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THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY**

**EMISSION SCENARIO DOCUMENT ON FORMULATION AND APPLICATION OF THERMAL
AND CARBONLESS COPY PAPER**

**Series on Emission Scenario Documents
No. 32**

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**OECD Environment, Health and Safety Publications
Series on Emission Scenario Documents
No. 32**

**EMISSION SCENARIO DOCUMENT ON FORMULATION AND APPLICATION OF
THERMAL AND CARBONLESS COPY PAPER**



INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

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

**Environment Directorate
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
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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 manufacture of thermal and carbonless copy paper. The document presents approaches for estimating the environmental releases of and occupational exposures to additives and components used in thermal and carbonless copy paper coatings. These approaches are intended to provide conservative, screening-level estimates resulting in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in the real world setting.

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

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to chemicals used in the manufacture of thermal and carbonless copy paper. 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 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 ESD-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and methodology

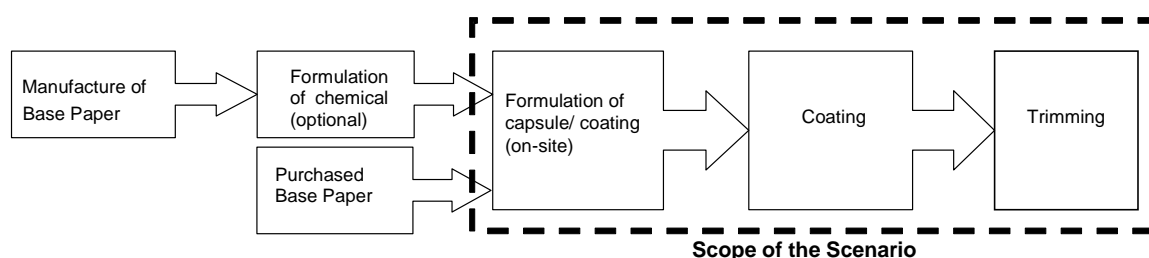
This document was developed using recent information on the thermal and carbonless copy paper industry, including process descriptions, operating information, chemicals used, wastes generated, waste treatment, worker activities, and exposure information by the lead country, the United States. The United States Environmental Protection Agency (EPA) supplemented the data collected with standard models¹ to develop approaches to estimate environmental release and occupational exposure presented in this ESD.

The primary sources of information cited in this ESD include process descriptions provided by thermal and carbonless copy paper manufacturers in response to a data request from EPA, and the Kirk-Othmer Encyclopedia of Chemical Technology. Additional information on the sources investigated and the references cited in this document are presented in Section 8.

¹ 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 information in this draft ESD is based on United States data. Certain aspects of the formulation and application of thermal and carbonless copy paper coatings may differ in other regions and/or countries; therefore, alternate assumptions and parameters may be necessary in some applications of this emission scenario.

This document presents a standard approach for estimating occupational exposures to and environmental releases of different functional components used in thermal and carbonless copy paper coating operations. The scenario covers the blending of raw materials into coating formulations, coating applications, product finishing and pre-consumer waste recycling (known as broke); however, this scenario does not address post-consumer waste recycling (e.g. de-inking and boxboard mills). Although these topics were addressed in the previous version of this scenario, they are excluded from the scope of this scenario. With the exception of solvents, most components of thermal and carbonless copy paper are non-volatile; therefore, this scenario focuses on releases of and exposures to non-volatile chemical components. Raw materials may be received in solid or liquid form. Coating of paper (converting) may be conducted at a paper mill site or alternatively at a dedicated converter site. Operations conducted at dedicated converter sites are also within the scope of this ESD; however it is important to note that certain general facility estimates discussed in Section 3 are specifically applicable to paper mills; number of sites and daily use rate of the chemical of interest do not apply to dedicated converter sites. The manufacturing of coating chemicals is not included in the scope of this ESD. Chemicals used in adhesives, which are applied prior to thermal coating, are also not included in the scope of this ESD. This scope is supported by a search of relevant Premanufacture Notice (PMN) submissions and the *Abbreviated Scoping Document for the Carbonless Copy Paper Manufacture Generic Scenario* (CEB, 2005). Information on paper-making process can be found the ESD on Pulp, Paper and Board Industry which covers the production/preparation of recycled fibre (paper recycling) and the paper-making process (OECD, 2009).



This scenario presents methods that can be used to estimate the following releases of and exposures to chemicals during the preparation and use of chemicals for the coating of thermal and carbonless copy paper:

- Inhalation and dermal exposures to solid and liquid chemicals of interest from unloading raw materials,
- Transport container residuals from bags, supersacks and bulk containers released to water, incineration or landfill,
- Inhalation and dermal exposures to solid and liquid chemicals during transport container cleaning,
- Dust losses from unloading of solid raw materials,
- Releases from cleaning of mixing vessels to on-site treatment,
- Releases from coating process losses and cleaning coating equipment to on-site treatment,

- Inhalation and dermal exposures to solid and liquid chemicals during equipment cleaning,
- Inhalation and dermal exposures to liquids during coating operations,
- Inhalation and dermal exposure to particulates during product finishing and,
- Product finishing losses from off-spec product and waste trimmings to on-site treatment after broke recycling.

How this document was developed

This ESD has been developed under the lead of the United States Environmental Protection Agency (EPA) with support from Eastern Research Group, Inc. (ERG), reviewed and approved by the OECD Task Force on Exposure Assessment (TFEA).

The scope of the ESD is designed to serve the needs of both OECD programs as well as EPA. In the United States, 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. This ESD supersedes EPA's 1991 Carbonless Copy Paper Manufacture and Recycling Operations Generic Scenario (CEB, 1991a). This ESD has been revised and expanded to meet EPA's revised quality standards for generic scenarios (CEB, 2011). Differences between the previous and updated scenario include:

- Scope of the scenario (expanded to include thermal paper and converter facilities, reduced to exclude post-consumer waste recycling),
- Number of workers exposed,
- Number of manufacturing/coating sites and
- Occupational exposure and environmental release estimates.

A Draft Generic Scenario was developed in November 2006. Glatfelter, a global supplier of specialty papers including carbonless copy paper (CCP) that provided process information in response to an EPA data request, reviewed this draft and subsequently provided additional data. The August 2009 ESD version incorporated industry-specific information and comments from Glatfelter on the draft scenario, as appropriate. The August, 2009 ESD version was submitted to the OECD Task Force for review in October of 2009. The TFEA approved the ESD in September 2012. Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology declassified the ESD in February 2014.

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

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1. INDUSTRY SUMMARY AND BACKGROUND

The following subsections provide descriptions of the thermal and carbonless copy paper industries and the types of products produced in the United States. As illustrated in the diagram on page ii, this scenario addresses facilities that manufacture thermal and carbonless copy paper using either base paper that has been manufactured on-site at a paper mill or using purchased base paper.

1.1 Carbonless Copy Paper Construction

Carbonless copy paper (CCP) was introduced in the 1950s by the National Cash Register Company (NCR) as a no-carbon required paper alternative to separate sheets with carbon paper (NIOSH, 2000). CCP, also referred to as reaction-copy paper, color-reaction paper, or self-copying paper, has become the accepted method for producing exact copies of documents on several layers of paper simultaneously (Schmidt, 2000). Figure 1-1 presents an example of a typical three-layer construction for carbonless copy paper. The key layers are:

- **Acid Developer** - During CCP production, acid developer is applied to the coated front (CF) and coated front back (CFB) top layers of a typical three-layer business form construction. The function of the developer layer is to activate the dye solution transferred from the coated back (CB) microcapsule layer upon pressure application through a change in pH or oxidation.
- **Microcapsule** - During CCP production, microcapsule slurry is applied to the coated back (CB) and coated front back (CFB) bottom layers of a typical three-layer business form construction. The function of the microcapsule layer is to suspend dye-containing microcapsules on the coated back (CB) layer until pressure is applied to the top of the construction. Pressure breaks the microcapsules, releasing the colorless dye solution, transferring the solution to the acid developer CF layer. This dye activation results in a pH change or oxidation. This change results in the formation of a dark color ink that penetrates throughout the subsequent layers of the CCP construction (Schmidt, 2000).

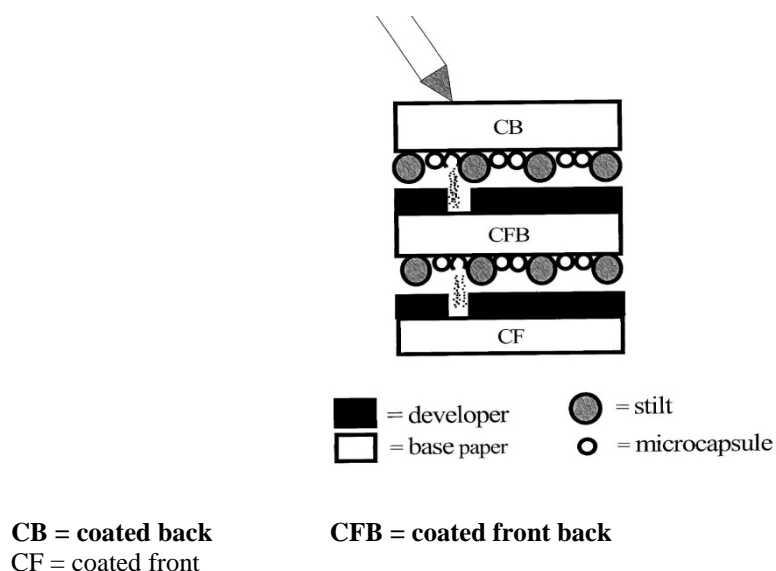


Figure 1-1. Typical CCP Construction
Reproduced from Schmidt (2000)

1.2 Thermal Paper Construction

Thermal paper was first introduced in the 1960s (Appleton, 2008) and has become increasingly popular around the world due to its high reliability, fast printing, low printer maintenance cost, low printer noise, and high image quality (Exponent, 2007). Thermal paper comprises a flexible base sheet and visibly heat-sensitive coating. An adhesive base coat may be applied to the paper before the thermally sensitive overcoat, and a top coat may be used to reduce fading and unintentional color change. End-use applications of thermal papers include facsimile machines, thermal printers, label stock, cashier receipts, tags, tickets and bar codes (Exponent, 2007).

