$$\%_{\text{air}} = 4\%$$

$$\text{Elocal}_{\text{application_losses}} \times \%_{\text{air}} = (71 \text{ kg/site - day}) \times 0.04 = 2.8 \text{ kg/site - day to air}$$

$$\text{Land or Incineration Releases: } \%_{\text{land_inc}} = F_{\text{capture_eff}} \times F_{\text{solidrem_eff}} \times 100 \quad [\text{Eqn. 4-3c}]$$

$$\%_{\text{land_inc}} = 0.96 \text{ kg captured/kg released} \times 0.90 \text{ kg removed/kg captured} \times 100$$

$$\%_{\text{land_inc}} = 86.4\%$$

$$\text{Elocal}_{\text{application_losses}} \times \%_{\text{land_inc}} = (71 \text{ kg/site - day}) \times 0.864 = 61.3 \text{ kg/site - day to land or incineration}$$

Equipment Cleaning Releases to Incineration or Landfill (Release 7)

$$\text{Elocal}_{\text{equipment_cleaning}} = Q_{\text{app_chem_site_day}} \times F_{\text{equipment_cleaning}} \quad [\text{Eqn. 4-5}]$$

$$\text{Elocal}_{\text{equipment_cleaning}} = \frac{95 \text{ kg chem.}}{\text{site - day}} \times \frac{0.02 \text{ kg chem released}}{\text{kg chem used}}$$

$$\text{Elocal}_{\text{equipment_cleaning}} = \frac{1.9 \text{ kg chem. released}}{\text{site - day}}$$

...over 105 days/year from 1 site

Open Surface Losses to Air During Equipment Cleaning (Release 8)

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:

[Eqn. B-1]

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

Table 0-4. Summary of ChemSTEER Inputs for Release 8

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	MW _{chem}	g/mol	100
Vapor Correction Factor	F _{correction factor}	Dimensionless	1
Vapor Pressure	VP _{chem}	Torr	0.1
Air Speed	RATE _{air speed}	ft/min	100
Surface Area of Pool Opening	AREA _{opening}	cm ²	6,648
Temperature	TEMP _{ambient}	K	298
Diameter of Pool Opening	D _{opening}	cm	92
Pressure	P _{ambient}	Atm	1

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:

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

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

$$\text{Elocal}_{\text{air_sample}} = 0.013 \text{ kg chem. emitted/ site} - \text{day}$$

...over 105 days/year from 1 site.

Occupational Exposure Assessments for Application of Radiation Curable Products

Total Number of Workers Potentially Exposed to the Chemical

It is assumed that the chemical is used in a coating formulation and falls under the *Metal Products and Machinery Manufacturing* end-use market. 24 radiation curable coating application workers are potentially exposed to the chemical at each site (see Table 5-2; Metal Products and Machinery); therefore, the total number of workers is calculated as:

$$24 \frac{\text{workers}}{\text{site}} \times N_{\text{sites}} = 24 \frac{\text{workers}}{\text{site}} \times 1 \text{ sites} = 24 \text{ total radiation curable application workers}$$

Note that all 24 workers are assumed to be exposed during each of the exposure activities performed at each of the thirteen application sites.

Exposure During Unloading Liquid Formulations (Exposure A)

Inhalation Exposure to Vapor:

The density of the liquid product 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 0-5. Summary of ChemSTEER Inputs for Exposure A

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	$F_{\text{mixing_factor}}$	Dimensionless	Typical = 0.5 Worst Case = 0.1
Temperature	$TEMP_{\text{ambient}}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{\text{ventilation}}$	ft ³ /min	Typical = 3000 Worst Case = 500
Vapor Generation Rate	$Q_{\text{vapor_generation}}$	g/s	Typical = 3.1×10^{-4} Worst Case = 6.2×10^{-4}
Breathing Rate	$RATE_{\text{breathing}}$	m ³ /hour	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$RATE_{\text{fill}}$	containers/hr	20
Duration of Exposure	$TIME_{\text{exposure}}$	hours/day	0.03

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

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

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

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

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

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

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

$$\text{EXP}_{\text{inhalation}} = (0.41 \text{ to } 25) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times \left(\frac{69 \text{ containers/site - yr}}{105 \text{ days/yr} \times 20 \text{ containers/hr}} \right)$$

$$\text{EXP}_{\text{inhalation}} = 0.02 - 1.03 \text{ mg chem./day}$$

...over 105 days/year.

Dermal Exposure to Liquids:

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

$$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [\text{Eqn. 5-1}]$$

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

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

...over 105 days/year

Exposure to Liquids from Sampling Raw Materials (Exposure B)

Inhalation Exposure to Vapor:

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

Table 0-6. Summary of ChemSTEER Inputs for Exposure B

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	$F_{\text{mixing_factor}}$	dimensionless	Typical = 0.5 Worst Case = 0.1
Temperature	$TEMP_{\text{ambient}}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{\text{ventilation}}$	ft ³ /min	Typical = 3000 Worst Case = 500
Vapor Generation Rate	$Q_{\text{vapor_generation}}$	g/s	Typical = 4.1×10^{-6} Worst Case = 3.3×10^{-5}
Breathing Rate	$RATE_{\text{breathing}}$	m ³ /hour	1.25
Molar Volume	V_{molar}	L/mol	24.45
Duration of Exposure	$TIME_{\text{exposure}}$	hours/day	1

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

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

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

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

$$C_{\text{chem_mass}} = 5.7 \times 10^{-3} \text{ mg/m}^3 \text{ for typical and } C_{\text{chem_mass}} = 1.4 \text{ mg/m}^3 \text{ for worst case}$$

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

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

$$\begin{aligned} EXP_{\text{inhalation}} &= (5.7 \times 10^{-3} \text{ to } 1.4) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times 1 \text{ hr/day} \\ EXP_{\text{inhalation}} &= 7.1 \times 10^{-3} - 1.7 \text{ mg chem./day} \\ &\dots \text{over } 105 \text{ days/year.} \end{aligned}$$

Dermal Exposure:

The potential worker exposure to the chemical within the liquid product is calculated using the *EPA/OPPT 1-Hand Dermal Contact with Liquid Model*:

$$\begin{aligned}
 \text{EXP}_{\text{dermal}} &= Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} & [\text{Eqn. 5-2}] \\
 &= \left[\frac{0.7 \text{ to } 2.1 \text{ mg prod.}}{\text{cm}^2 \text{ - incident}} \right] \times 420 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.7 \text{ mg chem.}}{\text{mg prod.}} \\
 \text{EXP}_{\text{dermal}} &= \frac{206 - 618 \text{ mg chem.}}{\text{day}} \\
 &\quad \dots \text{over 105 days/year}
 \end{aligned}$$

Exposure to Liquids During Container Cleaning (Exposure C)

Inhalation Exposure to Vapor:

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

Table 0-7. Summary of ChemSTEER Inputs for Exposure C

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	$F_{\text{mixing_factor}}$	dimensionless	Typical = 0.5 Worst Case = 0.1
Temperature	$\text{TEMP}_{\text{ambient}}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$\text{RATE}_{\text{ventilation}}$	ft ³ /min	Typical = 3000 Worst Case = 500
Vapor Generation Rate	$Q_{\text{vapor_generation}}$	g/s	1.2×10^{-5}
Breathing Rate	$\text{RATE}_{\text{breathing}}$	m ³ /hour	1.25
Molar Volume	V_{molar}	L/mol	24.45
Fill Rate	$\text{RATE}_{\text{fill}}$	containers/hr	20

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

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

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

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

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

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

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

$$EXP_{\text{inhalation}} = (0.017 \text{ to } 0.49) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times \left(\frac{164 \text{ containers/site - yr}}{105 \text{ days/yr} \times 20 \text{ containers/hr}} \right)$$

$$EXP_{\text{inhalation}} = 0.002 - 0.05 \text{ mg chem./day}$$

...over 105 days/year.