The most common type of thermal paper system is the dye-developing type system. This system comprises three components which produce color when interacted: color former, color developer (bisphenol or acidic material) and sensitizer. The thermal coating includes these materials along with lubricants, pigments and binders. Images appear on the coated surface when heat is applied to melt together the color-producing materials (Hallbrook, 2001). Figure 1-2 presents an example of a typical construction for thermal paper.

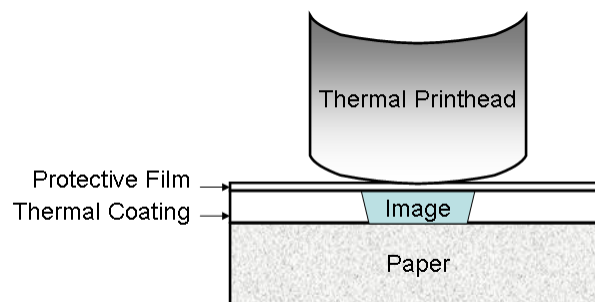


Figure 1-2. Typical Thermal Paper Construction

Reproduced from Appleton (2008)

1.3 Thermal and Carbonless Copy Paper Industry Description

The United States thermal and CCP industry manufactured approximately 415 million kilograms of CCP and 135 million kilograms of thermal paper in 2008 (Fisher, 2008). The CCP industry has experienced a gradual decline over the past decade, as shown in Table 1-1.

As of 2008, there were four companies that manufacture thermal and CCP products at a total of five sites (Fisher, 2008). Table 1-2 contains a list of companies and corresponding site locations for all thermal and CCP manufacturing facilities in the United States.

Companies in the paper converting industry create paper and paperboard products that are suited to specific uses. Converter facilities typically perform a wide variety of operations, including sheeting, embossing, impregnating, saturating, laminating and forming special shapes and sizes (e.g. bags, envelopes and boxes) (Kirk-Othmer, 2005). Converter facilities may also possess coating capabilities to create thermal and CCP from purchased base paper. This extent to which converter sites perform this specific operation is not known; thermal and CCP production data for converter sites are not available (Lockwood Post, 2009; Fisher, 2009). Based on available information, thermal and CCP production occurs primarily at paper mills. A review of recent (post-1999) PMN submissions confirmed that for the majority of cases in which use sites were specified for the use of thermal or CCP additives, the sites were paper mills.

Table 1-1. Comparison of CCP Production 1998 through 2006

Year	US. Production Million kilograms^a	Worldwide Production Million kilograms^a
1998	638.7	NA
1999	621.4	NA
2000	627.9	NA
2001	619.6	1,597.3
2002	617.8	NA
2003	602.4	NA
2004	577.0	NA
2005 ^b	556.1	NA
2006 ^b	537.1	NA
2007	NA	NA
2008 ^b	414.7	NA

Source: Glatfelter, 2005; Fisher, 2008.

a – Calculated based on a conversion factor of 907.18 kg/ton.

b – Predictions based upon business projections.

NA – Not available

Table 1-2. Thermal and CCP Manufacturing Facilities (U.S., 2008)

Company	Location	Thermal Paper Production (million kg/yr)	CCP Production (million kg/yr)
Glatfelter (formerly New Page)	Chillicothe, OH	0	161.3 (2 machines)
Arjowiggins SAS	Combined Locks, WI	35.1 (1 machine)	43.7 (2 machines)
Fraser Papers Inc.	Madawaska, ME	61.1 (2 machines)	0
Appleton	West Carrollton, OH	39.1 (1 machine)	119.4 (3 machines)
	Roaring Spring, PA	0	90.4 (3 machines)

Source: Fisher, 2008.

2. PROCESS DESCRIPTIONS

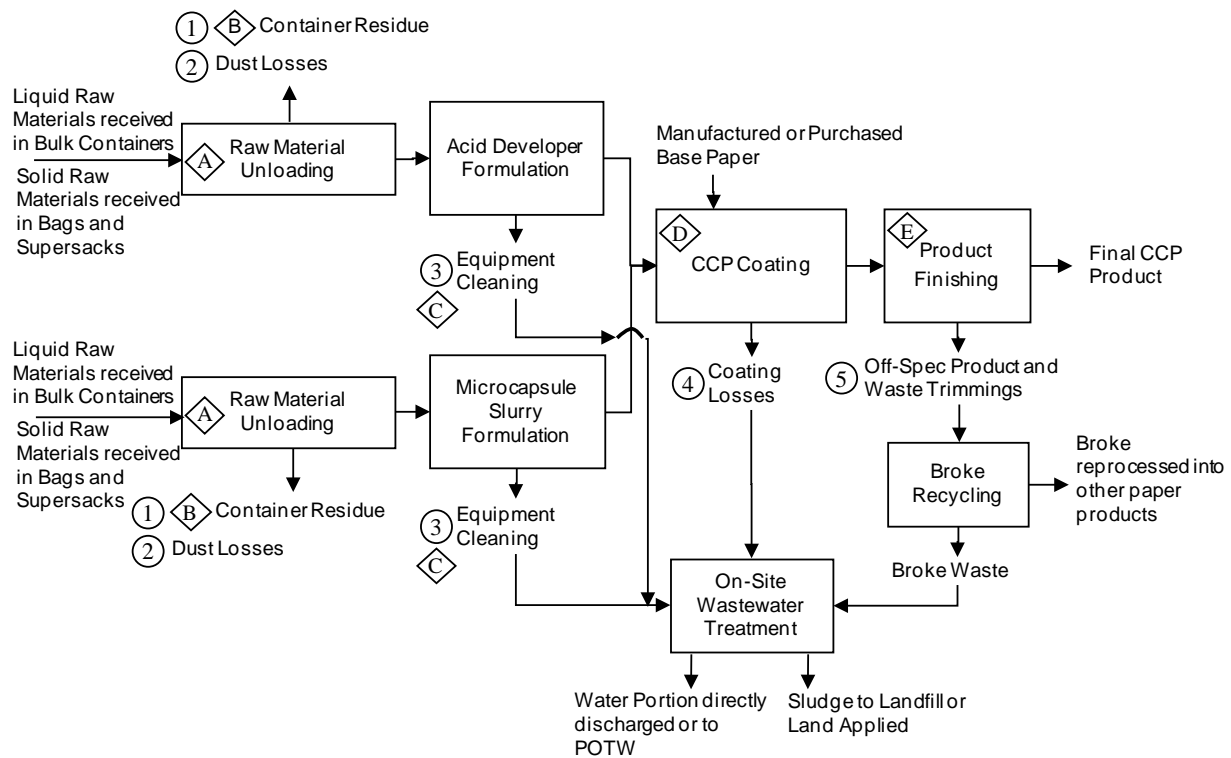
For the purposes of this generic scenario, the manufacture of CCP includes acid developer and aqueous microcapsule slurry formulation, coating of construction components and finishing. Other types of CCP manufacture include CCP may combined with carbon paper and pressure sensitive CCP; other types of CCP manufacture are not included in the scope of this scenario (NIOSH, 2000). The general process flow for thermal paper coating is very similar to that of CCP. The manufacture of thermal paper includes acid developer formulation, coating of construction components and finishing (i.e. does not include aqueous microcapsule slurry formulation, as occurs during CCP manufacture). Figure 2-1 presents a process flow diagram for the CCP manufacturing process. The exposures and releases presented in Figure 2-1 are consistent with thermal paper processing as well, as shown in Figure 2-2—the notable difference in thermal paper manufacture is that a single mix tank may be used in formulation of the thermal coating (Exponent, 2007).

2.1 Acid Developer Formulation (Thermal paper and CCP)

Preparation of the acid developer formulation used in both thermal and CCP manufacture begins with unloading of raw materials into the mixing vessel. Typical CCP acid developer formulation consists of fillers, color activators, binders, stabilizers, dispersants, thickeners and other miscellaneous minor components. Table 2-1 presents the weight percents of each component in a typical CCP acid developer formulation; available industry-specific information from two CCP sites indicates that two separate, yet similar developer formulations may be utilized at each site (Glatfelter, 2005). The developer formulation for thermal paper comprises alcohol, adhesives, oils and a thermal developer. The thermal developer is present at a concentration of up to 10 percent in the formulation (Exponent, 2007).

Based on available information from one of the primary domestic CCP manufacturers, the majority of CCP raw materials are expected to be received in bulk sacks, tankers or rail car whenever feasible (Glatfelter, 2005). Raw materials are not typically manually unloaded (e.g. scooping, pouring); rather, raw materials are typically pumped, piped or other means of automatic transfer. Materials are received as either non-volatile liquids or solids (note that solvents are expected to be volatile liquids; however, they are outside the scope of this scenario).

Based upon industry-specific information for both CCP and thermal paper manufacture, all bags originally containing solid raw materials are disposed of at a third party permitted landfill facility (Glatfelter, 2005; Exponent, 2007). No mention of procedures for cleaning of tanker or railcar was provided; therefore, these wastes are assessed to an uncertain media of release (water, incineration or landfill).



☐ Environmental Releases:

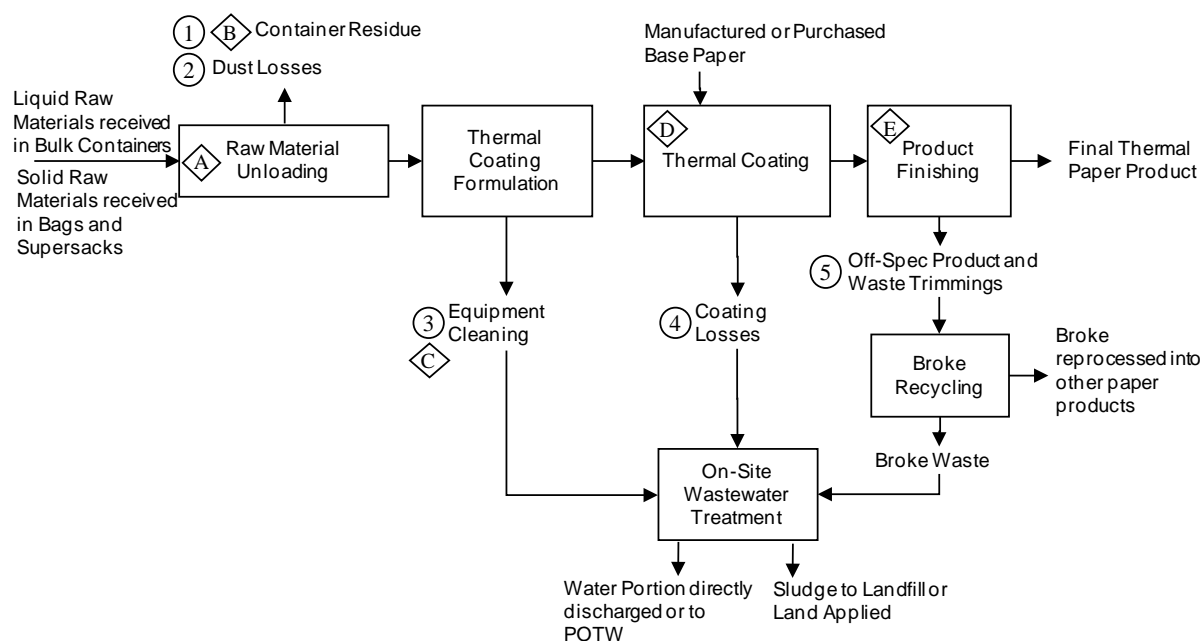
1. Container residual release (Default media: Solids - landfill; Liquids -uncertain*)
2. Dust losses from solid raw material unloading (Default media: uncertain*)
3. Release from cleaning CCP coating formulation equipment (Default media: on-site treatment)
4. Releases from the CCP coating operations (Default media: on-site treatment)
5. Product finishing losses (off-spec product and waste trimmings (Default media: on-site treatment after broke recycling))

 Occupational Exposures:

- Occupational Exposure:
- A. Inhalation and dermal exposure to solid and liquid raw materials during unloading
 - B. Dermal exposure to liquids during transport container cleaning
 - C. Dermal exposure to liquids during equipment cleaning
 - D. Dermal exposure to liquids during coating operations
 - E. Inhalation and dermal exposure to particulates during product finishing

*uncertain media means water, incinerator, land, or air

Figure 2-1. CCP Process Diagram



○ Environmental Releases:

1. Container residual release (Default media: Solids - landfill; Liquids -uncertain*)
2. Dust losses from solid raw material unloading (Default media: uncertain*)
3. Release from cleaning CCP coating formulation equipment (Default media: on-site treatment)
4. Releases from the CCP coating operations (Default media: on-site treatment)
5. Product finishing losses (off-spec product and waste trimmings (Default media: on-site treatment after broke recycling)

◇ Occupational Exposures:

- A. Inhalation and dermal exposure to solid and liquid raw materials during unloading
- B. Dermal exposure to liquids during transport container cleaning
- C. Dermal exposure to liquids during equipment cleaning
- D. Dermal exposure to liquids during coating operations
- E. Inhalation and dermal exposure to particulates during product finishing

*uncertain media means water, incinerator, land, or air

Figure 2-2. Thermal Paper Process Diagram

Table 2-1. Typical Compositions of CCP Acid Developer Formulation

CCP Formulation	Typical Weight Fraction of Components in Formulation
Acid Developer	Clay: 0.60-0.70
	Resin: 0.10-0.15
	Starch: 0.05-0.10
	Latex: 0.05-0.08
	PVA: 0.02-0.03
	Dispersant: 0.01-0.02
	Dye: <0.01

Source: Glatfelter, 2005.

Raw materials are transferred to the mixing tank for blending of the acid developer formulation. Typical mixing conditions are negative pressure conditions to minimize losses. The resultant liquid formulation is transferred to a coater for application of paper.

Data from two CCP sites estimate a loss fraction of 1-2 percent of the acid developer formulation from the cleaning of formulation equipment (Glatfelter, 2005). Cleaning wastes are typically sent to on-site wastewater treatment.

2.2 Microcapsule Slurry Formulation (CCP only)

Preparation of the microcapsule slurry formulation for CCP manufacture is a two-step operation. Microencapsulation is followed by incorporation with fillers and binders to ensure stability of the slurry for coating. This process begins with unloading of raw materials into the mixing vessel. Typical microcapsule slurry formulation consists of color formers, dye solvents, encapsulating materials and other miscellaneous minor components. Table 2-2 presents the weight percents of each component in a typical microcapsule slurry formulation. Available industry-specific information from two sites indicates that five to six similar color formers may be utilized at each site (Glatfelter, 2005).

Table 2-2. Typical Compositions of CCP Microcapsule Slurry Formulation

CCP Formulation	Component	Typical Weight Fraction of Components in Formulation	
Microcapsule Slurry	Capsule Formulation	Solvent:	0.35-0.45
		Diluent:	0.14-0.23
		External Phase:	0.04-0.06
		Wall former:	0.02-0.05
		Color former:	0.02-0.05
		Cross linker:	0.01-0.03
	Fillers	Wheat Stilts:	0.15-0.20
		Starch:	0.05-0.10

Source: Glatfelter, 2005.

There are three main methods of microencapsulation currently employed: coacervation, interfacial polymerization and in-situ polymerization. Each method is specific to the type of application and size of capsules necessary. Research on CCP manufacture indicates that all three methods could be employed for carbonless copy applications (Kirk-Othmer, 2004). Microcapsule specifications necessary for carbonless copy performance are uniform capsule size and particle size in the range of 3-6 μm . A large variation in the uniformity of capsule shape or size will impact the performance of the CCP product (NIOSH, 2000).

Once microcapsules have been produced to the required specifications, fillers and binders are added to the capsules to formulate the slurry. The purpose of the fillers is to provide larger particles in the coating solution for stability during coating operations. The microcapsules are designed to rupture when pressure is applied in the application, not during coating to the paper substrate. Typical mixing conditions are negative pressure conditions to minimize losses. The resultant liquid formulation is transferred to a coater for application of paper to form the CB portion of the paper.

Based upon industry-specific information received from two sites, all bags originally containing solid raw materials are disposed of at a third party permitted landfill facility (Glatfelter, 2005). No mention of procedures for cleaning of tanker or railcar was provided; therefore, these wastes are assessed to an uncertain media of release (water, incineration or landfill).

Data from two sites estimates a loss fraction of 1-2 percent of the microcapsule slurry formulation from the cleaning of formulation equipment (Glatfelter, 2005). Cleaning wastes are typically sent to on-site wastewater treatment.

2.3 Coating (Thermal paper and CCP)

In CCP coating, the CF, CB and CFB coatings may be applied to CCP substrates by two different methods. The coatings may be directly applied to wet paper pulp prior to drying or applied to dried paperstock. The coating is dried through a high speed air oven at approximately 93°C and wound for later use (NIOSH, 2000). The coating operations are enclosed. Monitoring data from two sites indicate no detectable levels of mists or particulates from the coating operations (Glatfelter, 2005). The acid developer is then applied to the CF portion of the top sheet and top of middle sheet of the construction (see Figure 1-1). The microcapsule slurry is applied to the CB portion of the middle sheet and bottom sheet of the construction. This application is accompanied by a binder for adhesion to the paper. Microcapsules slurries are coated to the CB layer at an average density of several million per cm².

In thermal paper coating, an adhesive basecoat may be first automatically metered onto the paper. The thermal developer formulation is then applied as an overcoat. After drying, a protective film may be applied to reduce fading and unintentional color change (Exponent, 2007).

Common coating processes used to apply the CCP or thermal coating include blade, air knife, and reverse roll coating (Dow, 2009; Truitt, 1976). In blade coating, the coating is metered onto the substrate, and a flexible or rigid blade is tilted at an acute angle from the incoming substrate to remove excess coating. The blade coating method has a maximum speed of approximately 1 500 meters per minute. In air knife coating, the coating is applied using a coating pan and roll; an air knife positioned after the pan applies a focused jet of air to the substrate to force off excess coating which can be collected and reused or disposed. The air knife coating method has a maximum speed of approximately 500 meters per minute. In reverse roll coating, an applicator roll picks up coating from a pan of fluid or fountain; the excess fluid is then metered off by a reverse-turning metering roll and the remaining fluid is completely transferred to the substrate traveling in the reverse direction. The reverse roll coating method has a maximum speed of approximately 400 meters per minute (Kirk-Othmer, 2002).

The weight of the final CCP product is approximately 5-10 percent acid developer, 5-10 percent microcapsule slurry and 80-90 percent base paper (Glatfelter, 2005; Schmidt, 2000). The weight of the final thermal product is approximately 1 percent acid developer (Exponent, 2007).

Estimated coating losses from CCP coating processes is 10-15 percent based upon data from two sites (Glatfelter, 2005). These estimates are significantly greater than estimates previously utilized in the 1991 Generic Scenario (CEB, 1991a). This estimate combines running losses and associated equipment cleaning losses during product changeover. The loss fraction is not expected to vary between CCP chemical components. The manufacture of thermal paper may employ a line for excess developer to be captured and returned to the mixing vessel for reuse (Exponent, 2007). Coating losses are sent to on-site wastewater treatment. After on-site treatment, treated water may be directly discharged or sent to a publicly owned treatment works (POTW) for additional treatment (Glatfelter, 2005).

2.4 Finishing (Thermal paper and CCP)

The finishing of coated paper involves combining of rolls weighing up to several tonnes and converting to the desired size of form based upon product type. During product finishing, products are spliced to specific size requirements, generating what is known as broke. This trimming (broke) product is handled in different ways. Approximately 4 percent of CCP production may be scrapped during trimming (Klass, 1990). Based on information from two CCP sites, broke may be recycled back into the paper-making process on-site or reprocessed at another site (Glatfelter, 2005). Data regarding broke handling at thermal paper manufacturing sites were not available.