Dermal Exposure to Liquids:

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*:

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [\text{Eqn. 5-3}]$$

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

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

...over 105 days/year

Exposure During Coating Operations (Exposure D)

Inhalation Exposure to Mist:

Since the spray coating technology is not known, the default particulate concentration in air can be used (using a conventional spray gun) from Table 5-6.

Table 0-8. Summary of ChemSTEER Inputs for Exposure D

Input Parameter	Variable	Units	ChemSTEER Input
Breathing Rate	RATE _{breathing}	m ³ /hour	1.25
Mass Concentration of Particulate in Air	C _{part_air}	mg/m ³	2.3
Duration of Exposure	TIME _{exposure}	hrs/day	8

The mass concentration of the chemical in air and the standard default values presented in Table 5-6 for the spray coating activity are used to estimate the amount of inhalation exposures per worker using the following equation:

$$EXP_{\text{inhalation}} = C_{\text{part_air}} \times TIME_{\text{exposure}} \times RATE_{\text{breathing}} \times F_{\text{chem_form}} \quad [\text{Eqn. 5-4}]$$

$$EXP_{\text{inhalation}} = 2.3 \text{ mg product/m}^3 \times 8\text{hr/day} \times 1.25 \text{ m}^3/\text{hr} \times 0.7\text{mg chemical/mg product}$$

$$EXP_{\text{inhalation}} = 16.1 \text{ mg chem./worker - day}$$

...over 105 days/yr.

Dermal Exposure to Liquids:

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

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

$$= \left[\frac{1.3 \text{ to } 10.3 \text{ mg comp.}}{\text{cm}^2 - \text{incident}} \right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.7 \text{ mg chem.}}{\text{mg prod.}}$$

$$EXP_{\text{dermal}} = \frac{764 - 6,056 \text{ mg chem.}}{\text{day}}$$

...over 105 days/year

Exposure to Liquids During Equipment Cleaning of Applicators and Other Process Equipment (Exposure E)

Inhalation Exposure to Vapor:

Using the vapor generation rate calculated in Release 8 and the CEB standard model for estimating inhalation exposure due to evaporation of volatile chemicals (*EPA/OPPT Mass Balance Model*), ChemSTEER calculates the worker exposure using the following equations:

Table 0-9. Summary of ChemSTEER Inputs for Exposure E

Input Parameter	Variable	Units	ChemSTEER Input
Mixing Factor	$F_{\text{mixing_factor}}$	dimensionless	Typical = 0.5 Worst Case = 0.1
Temperature	$TEMP_{\text{ambient}}$	K	298
Molecular Weight	MW_{chem}	g/mol	100
Ventilation Rate	$RATE_{\text{ventilation}}$	ft ³ /min	Typical = 3000 Worst Case = 500
Vapor Generation Rate	$Q_{\text{vapor_generation}}$	g/s	9.2×10^{-4}
Breathing Rate	$RATE_{\text{breathing}}$	m ³ /hour	1.25
Molar Volume	V_{molar}	L/mol	24.45
Duration of Exposure	$TIME_{\text{exposure}}$	hours/day	1

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

$$C_{\text{chem_volumetric}} = 0.31 - 9.3 \text{ ppm}$$

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

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

$$C_{\text{chem_mass}} = \frac{(0.31 \text{ to } 9.3) \text{ ppm} \times 100 \text{ g/mol}}{24.45 \text{ L/mol}}$$

$$C_{\text{chem_mass}} = 1.3 - 38.2 \text{ mg/m}^3$$

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

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

$$\text{EXP}_{\text{inhalation}} = (1.3 \text{ to } 38.2) \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times 1 \text{ hrs/site} - \text{day}$$

$$\text{EXP}_{\text{inhalation}} = 6.4 - 191.2 \text{ mg chem./day}$$

...over 105 days/year.

Dermal Exposure:

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

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

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

...over 105 days/year

DATA GAPS/UNCERTAINTIES AND FUTURE WORK

This ESD is primarily based on information provided by RadTech and U.S. Census Bureau data. These sources provide extensive industry market and background information and process descriptions that have been presented in this ESD. However, EPA wishes to make this ESD as detailed and up-to-date as possible, such that the risk-screening assessments reflect current industrial practices. 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 and application site.

OECD is currently reviewing this draft ESD. RadTech has also agreed to review this ESD and provide input. Reviewers should feel free to provide additional information and data that could further enhance and improve the methods described in this ESD, as well as to recommend additional resources that may be useful to the development of this ESD.

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

1. The ESD incorporates average facility use rates that are estimated using the radiation curable products industry market data and several different sources of numbers for U.S. application sites. The quality of these facility use rates could be improved with additional data on typical application site product use rates for the various end-use markets and application methods (e.g., kg/batch, kg/site-day).
2. The ESD assumes that all radiation curable products used at an application site contain a component (containing the chemical of interest). Additional information on the validity of these assumptions would improve the quality of the estimates. In other words, might radiation curable products use one of several available types of stabilizers when formulating a radiation curable product that may or may not contain the chemical of interest?
3. The ESD assumes that application sites either use the radiation curable product containing the chemical of interest at a facility or use other formulations at a facility, but not both. Additional information on the validity of these assumptions would improve the quality of the estimates. In other words, might applicators alternately use one of several available types of formulations for end-products of the same type?
4. No specific information was found on the typical release control technologies employed in radiation curable application 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.
5. Specific data on the numbers of workers performing the various exposure activities in the radiation curable application processes were not found. Therefore, the ESD assumes that the number of workers per facility estimated for each radiation curable product and end-use market (Table 5-2) perform each of the exposure activities. Additional information on the numbers workers performing each exposure activity would further enhance the calculations.

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

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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:

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- 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).

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 - “Ophthalmic Goods Manufacturing”:
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 - “Reconstituted Wood Product Manufacturing”:
<http://www.census.gov/prod/ec02/ec0231i321219t.pdf>
 - “Resilient Floor Covering Manufacturing”:
<http://www.census.gov/prod/ec02/ec0231i326192t.pdf>
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<http://www.census.gov/prod/ec02/ec0231i321918t.pdf>
 - “Metal Can Manufacturing”: <http://www.census.gov/prod/ec02/ec0231i332431t.pdf>
 - Other Metal Container Manufacturing”:
<http://www.census.gov/prod/ec02/ec0231i332439t.pdf>
 - “Printing Machinery and Equipment Manufacturing”:
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Appendix A

ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES

Summary of Release and Exposure Estimation Equations for Application 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 application of radiation curable products. A description of each input variable and associated default is provided in Table A-2.

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

General Facility Estimates	
Annual Facility Product Use Rate ($Q_{app_site_yr}$):	$Q_{app_site_yr} = Q_{app_site_use_rate} \times F_{app_radcur}$ (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 Application Sites (N_{app_sites}):	$N_{app_sites} = \frac{Q_{chem_yr}}{Q_{app_site_yr} \times F_{chem_form}}$ (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> $Q_{app_site_y} = \frac{Q_{chem_yr}}{N_{app_sites} \times F_{chem_form}}$ <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>	
Daily Use Rate of the Chemical of Interest (kg chemical/site-day) ($Q_{app_chem_site_day}$):	$Q_{app_chem_site_day} = \frac{Q_{app_site_yr} \times F_{chem_form}}{TIME_{app_working_days}}$ (Eqn. 3-4)
Annual Number of Radiation Curable Product Containers Emptied per Facility (containers/site-year) ($N_{form_cont_empty_site_yr}$):	$N_{form_cont_empty_site_yr} = \frac{Q_{app_chem_site_day} \times TIME_{app_working_days}}{F_{chem_form} \times Q_{cont_empty}}$ (Eqn. 3-5)