Table 2-3 presents physical properties of example CCP chemicals, including the typical composition data that are also presented in Tables 2-1 and 2-2. Similar data were not available for thermal paper chemicals.

Table 2-3. Physical Properties of Example CCP Chemicals

CCP Formulation Category	Additive Category	Typical Weight Fraction of Additive in Formulation	Chemical (CAS)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (g/L)	Other (Density(ρ), Oct/H ₂ O, etc.)
Acid developer	Clay	0.60 – 0.70	Kaolin clay ^a (1332-58-7)	Solid powder	258.15	Unk.	N/A	Unk.	Insoluble	1.8 - 2.6 g/cm ³
Acid developer	Resin	0.10 – 0.15	Alkylphenol Novolac resin dispersion ^b	Liquid	N/A	N/A	Unk.	Unk.	>25%	1.066 g/cm ³
Acid developer	Starch	0.05 – 0.10	Hydroxyethyl starch ^c (9005-27-0)	Solid	Unk.	Unk.	Unk.	Unk.	Unk.	Unk.
Acid developer	Latex	0.05 – 0.08	Styrene-butadiene latex ^d (9003-55-8)	Solid or viscous liquid, depending upon the degree of polymerization	Unk.	Unk.	Unk.	Unk.	Unk.	Unk.
Acid developer	PVA	0.02 – 0.03	Polyvinyl alcohol ^e (9002-89-5)	Granules or powder	44.053	Unk.	Unk.	228	Unk.	1.3 g/cm ³
Acid developer	Dispersant	0.01 – 0.02	Not available	-	-	-	-	-	-	-

CCP Formulation Category	Additive Category	Typical Weight Fraction of Additive in Formulation	Chemical (CAS)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (g/L)	Other (Density(ρ), Oct/H ₂ O, etc.)
Acid developer	Dye	<0.01	Crystal violet lactone ^{f,g} (1552-42-7)	Crystalline powder	415.53	Unk.	Unk.	180-183	<1 at 22.5°C	Unk.
Microcapsule slurry	Solvent	0.35 – 0.45	2,6-Diisopropyl-naphthalene ^h (24157-81-1)		212.33	Unk.	279.3	67-70	Unk.	Unk.
Microcapsule slurry	Diluent	0.14 – 0.23	Not available	-	-	-	-	-	-	-
Microcapsule slurry	External Phase	0.04 – 0.06	Diethylenetri-amine (DETA) ⁱ (111-40-0)	Liquid	103.1	0.37 at 20°C	207	-39	Unk.	0.95 g/mL
Microcapsule slurry	Wall Former	0.02 – 0.05	Not available	-	-	-	-	-	-	-
Microcapsule slurry	Color Former	0.02 – 0.05	Not available	-	-	-	-	-	-	-
Microcapsule slurry	Cross Linker	0.01 – 0.03	Not available	-	-	-	-	-	-	-

N/A – Not Applicable.

Unk. – Unknown.

a – Source: Mallinckrodt Baker, 2006.

b – Source: SIGroup, 2007.

c – Source: Sigma-Aldrich, 2008.

d – Source: Oxford, 2003.

e – Source: CambridgeSoft, 2008.

f – Source: chemBlink, 2008.

g – Source: Enlexica, 2008.

h – Source: ChemExper, 2008.

i – Source: Huntsman, 2008.

3. OVERALL APPROACH AND GENERAL FACILITY ESTIMATES

This document presents a standard approach for estimating environmental releases of and worker exposures to chemicals (additives) used in the manufacture of thermal and CCP at coating facilities. The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible; however, there are several areas in which additional chemical information would benefit the scenario. These data needs are summarized in Section 7. The default values cited throughout this scenario could only be used when appropriate site-specific or industry-specific information is not available.

Because this scenario presents several alternative default assumptions or values for some estimation parameters, selecting different defaults will affect the final assessment results differently. For example, conservative or high-end daily use rates will result in more conservative release estimates². Alternatively, average or median use rates will result in release estimates that are more “typical” of the industry. This ESD presents available data that support alternative input values.

This section of this generic scenario presents general facility calculations, which estimates the operating days, concentration of the chemical of interest in thermal and carbonless copy products, throughput of the product containing the chemical of interest, number of industrial sites that use the chemical and the number of containers used per facility.

Operations conducted at dedicated converter sites, as opposed to paper mills, are within the scope of this ESD; however, it is important to note that certain general facility estimates discussed in this section are specifically applicable to paper mills; number of sites and daily use rate of the chemical of interest do not apply to dedicated converter sites.

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

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

² Note: When evaluating environmental releases, EPA typically assumes the highest daily release is the most conservative, because it will result in the highest aquatic stream concentrations. Therefore, EPA typically uses high-end daily use rates to generate conservative environmental release estimates. Conversely, for conservative occupational exposure assessments, EPA typically utilizes lower daily use rates, which will result in a greater number of use sites, longer use duration, and a greater number of workers exposed.

3.1 Introduction to the General Facility Estimates

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-4 in Appendix A presents a detailed summary of the default values used as inputs to each of the general facility estimates, accompanied by their references.

Table 3-1. Summary of General Facility Parameters

Parameter	Description	ESD Section
$F_{\text{chem_form}}$	Weight fraction of the chemical of interest in the coating formulation (kg chemical/kg formulation)	3.3
$F_{\text{chem_prod}}$	Weight fraction of the additive in the final coated product (kg additive/kg formulation)	3.3
N_{sites}	Number of facilities using the chemical of interest	3.4
$Q_{\text{chem_site_day}}$	Daily use rate of the chemical of interest per site (kg/site-day)	3.5

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

3.2 Days of Operation

The previous generic scenario estimated 350 days per year of operation for CCP manufacture and broke processing (CEB, 1991a). Information collected from the CCP industry indicates operating conditions ranging from 250 days per year (3 shift, 5 days per week, 50 weeks per year) to 350 days/year (3 shifts, 7 days per week, 50 weeks per year) (Glatfelter, 2005). As a conservative estimate, assume 250 days of operation per year for thermal and CCP manufacture. A decrease in number of operating days per year from the previous scenario can be attributed to a decrease in the size of the CCP market since 1998, as shown in Table 1-1. An estimate of 250 days per year is also more conservative, because fewer days will yield greater daily environmental releases. Additionally, assuming 250 days per year is the CEB maximum for a single worker's exposure, based on a 5-day work week and two weeks of vacation/sick time per year (CEB, 1994).

3.3 Weight Fraction of the Chemical of Interest

The following weight fractions are utilized in this generic scenario:

$$F_{\text{chem_form}} = F_{\text{chem_additive}} \times F_{\text{additive_form}} \quad (3-1a)$$

$$F_{\text{chem_prod}} = F_{\text{chem_form}} \times F_{\text{form_prod}} \quad (3-1b)$$

Where:

$F_{\text{chem_form}}$ = Weight fraction of the chemical of interest in the coating formulation

$F_{\text{chem_additive}}$ = Weight fraction of the chemical of interest in additive. If chemical-specific information is not available, assume the chemical is received at 100 percent concentration (Default = 1 kg chem/kg additive)

$F_{\text{additive_form}}$ = Weight fraction of the additive in coating formulation. If chemical-specific information is not available, utilize concentration information presented in Tables 2-1 or 2-2. If the additive type is unknown, assume that a CCP chemical is used as a diluent in a microcapsule slurry formulation, or that a thermal paper chemical is used as a thermal developer. While clays and solvents may be used at a higher concentration, it is assumed that these chemicals would be easy to identify based on their chemistry (CCP Default = 0.23 kg additive/kg formulation, see Table 2-2; Thermal Default = 0.10 kg additive/kg formulation, see Table 2-1)

$F_{\text{chem_prod}}$ = Weight fraction of the chemical of interest in the final coated product

$F_{\text{form_prod}}$ = Weight fraction of the coating formulation in the final coated product. The weight of a CCP final product is approximately 5-10 percent acid developer, 5-10 percent microcapsule slurry and 80-90 percent base paper (Glatfelter, 2005; Schmidt, 2000). The weight of a thermal paper final product is approximately 10 percent thermal developer formulation (Exponent, 2007). (CCP and Thermal Default = 0.1 kg formulation / kg coated paper)

3.4 Number of Sites

The number of use sites can be calculated based on the information below, depending on whether the chemical is used in CCP or thermal paper coating applications. Note, these estimates apply to paper mills that manufacture thermal or CCP, not to dedicated converter sites.

Carbonless Copy Paper

In 2008, 415 million kilograms of CCP was manufactured by three companies controlling four CCP manufacturing sites operating in the United States. Table 1-2 presents the names, locations and production of the facilities currently manufacturing CCP products. Therefore, each site manufactured an average of 103.75 million kilograms of CCP in 2008. Based on available data, these sites are assumed to be the primary facilities conducting CCP coating operations; production data for converter facilities (i.e. where the coating is applied to purchased rather than on-site-manufactured base paper) that may also perform CCP coating is not available (see Section 1.3, Industry Description). In the absence of chemical-specific information, the following equation may be used to estimate the number of CCP production sites:

$$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{prod_yr}} \times F_{\text{form_site}} \times F_{\text{chem_prod}}} \quad (3-2a)$$

Where:

N_{sites} ³	=	Number of sites (sites)
$Q_{\text{chem_yr}}$	=	Annual production volume of chemical of interest (kg chem/yr)
$Q_{\text{prod_yr}}$	=	Average annual production volume of CCP (Default = 103.75 x 10 ⁶ kg of CCP/site-yr)
$F_{\text{form_site}}$	=	Fraction of formulations used per site containing the chemical of interest (Default = 1 kg formulation with chem/kg formulation used) ⁴
$F_{\text{chem_prod}}$	=	Weight fraction of the chemical of interest in the final CCP product (see Section 3.2)

³ N_{sites} should always be rounded up.