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)
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 4.4)
Container Residue	Water Landfill Incineration	<p>If $N_{\text{form_cont_empty_site_yr}}$ is fewer than $\text{TIME}_{\text{app_working_days}}$:</p> $\text{Elocal}_{\text{app_container_residue_disp}} = Q_{\text{cont_empty}} \times F_{\text{chem_form}} \times F_{\text{container_residue}} \times N_{\text{form_cont_empty_site_day}}$ <p>... released over $[N_{\text{form_cont_empty_site_yr}}]$ days/year from $[N_{\text{app_sites}}]$ sites (Eqn. 4-1a)</p> <p>If $N_{\text{form_cont_empty_site_yr}}$ is greater than $\text{TIME}_{\text{app_working_days}}$:</p> $\text{Elocal}_{\text{app_container_residue_disp}} = Q_{\text{app_chem_site_day}} \times F_{\text{container_residue}}$ <p>... released over $[\text{TIME}_{\text{app_working_days}}]$ days/year from $[N_{\text{app_sites}}]$ sites (Eqn. 4-1b)</p>
Container Cleaning (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.5)
Process Releases During Operations	Water Air Landfill Incineration	<p><i>Spray Coating</i></p> $\text{Elocal}_{\text{application_losses}} = Q_{\text{app_chem_site_day}} \times (1 - F_{\text{transfer_eff}})$ <p>... released over $[\text{TIME}_{\text{app_working_days}}]$ days/year from $[N_{\text{app_sites}}]$ sites (Eqn. 4-2)</p> <p>The releases can be partitioned to multi-media:</p> $\%_{\text{water}} = F_{\text{capture_eff}} \times (1 - F_{\text{solidrem_eff}}) \times 100$ (Eqn. 4-3a) $\%_{\text{air}} = (1 - F_{\text{capture_eff}}) \times 100$ (Eqn. 4-3b) $\%_{\text{land_inc}} = F_{\text{capture_eff}} \times F_{\text{solidrem_eff}} \times 100$ (Eqn. 4-3c) <p><i>Roll or Curtain Coating</i></p> <p>EPA/OPPT Generic Model to Estimate Application Loss Releases from Roll Coating and Curtain Coating Operations (See Section 4.7)</p> $\text{Elocal}_{\text{application_losses}} = Q_{\text{app_chem_site_day}} \times (1 - F_{\text{transfer_eff}})$ <p>... released over $[\text{TIME}_{\text{app_working_days}}]$ days/year from $[N_{\text{app_sites}}]$ sites (Eqn. 4-4)</p>
Equipment Cleaning	Landfill Incineration	<p>Continuous process:</p> $\text{Elocal}_{\text{air_equip_cleaning}} = Q_{\text{app_chem_site_day}} \times F_{\text{equipment_cleaning}}$ (Eqn. 4-5)

Release Calculations		
Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Equipment Cleaning (Volatile Releases)	Air	EPA/OPPT Penetration Model (See Section 4.9)

Occupational Exposure Calculations
<p>Number of Workers Exposed Per Site: See Section 5.2.</p>
<p>Exposure from Unloading Liquid Formulations:</p> <p><i>Inhalation:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.3)</p> <p><i>Dermal</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (\text{Eqn. 5-1})$ <p>... over [the lesser of $N_{\text{form_cont_empty_site_yr}}$ or $TIME_{\text{app_working_days}}$ (consistent with Section 4.2), up to 250] days per year</p>
<p>Exposure from Sampling Raw Material:</p> <p><i>Inhalation Exposure:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.4)</p> <p><i>Dermal Exposure:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (\text{Eqn. 5-2})$ <p>... over [$TIME_{\text{app_working_days}}$] days/year (consistent with Section 4.4)</p>
<p>Exposures During Container Cleaning:</p> <p><i>Inhalation:</i></p> <p>EPA/OPPT Mass Balance Inhalation Model (See Section 5.5)</p> <p><i>Dermal:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad (\text{Eqn. 5-3})$ <p>... over [the lesser of $N_{\text{form_cont_empty_site_yr}}$ or $TIME_{\text{app_working_days}}$ (consistent with Section 4.6), up to 250] days per year</p>

Occupational Exposure Calculations	
Exposure During the Coating Process:	
<i>Inhalation Exposure:</i>	
$EXP_{inhalation} = C_{part_air} \times TIME_{exposure} \times RATE_{breathing} \times F_{chem_form}$	(Eqn. 5-4)
... over [TIME _{app_working_days} (consistent with Section 4.7), up to 250] days per year.	
<i>Dermal Exposure:</i>	
$EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_form}$	(Eqn. 5-5)
... over [TIME _{app_working_days} (consistent with Section 4.7), up to 250] days per year.	
Exposure to Liquids During the Equipment Cleaning of Mixers and Other Process Equipment:	
<i>Inhalation Exposure:</i>	
EPA/OPPT Mass Balance Inhalation Model (See Section 5.7)	
<i>Dermal Exposure:</i>	
$EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_form}$	(Eqn. 5-6)
... over [the number of cleanings per year (consistent with Section 4.8), up to 250] days per year.	

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 _{part_air}	Mass concentration of particulate in air (based on application method)	2.3 mg/m ³ (conventional spray gun); for roll-coating, 0.04 mg/m ³ (low end) and 0.26 mg/m ³ (high end)	CEB, 1996 CEB, 1994
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 _{app_radcur}	Fraction of the total radiation curable type produced that incorporates the chemical of interest (kg product with chemical/kg total product produced)	1	EPA assumption
F _{capture_eff}	Fraction of mist captured in spray booth technology (kg mist captured/kg released)	0.90	
F _{chem_comp}	Mass fraction of the chemical of interest in the radiation curable component (kg chemical/kg component)	1	
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 radiation curable 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)	0.02	CEB, 1992a
F _{solidrem_eff}	Fraction of solid removed in the spray mist (kg solid removed/kg mist captured)	1.0	CEB, 1996
F _{transfer_eff}	Transfer efficiency of coating applications (kg transferred/kg applied)	0.25	EPA Assumption
N _{exp_incident}	Number of exposure incidents per day (incidents/day)	1	CEB, 2000
Q _{app_use_rate}	Total annual facility radiation curable product use rate (kg total product used/site-yr)	137,000 For unknown radiation curable product with release and exposure concerns.	See Table 3-2 for alternate values.

Variable	Variable Description	Default Value	Data Source
$Q_{\text{liquid_skin}}$	Quantity of liquid component or product remaining on skin (mg/cm ² -incident)	0.7 - 2.1 (dermal contact) 1.3 - 10.3 (dermal immersion)	CEB, 2000
$\text{RATE}_{\text{breathing}}$	Typical worker breathing rate (m ³ /hr)	1.25	CEB, 1991
$\text{RHO}_{\text{product}}$	Density of the radiation curable product (kg/L)	1	EPA assumption
$\text{RHO}_{\text{component}}$	Density of the radiation curable component (kg/L)	1	EPA assumption
$\text{TIME}_{\text{exposure}}$	Duration of exposure (hrs/day)	8	
$\text{TIME}_{\text{app_working_days}}$	Annual number of days the radiation curable product is applied (days/yr)	250	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).

Model Equations:

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

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

Where:

$$Q_{\text{vapor_generation}} = \text{Average vapor generation rate (g of chemical/sec)}$$

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

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).

$F_{\text{correction_factor}}$	=	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:

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

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

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.

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.

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).

Model Equations:

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

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

Where:

$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical of interest/sec)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default =1) ²

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).

²The 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.

VP _{chem}	=	Vapor pressure of the chemical of interest (torr)
RATE _{air_speed}	=	Air speed (EPA default = 440 feet/min; value must be > 100 feet/min for this model)
AREA _{opening}	=	Surface area of the static pool or opening (cm ² ; B × D _{opening} ² / 4)
TEMP _{ambient}	=	Ambient temperature (EPA default = 298 K)
D _{opening}	=	Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)

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

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

$$\text{Elocal}_{\text{air}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \quad [\text{B-4}]$$

Where:

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

References:

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

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

B.2.1.3 EPA/OAQPS AP-42 Loading Model

Model Description and Rationale:

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

This model is used as the default for estimating volatile air releases during both loading activities and unloading activities. This model is used for unloading activities because it is assumed while one vessel is being unloaded another is assumed to be loaded. The *EPA/OAQPS AP-42 Loading Model* is

used because it provides a more conservative estimate than either the *EPA/OPPT Penetration Model* or the *Mass Transfer Coefficient Model* for unloading activities.

Model Equations:

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

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

Where:

$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical/sec)
$F_{\text{saturation_factor}}$	=	Saturation factor (See Table B-1 for appropriate EPA default values)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$V_{\text{cont_empty}}$	=	Volume of the container (gallons; see Table B-1 for appropriate EPA default values)
$\text{RATE}_{\text{fill}}$	=	Fill rate (containers/hour; see Table B-1 for appropriate EPA default values)
$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default = 1) ¹
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
R	=	Universal Gas Constant (82.05 atm-cm ³ /mol-K)
$\text{TEMP}_{\text{ambient}}$	=	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)

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

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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.

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:					
Sampling Liquids (Indoors)	Not applicable	Typical: 2.5 ^a Worst Case: 10	Not applicable	1	1

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

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

B.2.2 Chemical Vapor Inhalation Model

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

B.2.2.1 EPA/OPPT Mass Balance Model

Model Description and Rationale:

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

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

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

Model Equations:

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

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

Where:

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

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

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

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

Where:

$C_{\text{chem_volumetric}}$	=	Volumetric concentration of the chemical of interest in air (ppm)
$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default = 1) ¹
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
P_{ambient}	=	Ambient pressure (Default = 760 torr)

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

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

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

Where:

$C_{\text{chem_mass}}$	=	Mass concentration of the chemical vapor in air (mg/m^3)
$C_{\text{chem_volumetric}}$	=	Volumetric concentration of the chemical vapor in air (ppm, see Equation B-7 or B-8, as appropriate)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
V_{molar}	=	Molar volume (Default = 24.45 L/mol at 25°C and 1 atm)

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

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

Where:

$EXP_{\text{inhalation}}$	=	Inhalation exposure to the chemical vapor per day (mg chemical/worker-day)
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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.

$C_{\text{chem_mass}}$	=	Mass concentration of the chemical vapor in air (mg/m^3 ; see Equation B-9]
$\text{RATE}_{\text{breathing}}$	=	Typical worker breathing rate (EPA default = $1.25 \text{ m}^3/\text{hr}$)
$\text{TIME}_{\text{exposure}}$	=	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	20				
Drums (Indoors)	55 Range: 20 to <100					
Totes (Indoors)	550 Range: 100 to <1,000					
Tank Trucks (Outdoors)	5,000 Range: 1,000 to <10,000	2	440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × RATE _{air_speed}) 5,280) ³ (Outdoors)		
Rail Car (Outdoors)	20,000 Range: 10,000 and up	1				
Equipment Cleaning Activities:						
Multiple Vessels (Outdoors)	Not applicable		440 (Outdoors)	Average: 237,600 Worst Case: 26,400 × (60 × RATE _{air_speed}) 5,280) ³ (Outdoors)	Typical: 0.5 Worst Case: 0.1	4
Single, Large Vessel (Outdoors)						1
Single, Small Vessel (Outdoors)						0.5
Sampling Activities:						
Sampling Liquids (Indoors)	Not applicable		100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical: 0.5 Worst Case: 0.1	1

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Activity Type (Location)	$V_{\text{cont empty}}$ (gallons)	$RATE_{\text{fill}}$ (containers/hour)	$RATE_{\text{air speed}}$ (feet/min)	$RATE_{\text{ventilation}}^a$	$F_{\text{mixing factor}}$	$TIME_{\text{exposure}}$ (hours/day)
Other Activities:						
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate models with the <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 $RATE_{\text{air speed}}$ should be set to 440 feet/min, as a default in determining the worst case $RATE_{\text{ventilation}}$.

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:

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

Where:

$E_{\text{local}_{\text{container_residue_disp}}}$	=	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

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

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

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

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

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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)) \times (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.

$$E_{\text{local}_{\text{dust}_{\text{fugitive}}}} = Q_{\text{transferred}} \times F_{\text{dust}_{\text{generation}}} \times (1 - F_{\text{dust}_{\text{control}}}) \quad [\text{B-13}]$$

Where:

$E_{\text{local}_{\text{dust}_{\text{fugitive}}}}$	=	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)
$F_{\text{dust}_{\text{generation}}}$	=	Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$F_{\text{dust}_{\text{control}}}$	=	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.

$$E_{\text{local}_{\text{dust}_{\text{captured}}}} = Q_{\text{transferred}} \times F_{\text{dust}_{\text{generation}}} \times F_{\text{dust}_{\text{control}}} \quad [\text{B-14}]$$

Where:

$E_{\text{local}_{\text{dust}_{\text{captured}}}}$	=	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*.
- *EPA/OPPT UV Roll Coating Inhalation Model (Non-volatiles)*

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

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).

		default 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) \times Number of containers/worker-shift
Container Cleaning	Quantity of residue in each container (kg/container) \times 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 \times 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:

$C_{\text{chem_mass}}$	=	Mass concentration of the chemical in air (mg/m^3)
$C_{\text{total_mass}}$	=	Mass concentration of total particulate (containing the chemical) in air (EPA default = $15 \text{ mg}/\text{m}^3$, 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)

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).

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 = $1.25 \text{ m}^3/\text{hr}$)
$\text{TIME}_{\text{exposure}}$	=	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.6.3 EPA/OPPT UV Roll Coating Inhalation Model (non-volatiles)

Model Description and Rationale:

The EPA/OPPT UV Roll Coating Inhalation Model utilizes worst case and typical exposure factors to estimate the amount of chemical inhaled by a worker who conducts activities near roll coater(s) using coatings, inks or adhesives containing the chemical.

The worst case and typical exposure factor data were derived from monitoring data for Ink Fly Misting of UV-Curable Coating used in Offset Lithography. The range of 0.04 to $0.26 \text{ mg}/\text{m}^3$ includes only data for the personal samples. Personal monitors were positioned in the operators' breathing zones, and area monitors were positioned at head height in the operators' area close to the print rollers. Collection media from monitors were solvent extracted, and the soluble fraction were assumed to be "ink fly" or ink misting as the ink film splits in transferring from roller to roller.

Model Equations:

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

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.

$$C_{\text{chem_mass}} = C_{\text{total_mass}} \times F_{\text{chem}} \quad [\text{B-18}]$$

Where:

$C_{\text{chem_mass}}$ = Mass concentration of the chemical in air (mg/m^3)
 $C_{\text{total_mass}}$ = Mass concentration of total particulate or non-volatile portion of mist in air (mg/m^3)

Output 1:

Default: 0.04 (Low end of range)

Non-default Option: 0.26 (High end of range)

Output 2:

Default: 0.26 (High end of range)

Non-default Option: 0.04 (Low end of range)

F_{chem} = Weight fraction of the chemical of interest in the particulate material or non-volatiles fraction of mist (default: lesser of $(Y_{\text{mist}}/Y_{\text{sf}})$ or 1)

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-18, to calculate the inhalation exposure to the particulate chemical using the following equation:

$$\text{EXP}_{\text{inhalation}} = C_{\text{chem_mass}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \quad [\text{B-19}]$$

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-19)

$\text{RATE}_{\text{breathing}}$ = Typical worker breathing rate (EPA default = $1.25 \text{ m}^3/\text{hr}$)

$\text{TIME}_{\text{exposure}}$ = Duration of exposure for the activity (EPA default = 8 hours/worker-day¹)

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

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.

a specific surface area of the skin that is contacted by a material containing the chemical of interest, as well as a specific surface density of that material in estimating the dermal exposure. The models also assume *no use of controls or gloves* to reduce the exposure. These assumptions and default parameters are defined based on the nature of the exposure (e.g., one hand or two hand, immersion in material, contact with surfaces) and are documented in the references listed in this section.