⁴ Note: Industry-specific information from two CCP sites indicates up to two acid developers and up to six color formers may be used per site. Because the chemical of interest may be used in multiple acid developer formulations and microcapsule formulations, the default for the fraction of formulations containing the chemical of interest used per site is assumed to be one (i.e. the chemical of interest is in all formulations); however, adjustments may be made based on engineering judgment or available chemical-specific information.

Thermal Paper

In 2008, 135 million kilograms of thermal paper was manufactured by three companies controlling three thermal paper manufacturing sites operating in the United States. Table 1-2 presents the names, locations and production of the facilities currently manufacturing thermal paper products. Therefore, each site manufactured an average of 45 million kilograms of thermal paper in 2008. Based on available data, these sites are assumed to be the primary facilities conducting thermal paper coating operations; production data for converter facilities (i.e. where the coating is applied to purchased rather than on-site-manufactured base paper) that may also perform thermal paper coating is not available (see Section 1.3, Industry Description). In the absence of chemical-specific information, the following equation may be used to estimate the number of thermal paper use sites:

$$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{prod_yr}} \times F_{\text{form_site}} \times F_{\text{chem_prod}}} \quad (3-2b)$$

Where:

N_{sites}^5	=	Number of sites (sites)
$Q_{\text{chem_yr}}$	=	Annual production volume of chemical of interest (kg chem/yr)
$Q_{\text{prod_yr}}$	=	Average annual production volume of thermal paper (Default = 45×10^6 kg of paper/site-yr)
$F_{\text{form_site}}$	=	Fraction of formulations used per site containing the chemical of interest (Default = 1 kg formulation with chem/kg formulation used)
$F_{\text{chem_prod}}$	=	Weight fraction of the chemical of interest in the final thermal paper product (see Section 3.2)

3.5 Daily Use Rate of the Chemical of Interest

Using the production volume of the chemical of interest, number of sites and days of operation, the daily use of chemical of interest may be estimated using the following equation.

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

Where:

$Q_{\text{chem_site_day}}$	=	Daily use rate of the chemical of interest per site (kg/site-day)
$Q_{\text{chem_yr}}$	=	Annual production volume of chemical of interest (kg chem/yr)
N_{sites}	=	Number of sites (sites)
$\text{TIME}_{\text{working_days}}$	=	Days of operation per year (Default = 250 days/yr)

⁵ N_{sites} should always be rounded up.

4. ENVIRONMENTAL RELEASE ASSESSMENTS

Many of the environmental release estimates presented in this document are based on standard EPA release models with the exception of the methodologies for estimating the amount of release from coating process losses and cleaning coating equipment, as described in Section 4.4, and trimmings and off-spec product, as described in Section 4.5. Table 4-1 summarizes the release estimation methods used in this ESD.

Table 4-1. Summary of Release Models

Release Source #	Description	Model Name or Description ^a	Standard EPA Model (✓)
1	Container residue released to non-air media	Specific model used is based on the type and size of the containers, and on the physical state of the chemical: <ul style="list-style-type: none"> • EPA/OPPT Bulk Transport Residual Model • EPA/OPPT Drum Residual Model • EPA/OPPT Solid Residuals in Transport Containers Model 	✓
2	Dust losses of solid chemical during unloading	EPA/OPPT Dust Emissions from Transferring Solids Model	✓
3	Mixing vessels cleaning residues released to wastewater treatment	EPA/OPPT Multiple Process Vessel Residual Model	✓
4	Coating process losses and coating equipment cleaning residues released to wastewater treatment	Loss rate is based on available industry-specific data	
5	Trimming and off-spec product release to wastewater treatment	Loss rate is based on available industry-specific data	

OPPT – Office of Pollution Prevention and Toxics.

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

4.1 Cleaning Residuals from Containers used to Transfer Raw Materials to Mixing Vessel (Release 1)

Information from industry sources indicates that almost all liquid raw materials are received at manufacturing facilities in bulk (tanker or railcar) and solids are received in bags (sacks or supersacks). If the coating application site(s) is/are known to be a converter facility, it is likely CCP or thermal coating may be among numerous other converting operations occurring on-site; therefore the CCP or thermal coating raw materials may be received in smaller containers such as drums.

If the physical form of the chemical of interest is unknown, it should be assumed the chemical is received in solid powder form, which will result in more conservative environmental release and occupational exposure assessments.

Liquids:

The *EPA/OPPT Bulk Transport Residual Model*⁶ may be utilized to estimate container residue releases from raw materials received in tankers or railcars. Alternatively, the *EPA/OPPT Drum Residual Model* may be used for drums containing between 20 and 100 gallons of liquid, if it is known that coating occurs on a relatively small scale such as at a converter facility. No information on container cleaning procedures was available; therefore, potential release to water, incineration or landfill may be assumed. The number of containers is estimated based on the daily use rate and container size. Assume 19 000-litre (5 000-gallon) tank truck and density of the additive (not the formulated CCP coating) of one kg/L (density of water) as defaults.

$$N_{\text{cont_site_yr}} = \frac{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{working_days}}}{V_{\text{container}} \times \text{RHO}_{\text{additive}} \times F_{\text{chem_additive}}} \quad (4-1)$$

Where:

$N_{\text{cont_site_yr}}$	=	Annual number of containers of CCP or thermal additive used per site (containers/site-yr)
$Q_{\text{chem_site_day}}$	=	Daily use rate of chemical of interest per site (kg chem/site-day)
$\text{TIME}_{\text{working_days}}$	=	Days of operation per year (Default = 250 days/yr)
$V_{\text{container}}$	=	Volume of container (Default = 19 000 L/container)
$\text{RHO}_{\text{additive}}$	=	Density of CCP or thermal additive (Default = 1 kg additive/L)
$F_{\text{chem_additive}}$	=	Weight fraction of the chemical of interest in additive (Default = 1 kg chem/kg additive)

If the number of containers is less than the days of operation, the days of release is equal to the number of containers and the daily release is calculated based on the following equation:

$$\text{Elocal}_{\text{container_residue_disp}} = V_{\text{container}} \times \text{RHO}_{\text{additive}} \times F_{\text{chem_additive}} \times F_{\text{container_residue}} \times 1 \frac{\text{container}}{\text{site-day}} \quad (4-2)$$

⁶ Note the information presented for standard CEB models is based on the current version of the model (as of the date of this generic scenario). Standard CEB models are subject to change; therefore, the current version of the standard CEB model should be used.

Where:

$E_{\text{local_container_residue_disp}}^7$	=	Daily release of chemical of interest from container residue (kg chem/site-day) (Default media: water, incineration or landfill)
$V_{\text{container}}$	=	Volume of container (Default = 19 000 L/container)
RHO_{additive}	=	Density of CCP or thermal additive (Default = 1 kg additive/L)
$F_{\text{chem_additive}}$	=	Weight fraction of the chemical of interest in additive (Default = 1 kg chem/kg additive)
$F_{\text{container_residue}}$	=	Fraction of CCP or thermal additive remaining in the container as residue (Default = 0.002 kg additive remaining/kg additive shipped in bulk containers) (CEB, 1992)

If the number of containers is greater than the days of operation, the days of release is equal to the days of operation, and the daily release is calculated based on the following equation (Note: most sites should use less than one container per day):

$$E_{\text{local_container_residue_disp}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}} \quad (4-3)$$

Where:

$E_{\text{local_container_residue_disp}}$	=	Daily release of chemical of interest from container residue (kg chem/site-day) (Default media: water, incineration or landfill)
$Q_{\text{chem_site_day}}$	=	Daily use rate of chemical of interest per site (kg chem/site-day)
$F_{\text{container_residue}}$	=	Fraction of CCP or thermal additive remaining in the container as residue (Default = 0.002 kg additive remaining/kg additive shipped in bulk containers; 0.03 kg additive remaining/kg additive shipped in drums) (CEB, 1992)

Solids:

The *EPA/OPPT Solids Residual in Transport Containers Model* may be utilized to estimate container residue releases from raw materials received in bags or supersacks. Information from industry sources indicates that all bags are disposed at a third party permitted landfill facility (Glatfelter, 2005; Exponent, 2007). As conservative, CEB assumes these wastes may also be incinerated. The daily release may be estimated using the following equation:

$$E_{\text{local_container_residue_disp}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}} \quad (4-4)$$

Where:

$E_{\text{local_container_residue_disp}}$	=	Daily release of chemical of interest from container residue (kg chem/site-day) (Default media: incineration or landfill)
$Q_{\text{chem_site_day}}$	=	Daily use rate of chemical of interest per site (kg chem/site-day)
$F_{\text{container_residue}}$	=	Fraction of CCP or thermal additive remaining in the container as residue (Default = 0.01 kg additive remaining/kg solid additive shipped) (CEB, 1992)

⁷ To partition Release 1, replace $E_{\text{local_coating_losses}}$ (Eqn. 4-9a,b) with $E_{\text{local_container_residue_disp}}$ for Release 1.

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

For liquid thermal and carbonless copy components received at manufacturing facilities, this release is negligible.

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

Most facilities utilize some type of control technology to collect fugitive emissions. In some cases, uncontrolled/uncollected particulate may be small enough to travel several miles from the facility, resulting in environmental and human exposures to the chemical of interest beyond the boundaries of the site. Some amount of the dust particles may alternately settle on the floor or equipment within the workspace and are disposed of during facility cleaning (water if the floors are rinsed, or land or incineration if the floors are swept). Therefore, if additional site specific information is not available, this release is conservatively assumed released to air, water, incineration or land (CEB, 2007).

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

$$E_{\text{local}_{\text{dust_fugitive}}} = Q_{\text{chem_site_day}} \times F_{\text{dust_generation}} \quad (4-5)$$

Where:

$E_{\text{local}_{\text{dust_fugitive}}}$	=	Daily amount not captured by control technology from transfers or unloading (kg/site-day)
$Q_{\text{chem_site_day}}$	=	Daily use rate of chemical of interest per site (kg chem/site-day; See Section 3.3)
$F_{\text{dust_generation}}$	=	Fraction of chemical lost during transfer/unloading of solid powders (Default = 0.005 kg released/kg handled) (CEB, 2007)

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

4.3 Releases from Cleaning Mixing Vessels (Release 3)

Available industry data from two CCP manufacturing sites estimates 1-2 percent of the acid developer or microcapsule slurry formulation is lost during equipment cleaning of the mixing vessels (Glatfelter, 2005). This is consistent with the *EPA/OPPT Multiple Vessel Residual Model*. The model assumes that no more than 2 percent of the batch size or capacity of the process vessel remains in the equipment as residue and released as equipment cleaning waste. Equipment cleaning wastes are typically sent to on-site wastewater treatment at CCP and thermal paper manufacturing sites (Glatfelter, 2005;

Exponent, 2007). Converter sites may not necessarily have on-site wastewater treatment, and may instead discharge without treatment directly to a POTW.

$$\text{Elocal}_{\text{equip_cleaning}} = Q_{\text{chem_site_day}} \times F_{\text{equip_cleaning}} \quad (4-6)$$

Where:

- $\text{Elocal}_{\text{equip_cleaning}}^8$ = Daily release of chemical of interest from cleaning formulation vessels (kg chem/site-day) (Default media: on-site treatment)
- $Q_{\text{chem_site_day}}$ = Daily use rate of chemical of interest per site (kg chemical/site-day)
- $F_{\text{equip_cleaning}}$ = Fraction of chemical remaining in the formulation vessel as residue (Default = 0.02 kg chem remaining/kg chem formulated)

4.4 Releases from Coating Process Losses and Cleaning Coating Equipment (Release 4)

Available industry data from two CCP manufacturing sites estimates 10-15 percent of the acid developer or microcapsule slurry formulation is lost during the coating process. This release includes wastes generated during product changeover, unused coating formulations and cleaning of the coating equipment. These wastes are typically sent to on-site wastewater treatment (Glatfelter, 2005). Converter sites may not necessarily have on-site wastewater treatment and may instead discharge without treatment directly to a POTW.

Available data for thermal paper manufacturing from an industry source indicates that thermal developer formulation lost during the coating process may be captured and returned to the mixing vessel for reuse. In the absence of site-specific information indicating recycling of wastes, the same conservative loss fraction applied to CCP formulations (15 percent) should be assessed for thermal paper manufacturing operations.

$$\text{Elocal}_{\text{coating_loss}} = Q_{\text{chem_site_day}} \times F_{\text{coating_loss}} \quad (4-7)$$

Where:

- $\text{Elocal}_{\text{coating_loss}}$ = Daily release of chemical of interest from the coating process (kg chem/site-day) (Default media: on-site treatment)
- $Q_{\text{chem_site_day}}$ = Daily use rate of chemical of interest per site (kg chemical/site-day)
- $F_{\text{coating_loss}}$ = Fraction of chemical lost during the coating process (Default = 0.15 kg chem released/kg chem formulated)

4.5 Trimmings and Off-Spec Product Releases (Release 5)

During product finishing, products are spliced to specific size requirements, generating scrap trimmings or broke. Additionally, off-spec product will also be generated. Approximately 4 percent of the throughput may be lost during CCP product finishing (Klass, 1990). This waste paper may be reprocessed as broke at the mill or be shipped to another paper manufacturing facility. During broke reprocessing, the chemical may be removed from the paper and released to on-site wastewater treatment or remain and be

⁸ To partition Release 3, replace $\text{Elocal}_{\text{coating_losses}}$ (Eq. 4-9a,b) with $\text{Elocal}_{\text{equip_cleaning}}$ for Release 3.

retained in the paper. Data regarding broke handling at thermal paper manufacturing sites were not available; the broke generation fraction assumed for CCP may be applied to thermal paper manufacturing sites to produce a release estimate, in absence of site-specific data. Converter sites may not necessarily have on-site wastewater treatment and may instead discharge without treatment directly to a POTW. See Section 4.6 for guidance on partitioning between water and solids disposal media.

$$\text{Elocal}_{\text{broke_release}} = Q_{\text{chem_site_day}} \times F_{\text{broke_generation}} \quad (4-8)$$

Where:

$\text{Elocal}_{\text{broke_release}}^9$	=	Daily release of chemical of interest from the broke reprocessing of trimmings and off-spec product (kg chem/site-day) (Default media: on-site treatment)
$Q_{\text{chem_site_day}}$	=	Daily use rate of chemical of interest per site (kg chemical/site-day)
$F_{\text{broke_generation}}$	=	Fraction of chemical lost from trimming and off-spec product (Default = 0.04 kg chem in broke/kg chem applied)

4.6 Control Technologies

All CCP manufacturing facilities operate on-site wastewater treatment. On-site treatment may include ultrafiltration, activated sludge, aeration, clarification (coagulation followed by settling) and powdered activated carbon. On-site treatment creates two waste streams: treated aqueous waste containing a low concentration of chemical of interest and the concentrated solids removed from the wastewater. The treated aqueous waste may be discharged directly to the environment or discharged to a POTW, while the concentrated waste is typically sent to landfill or land applied (Glatfelter, 2005). Thermal paper manufacturing facilities typically treat wastewater using primary clarification, from which the solids stream is generally routed to a landfill, but may be incinerated at some facilities (Exponent, 2007). Converter sites may not necessarily have on-site wastewater treatment and may instead discharge without treatment directly to a POTW.

Treatment data from one CCP manufacturing site indicate removal efficiencies of 98.9 percent for biological oxygen demand (BOD), 89.1 percent for chemical oxygen demand (COD), 98.6 percent for total suspended solids (TSS) and 98.2 percent for volatile suspended solids (VSS). These data may be utilized to partition the release to on-site wastewater treatment between water and land. Note that most chemicals reviewed by CEB are not typically removed by biological digestion processes and are non-volatile; therefore, BOD and VSS are not expected to be applicable. Data for COD versus TSS may be selected based on the water solubility of the chemical (COD if the chemical is soluble, TSS if insoluble in water); however, as a conservative estimate, data for COD should be utilized. The percent removal efficiency for COD is based on the percent of organic matter within the waste stream that will partition to the solids phase rather than aqueous phase during treatment.

The following equations may be utilized to partition releases between water and solids disposal media for wastewater treatment. The default value for wastewater treatment efficiency is based on COD data for one CCP manufacturing site. If site-specific wastewater treatment efficiency data are available, they should be used in place of the default value. The applicability of the default efficiency to wastewater treatment operations at thermal paper manufacturing sites is not known. To conservatively assess water releases from a thermal paper manufacturing site, the default treatment efficiency should not be applied

⁹ To partition Releases 1, 3, and 5, replace $\text{Elocal}_{\text{coating_losses}}$ (Eqn. 4-9a,b) with $\text{Elocal}_{\text{broke_release}}$ for Release 5.

without sufficient basis. The sample equations show the partition of Release 4 between water and solids disposal media, respectively. Similar equations may be used to partition Releases 1, 3 and 5 if water releases are assessed.¹⁰

$$\text{Elocal}_{\text{water_WWT}} = \text{Elocal}_{\text{coating_loss}} \times (1 - F_{\text{eff_WWT}}) \quad (4-9a)$$

Where:

- $\text{Elocal}_{\text{water_WWT}}$ = Daily release of chemical of interest to water or POTW after wastewater treatment (kg chem/site-day) (Default medium: water)
- $\text{Elocal}_{\text{coating_loss}}^6$ = Daily release of chemical of interest from the coating process (kg chem/site-day)
- $F_{\text{eff_WWT}}$ = Wastewater treatment efficiency (Default = 0.891 (COD))

$$\text{Elocal}_{\text{concentrate}} = \text{Elocal}_{\text{coating_loss}} \times F_{\text{eff_WWT}} \quad (4-9b)$$

Where:

- $\text{Elocal}_{\text{concentrate}}$ = Daily release of chemical of interest in concentrated treatment waste (kg chem/site-day) (Default medium: landfill for CCP; landfill or incineration for thermal)
- $\text{Elocal}_{\text{coating_loss}}^6$ = Daily release of chemical of interest from the coating process (kg chem/site-day)
- $F_{\text{eff_WWT}}$ = Wastewater treatment efficiency (Default = 0.891 (COD))

¹⁰ To partition Releases 1, 3, and 5, replace $\text{Elocal}_{\text{coating_losses}}$ (Eqn. 4-9a,b) with $\text{Elocal}_{\text{container_residue_disp}}$ for Release 1, $\text{Elocal}_{\text{equip_cleaning}}$ for Release 3, and $\text{Elocal}_{\text{broke_release}}$ for Release 5.

5. OCCUPATIONAL EXPOSURE ASSESSMENTS

The occupational exposure estimates presented in this document are based on standard EPA exposure models with the exception of the methodology for estimating inhalation exposure to particulate during product finishing, as described in Section 5.7. Table 5-1 summarizes the exposure estimation methods used in this Methodology review draft.

Table 5-1. Summary of Exposure Models

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description ^a	Standard EPA Model (✓)
A	Exposure during unloading of solid or liquid chemicals	Inhalation of solid particulate	Occupational Safety and Health Administration (OSHA) Total PNOR PEL-Limiting Model	✓
		Dermal exposure to liquid chemical or solid chemical	Specific model is based on the physical form of the material: • EPA/OPPT 2-Hand Dermal Contact with Liquid Model • EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model	✓
B	Exposure during transport container cleaning	Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
C	Exposure during equipment cleaning	Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
D	Exposure during coating operations	Inhalation of mist from coating	EPA/OPPT UV Roll Coating Inhalation Model	✓
		Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
E	Exposure to particulate during product finishing	Inhalation of particulate during product finishing	Inhalation exposure is based on available industry-specific data	
		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 Methodology review draft.

5.1 Personal Protective Equipment (PPE)

Information from two CCP manufacturing sites indicates that exposures are minimized through engineering controls, PPE and process automation; however, the specific PPE worn is not available. Information from one thermal paper manufacturer indicates that no PPE is generally used in the thermal paper manufacturing industry (Exponent, 2007). At a minimum, CEB assumes standard PPE includes gloves and eye protection. The CCP manufacturing sites also conduct continuous air monitoring of the unloading, mixing, coating and finishing areas (Glatfelter, 2005).