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

Model Equation:

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

$$EXP_{\text{dermal}} = AREA_{\text{surface}} \times Q_{\text{remain_skin}} \times F_{\text{chem}} \times N_{\text{event}} \quad [\text{B-20}]$$

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;*

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.

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

For several categories of exposure, EPA uses qualitative assessments to estimate dermal exposure. Table B-10 summarizes these categories and the resulting qualitative dermal exposure assessments.

References:

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

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

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. Breelen, J. Marquart, and J.J. van Hemmen: Skin Exposure to Calcium Carbonate in the Paint Industry. Preliminary Modeling of Skin Exposure Levels to Powders Based on Field Data (TNO Report V 96.064). Rijswijk, The Netherlands: TNO Nutrition and Food Research Institute, 1996.

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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.

Appendix C

**METHODOLOGY TO DERIVE THE TOTAL ANNUAL FACILITY USE RATE FOR
APPLICATION SITES**

Facility-specific information on the use rate of radiation curable products was not available. This appendix presents two options that may be used to determine a typical total annual facility use rate ($Q_{app_site_use_rate}$) at an application site for the radiation curable products industry. Option 1 presents a “top-down” approach that estimates the facility use rate based on total market production data. Option 1 also provides a method for estimating the number of workers exposed per site for each general end use category. Option 2 presents a “bottom-up” approach based on assumed operating parameters. Option 2 is application method-specific and is an alternative approach to estimate the total annual facility use rate if the facility parameters are known.

Option 1

Option 1 presents a “top-down” methodology that is independent of the application method and can be used to derive the total annual facility use rate (Table 3-2). The following resources were referenced for end-use market production and facility data to generate the estimates presented in this ESD:

- RadTech 2005 Industry Data – Provides 2005 production volume data by end use market;
- 2002 U.S. Census Bureau Economic Census Data – Provides data on the total number of U.S. sites and workers for several end-use categories;
- 2007 U.S. Census Bureau Current Industrial Report on Paint and Allied Products (Table 2) – Provides data on the 2006 U.S. production for products related to the paints and coatings industry;
- 2005 Impact Marketing – Provides U.S. production information for the adhesive market; and
- 1997 U.S. Census of Manufacturers, Industry Series, Printing Ink Manufacturing – Provides data on the U.S. production of several ink products.

In lieu of facility-specific use data for radiation curable products, the methodology that is discussed below is an attempt to capture the radiation curable products market within the various industries. The following general assumptions were made when developing this methodology:

1. A relationship can be developed between the data sources.
2. Production data were unchanging between the range of data (i.e., between 1997 and 2006).
3. The number of radiation curable application sites is a portion of the total number of coating, inks, and adhesives application sites.

RadTech, a leading trade association in the industry, provided the total volume of radiation curable products used by end use market; however, the number of radiation curable application sites is not known and the facility use rate could not be determined. Therefore, to estimate the facility use rate, the number of radiation curable application sites need to be determined. In conjunction with RadTech’s radiation curable production data and the total

number of application sites estimated from readily available sources, the total annual facility use rate ($Q_{app_site_use_rate}$) for radiation curable products can be derived.

The steps taken to estimate the number of radiation curable application sites (and to ultimately calculate the total annual facility use rate) are:

1. Aggregate the radiation curable production volumes for the given end uses (in Table 1-2) into general end use categories. These general categories help to consolidate data between the different sources that were identified previously.
2. Determine the related production volumes for subcategories that fall under the general end use categories and determine the market share of radiation curable products in the total production of coatings, inks, or adhesives used in these industries.
3. Determine the total number of radiation curable application sites based on the market share of radiation curable products and total number of application sites. Calculate the facility use rate based on the end-use production volumes provided by RadTech (in Table 1-2) and the number of radiation curable application sites.

Step 1:

Table 1-2 presents detailed information on the current North American market for radiation curable product provided by RadTech. The end use markets were then grouped into general end use categories as shown in Table C-1. The total North American production volume for each general category is the sum of the production volumes for each end use market. Note that the United States production volume was assumed equal to the North American production and will result in more conservative estimates.

Table C-1. Total 2005 North American Radiation Curable Production Volume by General End Use

End Use Market	North American Radiation Curable Production Volume (million kg/yr) ^a	General End Use Category	Total North American Radiation Curable Production Volume (million kg/yr) ^b		
Automotive Lens & Reflector	2.000	Automotive	2.740		
Interior Trim	0.740				
Optical Fiber – Coatings, Inks, and Adhesives	3.150	Optical	3.168		
Optical Adhesives	0.018				
Coatings – Fillers	6.100	Furniture (Wood)	17.025		
Coatings – Stains and Sealers	1.150				
Coatings – Pigmented Coatings	3.175				
Coatings – Clear Finishes	6.600				
Vinyl Flooring	4.500	Flooring	7.600		
Wood – Flooring (Prefinished)	2.300				
Plastics – Flooring (Prefinished)	0.800				
Metal Decorating – Inks ^c	0.900	Metal Products and Machinery	10.350		
Metal Decorating – Overprint Varnishes	0.875				
Metal Decorating – Can End Varnishes	0.425				
Metal – Tubing & Pipe	0.600				
Metal – Name Plates	0.018				
Metal – Wire Coating	0.011				
Coatings – Printing Plates ^d	7.200				
Coatings – Stereolithography/Solid Modeling	0.320				
Overprint Varnish, Clear – General	22.000			Paper, Paperboard, Film, and Foil Finishes	25.000
Overprint Varnish, Clear – Specialty	3.000				
Letterpress Inks	0.700	Letterpress Inks	0.700		
Screen Inks	6.700	Screen Printing Inks	6.700		
Off-set (Lithography)	7.900	Lithographic Inks	7.900		
Flexography	6.000	Flexographic Inks	6.000		
Inkjet Inks	0.350	Inkjet Inks	0.350		
Laminating Adhesives	3.200	Laminating Adhesives	3.200		
Silicone Release Coatings	1.050	Pressure Sensitive Adhesives	1.500		
Pressure Sensitive	0.450				

End Use Market	North American Radiation Curable Production Volume (million kg/yr) ^a	General End Use Category	Total North American Radiation Curable Production Volume (million kg/yr) ^b
Electronic Adhesives	0.350	Electronic Assembly	1.250
Conformal Coatings	0.900		

a – RadTech, 2005. See Table 1-2.

b – The total North American radiation curable production volume for each general end-use category is a sum of the North American production volumes for the individual end-use markets included under the category.

c – Metal decorating inks are used in metal can manufacturing and are intentionally included in the Metal Products and Machinery category (and not in one of the inks categories).

d – Coatings are applied on metal printing plates and are further used in printing processes. This end use market is included in the Metal Products and Machinery category (and not in one of the inks categories) because the application of the coatings onto printing plates is closely related to metal coating applications.

Step 2:

Table C-2 presents the estimation of the total U.S. production volume for each general end-use category. Note that the total U.S. production volume represents all coatings, inks, and adhesives used in the general use category, not just radiation curable products (e.g., the values for automotive coatings represents water-based coatings, solvent-based coatings, and radiation curable coatings). The total volume of coatings, inks, or adhesives for each general end use category was estimated from the 2006 data in the Current Industrial Report (CIR) for Paint and Allied Products, the 2005 Impact Marketing Report for Adhesives, and the 1997 Census data on Printing Ink Manufacturing.

The 2006 data in the CIR involved several subcategories that may fall under the general use category. Selection of the subcategories was based on the following criteria:

1. The type of coating is included within the scope of the ESD. Powder coatings and architectural coatings were excluded from the total calculated production volume.
2. The subcategory fits within the description of end use markets identified in RadTech sources.
3. The subcategory has a potential to include other end use markets identified in RadTech sources but not explicitly identified in the CIR.