5.2 Number of Workers Exposed per Site

Using data from two CCP manufacturing sites, Table 5-2. Number of Workers Exposed During CCP Manufacturing, was generated providing an estimate of the number of workers exposed to the CCP coating chemicals during the CCP manufacturing process. As shown by Table 5-1, approximately 90 workers may be exposed to the CCP chemical per site. As previously discussed, CCP manufacturing facilities are assumed to operate 250 days per year (Glatfelter, 2005); therefore, all occupational exposure estimates should be based on 250 days/yr of exposure. Additionally, because 3 shifts support manufacturing operations, exposure estimates should be based on 8 hours of exposure per day.

Data from a thermal paper manufacturing industry source indicates two workers are exposed during mixing, and that workers monitor the coating process from control rooms (Exponent, 2007). Since a specific breakdown of the number of workers for each thermal paper manufacturing activity (e.g. raw material unloading, product finishing,) is not available, assume that the total number of workers per site is similar to that as for CCP manufacture. This assumption is valid since CCP manufacturing sites commonly also produce thermal paper.

These data may be utilized as default for both CCP and thermal paper manufacturing if site-specific information is not available. For converter facilities (i.e. where the coating is applied to purchased rather than on-site-manufactured base paper), the number of workers may be less than shown in Table 5-2. Number of Workers Exposed During CCP Manufacturing; additionally, converter facilities may operate with only one working shift per day. Therefore, the values in Table 5-2. Number of Workers Exposed During CCP Manufacturing represent conservative estimates of the number of workers potentially exposed at converter facilities.

Table 5-2. Number of Workers Exposed During CCP Manufacturing

Activity	Number of Exposed Workers per Coater per Shift	Number of Coaters per Site	Number of Shifts	Number of Workers Exposed per Site
A. Raw Material Unloading	2	2	3	12
B. Coating Operation	5	2	3	30
C. Product Finishing	8	2	3	48
Total	15	2	3	90

Source: Glatfelter, 2005.

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

Liquid chemicals are typically received in bulk containers (tankers or rail cars); therefore, workers may be exposed when connecting transfer lines. Alternatively, solid raw materials are typically received in bags or supersacks. Workers may operate machinery to dump solid raw materials into process vessels (Glatfelter, 2005). Manual unloading of chemicals from transport containers into the process vessels tanks is rare at CCP manufacturing sites. Assume 12 workers per site are exposed to the chemical of interest during this activity if site-specific information is not available (see Table 5-2. Number of Workers Exposed During CCP Manufacturing). If the physical form of the raw material containing the chemical of interest is unknown, solid powder should be assumed for more conservative exposure estimates.

Inhalation: For liquid additives, inhalation exposure is negligible for non-volatile chemicals (vapor pressure < 0.001 torr). Volatile chemicals are outside the scope of this scenario.

For solid additives, most sites handle greater than 54 kg/site-day of the raw material. Therefore, the *United States Occupational Safety and Health Administration (OSHA) Total PNOR PEL-Limiting Model* should be used to estimate inhalation exposure to solid powders. The *EPA/OPPT Small Volume Solids Handling Inhalation Model* may be used for sites handling less than 54 kg/site-day of the raw material; however, this is not expected in the CCP or thermal manufacturing industry. To estimate inhalation exposure using the *OSHA Total PNOR PEL-Limiting Model*, use the following equation:

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

Where:

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

*TWA = Time-weighted average.

Dermal: The *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* or the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure during unloading depending on the physical form of the raw material containing the chemical of interest.

Liquid Raw Materials:

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

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chem/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid product remaining on skin (Defaults = 2.1 mg additive/cm ² -incident (high-end) and 0.7 mg additive/cm ² -incident (low-end) for routine or incidental contact) (CEB, 2000)
$AREA_{\text{surface}}$	=	Surface area of contact (Default = 840 cm ² , 2 hands) (CEB, 2000)
$N_{\text{exp_incident}}^{11}$	=	Number of exposure incidents per day (Default = 1 incident/day)
$F_{\text{chem_additive}}$	=	Weight fraction of the chemical of interest in additive (Default = 1 kg chem/kg additive)

Solid Raw Materials:

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

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chem/day)
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default = 1 incident/day)
$F_{\text{chem_additive}}$	=	Weight fraction of the chemical of interest in additive (Default = 1 kg chem/kg additive)

5.4 Exposure During Transport Container Cleaning (Exposure B)

Exposure to the raw chemical may occur during container cleaning. Assume 12 workers per site are exposed to the chemical of interest during this activity if site-specific information is not available (see Table 5-2. Number of Workers Exposed During CCP Manufacturing).

¹¹ Only 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.

Dermal: There is potential for dermal exposure during transport container cleaning. No industry-specific dermal monitoring data on transport containers cleaning were found. In the absence of data, the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* can be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these activities.

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad (5-4)$$

Where:

EXP_{dermal}	= Potential dermal exposure to the chemical of interest per day (mg chem/day)
$Q_{\text{liquid_skin}}$	= Quantity of liquid product remaining on skin (Defaults = 2.1 mg additive/cm ² -incident (high-end) and 0.7 mg additive/cm ² -incident (low-end) for routine or incidental contact) (CEB, 2000)
$AREA_{\text{surface}}$	= Surface area of contact (Default = 840 cm ² , 2 hands) (CEB, 2000)
$N_{\text{exp_incident}}^{12}$	= Number of exposure incidents per day (Default = 1 incident/day)
$F_{\text{chem_additive}}$	= Weight fraction of the chemical of interest in additive (Default = 1 kg chem/kg additive)

5.5 Exposure During Equipment Cleaning (Exposure C)

Workers may be exposed to the aroma chemical when they manually wipe down the equipment. Assume 12 workers per site are exposed to the chemical of interest during this activity if site-specific information is not available (see Table 5-2. Number of Workers Exposed During CCP Manufacturing).

Dermal: There is potential for dermal exposure during transport equipment cleaning. No industry-specific dermal monitoring data on transport containers cleaning were found. In the absence of data, the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* can be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these activities.

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

Where:

EXP_{dermal}	= Potential dermal exposure to the chemical of interest per day (mg chem/day)
$Q_{\text{liquid_skin}}$	= Quantity of liquid product remaining on skin (Defaults = 2.1 mg additive/cm ² -incident (high-end) and 0.7 mg additive/cm ² -incident (low-end) for routine or incidental contact)

¹² Only 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.

	incident (low-end) for routine or incidental contact) (CEB, 2000)
$AREA_{\text{surface}}$	= Surface area of contact (Default = 840 cm ² , 2 hands) (CEB, 2000)
$N_{\text{exp_incident}}$ ¹³	= Number of exposure incidents per day (Default = 1 incident/day)
$F_{\text{chem_additive}}$	= Weight fraction of the chemical of interest in additive (Default = 1 kg chem/kg additive)

5.6 Exposure During Coating Operations (Exposure D)

Types of potential coating processes are discussed in Section 2.3, and include blade coating, air knife coating and reverse roll coating. Maximum speeds achievable for each of these technologies are relatively high: 1 500 meters per minute, 500 meters per minute and 400 meters per minute, respectively. Coaters are typically enclosed. Inhalation monitoring data from two sites indicate no detectable levels of mists or particulates from coating operations (Glatfelter, 2005). However, mist generation from high speed coating and resulting inhalation exposure are assumed to occur, as conservative. Additionally, a potential for dermal exposure exists during transfers of chemicals to the coating equipment and during the cleaning of process equipment with organic solvents. Assume 30 workers per site are exposed to the chemical of interest during this activity if site-specific information is not available (see Table 5-2. Number of Workers Exposed During CCP Manufacturing).

Inhalation: Volatile chemicals are outside the scope of this scenario. All materials are in liquid form for coating operations. For non-volatile chemicals, 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. This model assumes 0.25 mg particulate/mg formulation as default mass fraction of particulate in the coating formulation.

$$EXP_{\text{inhalation}} = C_{\text{part_air}} \times TIME_{\text{exposure}} \times RATE_{\text{breathing}} \times F_{\text{chem_form}} / F_{\text{particulate_prod}} \quad (5-6)$$

Where:

$EXP_{\text{inhalation}}$	=	Inhalation potential dose rate of chemical during spray coating (mg chem/day)
$C_{\text{part_air}}$	=	Mass concentration of total particulate in air (Default = 0.04 (low end of range), 0.26 (high end of range) mg/m ³ of air)
$TIME_{\text{exposure}}$	=	Duration of exposure to the chemical during the coating process (Default = 8 hours/day)

¹³ Only 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.

$RATE_{breathing}$	=	Inhalation rate (CEB default = 1.25 m ³ /hr) (CEB, 1991b)
F_{chem_form}	=	Mass fraction of chemical in the coating formulation (see Section 3.3)
$F_{particulate_prod}$	=	Mass fraction of particulate in the coating formulation (Default = 0.25 mg particulate/mg formulation)

Dermal: The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure during coating operations.

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

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chem/day)
Q_{liquid_skin}	=	Quantity of liquid product remaining on skin (Defaults = 2.1 mg formulation/cm ² -incident (high-end) and 0.7 mg additive/cm ² -incident (low-end) for routine or incidental contact) (CEB, 2000)
$AREA_{surface}$	=	Surface area of contact (Default = 840 cm ² , 2 hands) (CEB, 2000)
$N_{exp_incident}$	=	Number of exposure incidents per day (Default = 1 incident/day)
F_{chem_form}	=	Weight fraction of the chemical of interest in the CCP or thermal formulation (kg chem/kg coating formulation)

5.7 Exposure to Particulates During Product Finishing (Exposure E)

Workers may be exposed while trimming and finishing the products. Rolls of coated paper are cut down to size by sheeters, cutters or trimmers, potentially generating airborne particulate (Glatfelter, 2005). Assume 48 workers per site are exposed to the chemical of interest during this activity if site-specific information is not available (see Table 5-2. Number of Workers Exposed During CCP Manufacturing).