The total production volume was calculated using the production volumes of the subcategories that met one of the three criteria listed above. Also, 2006 Census data are provided in units of thousands of gallons, which were converted to million kg per year by applying a conversion factor of 0.0038. The density of coating, ink, and adhesive products were assumed to be the density of water (1 kg/L). The addition of components such as fillers and pigments in radiation curable products may result in a product that is denser than water. In lieu of industry-specific information, this density assumption provides a more conservative estimate of the production volume for radiation curable products.

Table C-2. Determination of Total U.S. Production Volume by General End Use Category

General End Use Category	Subcategories	U.S. Production Volume (thous. gallons/yr)	U.S. Production Volume (million kg/yr) ^d	Total U.S. Production Volume (million kg/yr)
Automotive ^a	Automobile parts finishes	5,853	22.2	22.2
Optical ^a	Special-purpose coatings, n.s.k.	841	3.2	6.5
	Electrical insulating coatings	880	3.3	
Furniture (Wood) ^a	Wood furniture, cabinet, and fixture finishes	42,661	161.5	161.5
Flooring ^a	Other industrial product finishes	34,985	132.4	171.5
	Wood and composition board flat stock finishes	10,332	39.1	
Metal Products and Machinery ^a	Container and closure finishes	33,345	126.2	135.0
	Product finishes for original equipment manufacturers (OEM)	2,337	8.8	
Paper, Paperboard, Film, and Foil Finishes ^a	Paper, paperboard, film, and foil finishes, including business equipment finishes	14,219	53.8	53.8
Letterpress Inks ^b	Letterpress Inks	-	72.9	72.9
Screen Printing Inks ^b	Screen Printing Inks	-	11.9	11.9
Lithographic Inks ^b	Lithographic Inks	-	373.8	373.8
Flexographic Inks ^b	Flexographic Inks	-	143.7	143.7
Inkjet Inks ^b	Inkjet Inks	-	158.9	158.9
Laminating Adhesives ^c	Miscellaneous	-	209.0	209.0
Pressure Sensitive Adhesives ^c	Pressure Sensitive Adhesives	-	318.0	318.0
Electronic Assembly ^c	Electronic Adhesives	-	34.0	34.0

n.s.k not specified by kind

a – USCB, 2007. 2006 production data provided.

b – USCB, 1999, as cited in CEB, 2000b.

c – Impact Marketing, 2005. 2003 production data provided.

d – U.S. production volume (million kg/yr) = U.S. production volume (thous. gallons/yr) × 3785 L/ thous. gallons × 1 kg/L × 1/1,000,000

Once the radiation curable production volumes and the overall total U.S. production volumes are determined, the radiation curable product market share is calculated, as shown in Table C-3. The radiation curable product market share is the fraction of the radiation curable market in the overall market for each general end-use category. Please note that the total North American radiation curable product production volume is assumed equal to the United States production.

Table C-3. Total Market Share of Radiation Curable Products by General End Use Category

General End Use Category	Total North American Radiation Curable Production Volume (million kg/yr)	Total U.S. Production Volume (million kg/yr)	Total Market Share (%) ^a
Automotive	2.740	22.2	12.3
Optical	3.168	6.5	48.7
Furniture (Wood)	17.025	161.5	10.5
Flooring	7.600	171.5	4.4
Metal Products and Machinery	10.350	135.0	7.7
Paper, Paperboard, Film, and Foil Finishes	25.00	53.8	46.5
Letterpress Inks	0.700	72.9	1.0
Screen Printing Inks	6.700	11.9	56.3
Lithographic Inks	7.900	373.8	2.1
Flexographic Inks	6.000	143.7	4.2
Inkjet Inks	0.350	158.9	0.2
Laminating Adhesives	3.200	209.0	1.5
Pressure Sensitive Adhesives	1.500	318.0	0.5
Electronic Assembly	1.250	34.0	3.7

a – Total market share (%) = Total North American radiation curable production volume (by end use category) ÷ Total U.S. production volume × 100%

Step 3:

The Census' Current Industrial Reports provided production data but not the number of sites. 2002 Economic Census data provided information on the number of sites for each general end use category. Because most of the general categories may apply to a number of industries (by NAICS codes), the total number of U.S. sites is the sum of the sites for each applicable NAICS code, as shown in Table C-4.

Due to the various sources of information that are referenced, several assumptions were made in selecting the appropriate NAICS codes for each general end use category that can also be related to the subcategories (from which production data were found for the general categories). Selection of the NAICS codes was based on the following criteria:

1. The NAICS code fits within the description of the end use markets identified in RadTech sources.

2. The NAICS codes fits within the general end use markets identified in RadTech sources, but further clarified using a web-based search.
3. The NAICS codes fits within the description of primary uses identified using a web-based search.

Table C-5 provides justification for the inclusion (or exclusion) of certain NAICS codes in each general end use category.

Table C-4. Total U.S Application Sites by General End Use

General End Use Category	Applicable NAICS^a	NAICS Category	Number of Sites	Total U.S. Sites
Automotive	336321	Vehicular lighting equipment	95	164
	3363601	Automobile trimmings	69	
Optical	335921	Fiber optic cable manufacturing	96	223
	3391153	Ophthalmic glass focal lenses	6	
	3391155	Ophthalmic plastic focal lenses	48	
	334613	Magnetic and optical recording media manufacturing	173	
Furniture (Wood)	337110	Wood kitchen cabinet and countertop manufacturing	9,557	14,518
	337122	Nonupholstered wood household furniture manufacturing	4,114	
	337211	Wood office furniture manufacturing	569	
	321219	Reconstituted wood product manufacturing	278	
Flooring	326192	Resilient floor coverings	59	448
	3219185	Other wood millwork products, including stairwork, exterior millwork, and softwood flooring	287	
	3219187	Hardwood flooring	102	
Metal Products and Machinery	332431	Metal can manufacturing	211	3,941
	332439	Other metal container manufacturing	412	
	332812	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	2,480	
	332996	Fabricated pipe and pipe fitting manufacturing	782	
	3332931	Printing presses, offset lithographic	27	

General End Use Category	Applicable NAICS ^a	NAICS Category	Number of Sites	Total U.S. Sites
	3332933	Printing presses, other than lithographic	29	
Paper, Paperboard, Film, and Foil Finishes	322221	Coated and laminated packaging paper and plastic film manufacturing	116	759
	322222	Coated and laminated paper manufacturing	541	
	322223	Plastic, foil, and coated paper bag manufacturing	41	
	322226	Surface-coated paperboard manufacturing	61	
Letterpress Inks	3231193	Label and wrapper printing (letterpress)	36	348
	3231199	Advertising printing (letterpress)	93	
	323119C	Other commercial and general job printing (letterpress)	219	
Screen Printing Inks	323113	Commercial screen printing	4,417	4,417
Lithographic Inks	323110	Commercial lithographic printing	15,606	15,606
Flexographic Inks	323112	Commercial flexographic printing	895	895
Inkjet Inks	323114	Quick printing	7,694	9,190
	323115	Digital printing	1,133	
	313312	Textile and fabric finishing mills	363	
Laminating Adhesives	322221	Coated and laminated packaging paper and plastic film manufacturing	116	493
	322223	Plastic, foil, and coated paper bag manufacturing	41	
	322225	Laminated aluminum foil rolls and sheets for flexible packaging uses	42	
	3261300	Thermosetting plastics laminates (excluding flexible packaging uses)	294	
Pressure Sensitive Adhesives	3222226	Wall coverings	22	196
	3222223	Gummed products	14	
	3222225	Pressure-sensitive products	160	
Electronic Assembly	334413	Semiconductor and related device manufacturing	1,032	1,532
	334418B	Printed circuit assembly (loaded boards and modules)	500	

a – USCB, 2002.

Table C-5. Justification for the Inclusion (or Exclusion) of NAICS Categories

General End Use Category	Applicable NAICS ^a	NAICS Category	Justification
Automotive	336321	Vehicular lighting equipment	Based on end use market information from RadTech (shown in Table C-1), automotive coatings are only used for interior trim and lens and reflector manufacturing. Only these NAICS categories were included.
	3363601	Automobile trimmings	
Optical	335921	Fiber optic cable manufacturing	Based on end use market information from RadTech (shown in Table C-1), optical fiber manufacturing was identified. Literature search for optical radiation curable adhesives primarily indicate uses in optical media and optical lens manufacturing. The RadTech primer also identified uses in optical media (RadTech, 1995).
	3391153	Ophthalmic glass focal lenses	
	3391155	Ophthalmic plastic focal lenses	
	334613	Magnetic and optical recording media manufacturing	
Furniture (Wood)	337110	Wood kitchen cabinet and countertop manufacturing	The RadTech primer identifies two categories of wood finishing applications: flat line finishing and three-dimensional curing of preassembled furniture (RadTech, 1995). (Flat line finishing wood applications are identified under the Flooring category.) Also identified in the primer is the use in wood filler-particle board and wall paneling. Radiation curable products are applied in a larger scale; therefore, NAICS categories such as <i>Custom Architectural Woodwork and Millwork Manufacturing</i> (337212) are probably not applicable.
	337122	Nonupholstered wood household furniture manufacturing	
	337211	Wood office furniture manufacturing	
	321219	Reconstituted wood product manufacturing	
Flooring	326192	Resilient floor covering manufacturing	Based on end use market information from RadTech (shown in Table C-1) and in the RadTech primer, the flooring category involves vinyl flooring and prefinished flooring (plastic or wood). All NAICS categories involving flooring were included.
	3219185	Other wood millwork products, including stairwork, exterior millwork, and softwood flooring	
	3219187	Hardwood flooring	
Metal Products and Machinery	332431	Metal can manufacturing	Based on end use market information from RadTech (shown in Table C-1), the NAICS categories for metal can or container manufacturing was included. Printing plates and tubing and pipe were also identified by RadTech and the relative NAICS codes included. The NAICS code 332812 was included in this end use category to cover other coating processes, such as name plates and stereolithography.
	332439	Other metal container manufacturing	
	332812	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	
	332996	Fabricated pipe and pipe fitting manufacturing	
	3332931	Printing presses, offset lithographic	

General End Use Category	Applicable NAICS ^a	NAICS Category	Justification
	3332933	Printing presses, other than lithographic	
Paper, Paperboard, Film, and Foil Finishes	322221	Coated and laminated packaging paper and plastic film manufacturing	All NAICS codes for paper, paperboard, film, and foil finishes were identified.
	322222	Coated and laminated paper manufacturing	
	322223	Plastic, foil, and coated paper bag manufacturing	
	322226	Surface-coated paperboard manufacturing	
Letterpress Inks	3231193	Label and wrapper printing (letterpress)	All NAICS codes for letterpress applications were identified.
	3231199	Advertising printing (letterpress)	
	323119C	Other commercial and general job printing (letterpress)	
Screen Printing Inks	323113	Commercial screen printing	All NAICS codes for screen printing were identified.
Lithographic Inks	323110	Commercial lithographic printing	All NAICS codes for lithographic printing applications were identified.
Flexographic Inks	323112	Commercial flexographic printing	All NAICS codes for flexographic printing applications were identified.
Inkjet Inks	323114	Quick printing	Literature search for radiation curable inkjet inks indicate primary uses for digital printing, with growing applications for small office uses and in the textile industry.
	323115	Digital printing	
	313312	Textile and fabric finishing mills	
Laminating Adhesives	322221	Coated and laminated packaging paper and plastic film manufacturing	Based on the RadTech primer, commercial adhesive products include laminating and packaging applications (foils, papers, and films) and wood panel laminations. Literature search for radiation curable laminating adhesives indicate primary uses in flexible packaging.
	322223	Plastic, foil, and coated paper bag manufacturing	
	322225	Laminated aluminum foil rolls and sheets for flexible packaging uses	
	3261300	Thermosetting plastics laminates (excluding flexible packaging uses)	
Pressure Sensitive Adhesives	3222226	Wall coverings	The NAICS codes for wall coverings and gummed products were also included under this general end use category, since the basic concept of applying these products to a substrate are comparable, and therefore, related to pressure sensitive adhesives.
	3222223	Gummed products	
	3222225	Pressure-sensitive products	
Electronic Assembly	334413	Semiconductor and related device manufacturing	Based on end use market information from RadTech (shown in Table C-1), electronic adhesives and conformal coatings are typically used in electronic assembly of semiconductors or printed circuit boards, which are captured under these NAICS codes. Literature search for conformal coatings and electronic adhesives confirm the primary uses in these areas.
	334418B	Printed circuit assembly (loaded boards and modules)	

To determine the total number of U.S. radiation curable application sites, the total market share that was previously calculated for each general category (in Table C-3) is used. Table C-6 shows the determination of the radiation curable application sites by multiplying the percentage of the radiation curable market by the total number of sites for each general category. This assumes that each site either uses non-radiation curable products or radiation curable products, but not both. Note that the total number of U.S. radiation curable sites for each end use category encompasses all sites that apply radiation curable products (not just radiation curable products containing the chemical of interest). Refer to Section 3.6 for estimating the number of application sites that apply products containing the chemical of interest.

Table C-6. Total U.S. Radiation Curable Application Sites

General End Use Category	Total U.S. Sites	Total Market Share (%)	Total U.S. Radiation Curable Sites
Automotive	164	12.3	20
Optical	223	48.7	109
Furniture (Wood)	14,518	10.5	1524
Flooring	448	4.4	20
Metal Products and Machinery	3,941	7.7	303
Paper, Paperboard, Film, and Foil Finishes	759	46.5	353
Letterpress Inks	348	1.0	3
Screen Printing Inks	4,417	56.3	2487
Lithographic Inks	15,606	2.1	328
Flexographic Inks	895	4.2	38
Inkjet Inks	9,190	0.2	19
Laminating Adhesives	493	1.5	7
Pressure Sensitive Adhesives	196	0.5	1
Electronic Assembly	1,532	3.7	57

Table C-7 shows the average annual facility use rates, which are calculated using the known radiation curable production volume and the number of radiation curable sites estimated in the previous steps.

Table C-7. Average Annual Facility Use Rate of Radiation Curable Products for Application Sites

General End Use Category	Total U.S. Radiation Curable Production Volume (million kg/yr)	Total U.S. Radiation Curable Sites (sites)	Average Annual Facility Use Rate ($Q_{app \text{ site use rate}}$) (kg/site-yr)
Coatings			
Automotive	2.74	20	137,000
Optical	3.17	109	29,083
Furniture (Wood)	19.33	1,524	12,684
Flooring	5.30	20	265,000
Metal Products and Machinery	10.35	303	34,158
Paper, Paperboard, Film, and Foil Finishes	25.00	353	70,822
Inks			
Letterpress Inks	0.70	3	233,333
Screen Printing Inks	6.70	2,487	2,694
Lithographic Inks	7.90	328	24,085
Flexographic Inks	6.00	38	157,895
Inkjet Inks	0.35	19	18,421
Adhesives			
Laminating Adhesives	3.20	7	457,143
Pressure Sensitive Adhesives	1.50	1	1,500,000
Electronic Assembly	1.25	57	21,930

Several key assumptions are inherent in these default use rates:

Assumption #1: Application sites use only radiation curable products.

The values for the number of sites in Table C-7 include a fraction of sites within particular NAICS categories. For example, there are 164 automobile parts manufacturing sites under NAICS codes 336321 and 3363601 (Table C-4). Based on market share of radiation curable coatings in the overall coatings industry (Table C-3), it is assumed that 12.3% of the total number of sites use radiation curable coatings (20 sites).

Lacking more specific data on the number of application sites that use each type of coating, ink, or adhesive, the assumption is made that the production amounts are evenly distributed across the entire industry.

Assumption #2: All radiation curable formulations used at the application site contain the chemical of interest (i.e., $F_{\text{radcur}} = 1$ kg product incorporating the chemical/kg total product applied).

Some sites may apply multiple formulations at a site; however, no information or data were found that could be used to determine the extent to which this is the case. Therefore, an estimate for the number of different formulations used at a site containing the chemical of interest versus the total number of formulations used at the site (i.e. the fraction of the formulations containing the chemical) cannot be quantified. In lieu of site-specific information, it is assumed that all formulations used at the site contain the chemical. It is possible that the formulation containing the chemical of interest is not used in all of a particular product type, which would make the default production rate in Table C-7 tends toward the high end (i.e., less conservative for exposures, more conservative for releases).

Referring to Step 3, the 2002 Economic Census data also provided the total number of production workers for each applicable NAICS code, which is included in Table C-8. The total production workers column is a sum of all the applicable NAICS codes for each general category. The total number of production workers can be used in conjunction with the total number of U.S. sites calculated in Table C-4 to estimate the number of production workers per site (shown in Table C-9). Note that the number of production workers per site is assumed to be constant throughout the coatings, inks, and adhesives (including radiation curable coatings, inks, and adhesives) industry.

Table C-8. Number of Workers by General End Use

General End Use Category	Applicable NAICS ^a	NAICS Category	Number of Production Workers	Total Number of Production Workers
Automotive	336321	Vehicular lighting equipment	11,611	27564
	3363601	Automobile trimmings	15,953	
Optical	335921	Fiber optic cable manufacturing	3,750	11242
	3391153	Ophthalmic glass focal lenses	334	
	3391155	Ophthalmic plastic focal lenses	3,165	
	334613	Magnetic and optical recording media manufacturing	3,993	
Furniture (Wood)	337110	Wood kitchen cabinet and countertop manufacturing	100,210	233297
	337122	Nonupholstered wood household furniture manufacturing	95,890	
	337211	Wood office furniture manufacturing	19,230	
	321219	Reconstituted wood product manufacturing	17,967	
Flooring	326192	Resilient floor coverings	4,429	22488
	3219185	Other wood millwork products, including stairwork, exterior Millwork, and softwood flooring	8,748	
	3219187	Hardwood flooring	9,311	
Metal Products and Machinery	332431	Metal can manufacturing	17,332	96204
	332439	Other metal container manufacturing	14,138	
	332812	Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	43,445	
	332996	Fabricated pipe and pipe fitting manufacturing	20,059	
	3332931	Printing presses, offset lithographic	1,230	

General End Use Category	Applicable NAICS ^a	NAICS Category	Number of Production Workers	Total Number of Production Workers
	3332933	Printing presses, other than lithographic	NA	
Paper, Paperboard, Film, and Foil Finishes	322221	Coated and laminated packaging paper and plastic film manufacturing	3,420	32999
	322222	Coated and laminated paper manufacturing	25,244	
	322223	Plastic, foil, and coated paper bag manufacturing	2,055	
	322226	Surface-coated paperboard manufacturing	2,280	
Letterpress Inks	3231193	Label and wrapper printing (letterpress)	1,150	7273
	3231199	Advertising printing (letterpress)	1,781	
	323119C	Other commercial and general job printing (letterpress)	4,342	
Screen Printing Inks	323113	Commercial screen printing	49,264	49264
Lithographic Inks	323110	Commercial lithographic printing	266,033	266033
Flexographic Inks	323112	Commercial flexographic printing	19,979	19979
Inkjet Inks	323114	Quick printing	29,219	60500
	323115	Digital printing	13,498	
	313312	Textile and fabric finishing mills	17,783	
Laminating Adhesives	322221	Coated and laminated packaging paper and plastic film manufacturing	3,420	18283
	322223	Plastic, foil, and coated paper bag manufacturing	2,055	
	322225	Laminated aluminum foil rolls and sheets for flexible packaging uses	3,528	
	3261300	Thermosetting plastics laminates (excluding flexible packaging uses)	9,280	
Pressure Sensitive Adhesives	3222226	Wall coverings	1,271	16673
	3222223	Gummed products	863	
	3222225	Pressure-sensitive products	14,539	
Electronic Assembly	334413	Semiconductor and related device manufacturing	86,115	127463
	334418B	Printed circuit assembly (loaded boards and modules)	41,348	

Table C-9. Number of Workers per Site by General End Use

General End Use Category	Total Number Production Workers	Total Number of Sites	Number of Production Workers per Site
Automotive	27,564	164	168
Optical	11,242	223	51
Furniture (Wood)	233,297	14,518	16
Flooring	22,488	448	50
Metal Products and Machinery	96,204	3,941	24
Paper, Paperboard, Film, and Foil Finishes	32,999	759	43
Letterpress Inks	7,273	348	21
Screen Printing Inks	49,264	4,417	11
Lithographic Inks	266,033	15,606	17
Flexographic Inks	19,979	895	22
Inkjet Inks	60,500	9,190	7
Laminating Adhesives	18,283	493	37
Pressure Sensitive Adhesives	16,673	196	85
Electronic Assembly	127,463	1,532	83

Option 2

This option is an alternative “bottom-up” approach that adopts the estimation method presented in the 1994 CEB Generic Scenario on UV/EB Roll Coating (CEB, 1994). This method is based on an audit of five facilities that apply radiation curable formulations via roll coating.

If application specific operating parameters are known, Option 2 may be an appropriate method to derive the annual facility use rate and number of application sites. If the application method is not known or the facility parameters are not available, refer to Option 1.

Annual Facility Use Rate ($Q_{app_site_use_rate}$)

The annual use rate of radiation-curable coatings containing the chemical of interest in roll-coating operations ($Q_{app_site_use_rate}$) depends on the following assumptions:

1. The average hourly use rate ($Q_{coating_hr}$) is 49 kg coating per hour. This is based on the assumptions that (1) 454 grams of cured coating is used to coat 1,000 square feet of substrate; (2) 100% of the coating is converted during curing; (3) only one face of the substrate is coated; (4) the web width is 6 feet; and (5) line speed is 300 feet per minute.
2. A facility operates one roll coater per site.
3. The operating efficiency of the roll coating process is 70%.
4. There are eight hours of operation per shift and two shifts per day.
5. The number of operating days per year is 250 days per year.
6. The density of the coating is greater than or equal to that of water.

The following equation can be used to estimate the amount of coating that is roll applied in a radiation-curable coating industry. The default values cited in this equation are taken from the original generic scenarios for roll-coating and should be used only in the absence of site-specific data.

$$Q_{app_site_use_rate} = Q_{coating_hr} \times N_{roller} \times TIME_{exposure} \times N_{shift} \times F_{eff} \times TIME_{app_working_days} \quad [C-1]$$

Where:

$Q_{app_site_use_rate}$	=	Annual facility radiation curable product use rate (kg product/site-yr)
$TIME_{app_working_days}$	=	Annual number of days the radiation curable product is applied (days/yr) (Default: 250 days/yr)
F_{eff}	=	Operating efficiency of site (Default = 70%)
$TIME_{exposure}$	=	Hours of operation per shift (Default = 8 hours/day)
N_{roller}	=	Number of rollers per site (Default = 1 roller/site)
N_{shift_day}	=	Number of shifts per day (Default = 2 shifts/day)
$Q_{coating_hr}$	=	Hourly coating use rate (Default = 49 kg coating/hr)

An audit of five facilities demonstrated use rates of 5,000 to 50,000 gallons of coatings per year. The annual coating use rate, $Q_{app_site_use_rate}$, based on the facility defaults is 140,000 kg/site-yr. Assuming

the density of the coating is greater than or equal to that of water, the annual coating use rate is 36,940 gal/site-yr, which is within the range of the audited facilities.

If the operation parameters for the facility are known, a similar “bottom-up” approach may be used for other application sites (including spray and curtain coating sites). For example, at a furniture spray coating site, if the amount of coating used for each piece of furniture and the total number of pieces of furniture coated in a day are known, a daily use rate can be determined from those parameters.