Inhalation:	Monitoring data from two CCP manufacturing sites found between negligible and 3.0 mg/m ³ of total particulate and between negligible and 1.87 mg/m ³ for respirable particulate in the product finishing area (Glatfelter, 2005). As a conservative estimate, a concentration of 3.0 mg of product/m ³ may be used to estimate inhalation exposure.
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$$EXP_{inhalation} = C_{part_finish} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_prod} \quad (5-8)$$

Where:

$EXP_{inhalation}$	=	Inhalation exposure from the unloading the chemical of interest per day (mg chem/day)
C_{part_finish}	=	Concentration of particulate in the workers breathing zone in the finishing area (Default = 3.0 mg/m ³)

$RATE_{\text{breathing}}$	= Typical worker breathing rate (Default = 1.25 m ³ /hr) (CEB, 1991b)
$TIME_{\text{exposure}}$	= Duration of exposure (Default = 8 hr/day)
$F_{\text{chem_prod}}$	= Weight fraction of the chemical of interest in the final product (see Section 3.3)

Dermal: Dermal exposure is typically not assessed for the handling of chemical coated onto a solid surface. However, during product trimming dust may be generated and microcapsules may break. Therefore, as a conservative estimate, the *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* may be used to estimate dermal exposure during product finishing.

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

Where:

EXP_{dermal}	= Potential dermal exposure to the chemical of interest per day (mg chem/day)
$N_{\text{exp_incident}}$	= Number of exposure incidents per day (Default = 1 incident/day)
$F_{\text{chem_prod}}$	= Weight fraction of the chemical of interest in the final product (see Section 3.3)

6 SAMPLE CALCULATIONS

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

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

- The chemical of interest is a dispersant;
- The chemical of interest has a molecular weight ($MW_{\text{chem.}}$) of 200 g/mol and is nonvolatile;
- The chemical is received at one CCP manufacturing facility in solid form at 100% concentration;
- The chemical of interest production volume ($Q_{\text{chem_yr}}$) is 10 000 kg/year; and
- Both environmental releases and occupational exposures are a concern.

6.1 General Facility Estimates

Operating Days

$$\text{TIME}_{\text{working_days}} = 250 \text{ days/yr}$$

Weight Fraction of the Chemical of Interest

The chemical of interest is a dispersant; therefore, as presented in Table 2-1, assume the chemical is received at the CCP manufacturing facility in a developer, at 0.01–0.02 weight fraction in total formulation. Use Equations 3-1a and 3-1b.

$$\begin{aligned} F_{\text{chem_form}} &= F_{\text{chem_additive}} \times F_{\text{additive_form}} = 1 \text{ kg chem/kg additive} \times 0.02 \text{ kg additive/kg formulation} \\ F_{\text{chem_form}} &= 0.02 \text{ kg chem/kg formulation} \end{aligned}$$

$$F_{\text{chem_prod}} = F_{\text{chem_form}} \times F_{\text{form_prod}} = 0.02 \text{ kg chem/kg form} \times 0.1 \text{ kg formulation/kg CCP}$$

$$F_{\text{chem_prod}} = 0.002 \text{ kg chem/kg product}$$

Daily Use Rate of the Chemical of Interest

Use the production volume of the chemical of interest, number of sites and days of operation in Equation 3-3.

$$Q_{\text{chem_site_day}} = \frac{Q_{\text{chem_yr}}}{N_{\text{sites}} \times \text{TIME}_{\text{working_days}}} = \frac{10\,000 \text{ kg/yr}}{1 \text{ site} \times 250 \text{ days/yr}}$$

$$Q_{\text{chem_site_day}} = 40 \text{ kg chem/site – day}$$

Number of Sites

$$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{prod_yr}} \times F_{\text{form_site}} \times F_{\text{chem_prod}}} = \frac{10,000 \frac{\text{kg}}{\text{yr}}}{8.24 \times 10^6 \frac{\text{kg}}{\text{site-yr}} \times 1 \frac{\text{kg form. with chem.}}{\text{kg form. used}} \times 0.002 \frac{\text{kg chem.}}{\text{kg prod.}}}$$

$$N_{\text{sites}} = 0.6 \text{ sites, rounds to 1 site}$$

6.2 Environmental Releases

Cleaning Residuals from Containers used to Transfer Raw Materials to Mixing Vessel (Release 1)

The *EPA/OPPT Solids Residual in Transport Containers Model* may be utilized to estimate container residue releases from raw materials received in bags or supersacks.

[4-4]

$$E_{\text{local_container_residue_disp}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}} = 40 \frac{\text{kg}}{\text{site-day}} \times 0.01 \frac{\text{kg add. remaining}}{\text{kg solid add. shipped}}$$

$$E_{\text{local_container_residue_disp}} = 0.40 \text{ kg/site – day}$$

...over 250 days/year from 1 site

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

The *EPA/OPPT Dust Emissions from Transferring Solids Model* may be used to estimate dust releases generated during the transfer of solid CCP or thermal paper manufacturing components. This model assumes that up to 0.5 percent of the transferred quantity may be released to the environment. The rationale, defaults and limitations of these models are further explained in Appendix B.

[4-5]

$$\begin{aligned} \text{Elocal}_{\text{dust_fugitive}} &= Q_{\text{chem_site_day}} \times F_{\text{dust_generation}} = 40 \text{ kg/site - day} \times 0.005 \text{ kg released/kg handled} \\ \text{Elocal}_{\text{dust_fugitive}} &= 0.20 \text{ kg/site-day} \\ &\dots \text{over 250 days/year from 1 site} \end{aligned}$$

Releases from Equipment Cleaning (Release 3)

The *EPA/OPPT Multiple Vessel Residual Model* assumes that no more than 2 percent of the batch size or capacity of the process vessel remains in the equipment as residue and released as equipment cleaning waste.

[4-6]

$$\begin{aligned} \text{Elocal}_{\text{equip_cleaning}} &= Q_{\text{chem_site_day}} \times F_{\text{equip_cleaning}} = 40 \text{ kg/site - day} \times 0.02 \text{ kg chem. remain./kg chem. form.} \\ \text{Elocal}_{\text{equip_cleaning}} &= 0.8 \text{ kg/site-day} \\ &\dots \text{over 250 days/yr from 1 site} \end{aligned}$$

Coating Process Losses (Release 4)

Use Equation 4-7 to estimate acid developer or microcapsule slurry formulation lost during the coating process.

$$\begin{aligned} \text{Elocal}_{\text{coating_loss}} &= Q_{\text{chem_site_day}} \times F_{\text{coating_loss}} = 40 \text{ kg/site - day} \times 0.15 \text{ kg chem. released/chem. form.} \\ \text{Elocal}_{\text{coating_loss}} &= 6 \text{ kg/site-day} \\ &\dots \text{over 250 days/yr from 1 site} \end{aligned}$$

Trimming and Off-Spec Product Releases (Release 5)

Use Equation 4-8 to estimate trimmings (broke) and off-spec product release.

$$\begin{aligned} \text{Elocal}_{\text{broke_release}} &= Q_{\text{chem_site_day}} \times F_{\text{broke_generation}} = 40 \text{ kg/site-day} \times 0.04 \text{ kg chemical in broke/kg chemical} \\ &\quad \text{applied} \\ \text{Elocal}_{\text{broke_release}} &= 1.6 \text{ kg/site-day} \\ &\dots \text{over 250 days/yr from 1 site} \end{aligned}$$

6.3 Occupational Exposure Assessments

Number of Workers Exposed per Site

$$N_{\text{workers}} = \text{up to 90 workers/site (see Section 5.2)}$$

Exposure from Unloading Solid or Liquid Chemicals (Exposure A)

Liquid chemicals are typically received in bulk containers (tankers or rail cars); therefore, workers may be exposed when connecting transfer lines. Alternatively, solid raw materials are typically received in bags or supersacks.

Inhalation Exposure:

For liquid additives, inhalation exposure is negligible for non-volatile chemicals (vapor pressure < 0.001 torr). Volatile chemicals are outside the scope of this scenario.

For solid additives, most sites handle greater than 54 kg/site-day of the raw material. Therefore, the *OSHA Total PNOR PEL-Limiting Model* should be used to estimate inhalation exposure to solid powders.

Table 6-1. Summary of Inputs¹⁴ for Inhalation Exposure A

Parameter	Units	Input
C _{particulate}	mg/m ³	15
RATE _{breathing}	m ³ /hr	1.25
TIME _{exposure}	hr/day	8

$$\begin{aligned} \text{EXP}_{\text{inhalation}} &= C_{\text{particulate}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \times F_{\text{chem_additive}} \text{ [5-1]} \\ \text{EXP}_{\text{inhalation}} &= 15 \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times 8 \text{ hr/day} \times 1 \text{ kg chem./kg add.} \\ \text{EXP}_{\text{inhalation}} &= 150 \text{ mg chemical/worker-day} \\ &\quad \dots \text{over 250 days/year} \end{aligned}$$

Dermal Exposure:

The *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* or the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure during unloading depending on the physical form of the raw material containing the chemical of interest.

¹⁴ These inputs are used in ChemSTEER. ChemSTEER is a Chemical Screening Tool for Exposures and Environmental Releases developed by the EPA for estimating workplace exposures and releases to a chemical.

Liquid Raw Materials:

Table 6-2. Summary of Inputs¹⁵ for Dermal Exposure A

Parameter	Units	Input
$Q_{\text{liquid_skin}}$	mg/cm ² -incident	High end: 2.1 Low end: 0.7
$AREA_{\text{surface}}$	cm ²	840
$N_{\text{exp_incident}}$	incident/day	1

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad [5-2]$$

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

$EXP_{\text{dermal}} = 1\,764 \text{ mg/cm}^2\text{-incident}$ for high end and $588 \text{ mg/cm}^2\text{-incident}$ for low end

Solid Raw Materials:

$$EXP_{\text{dermal}} = \text{up to } 3\,100 \text{ mg additive/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad [5-3]$$

$$EXP_{\text{dermal}} = 3\,100 \text{ mg additive/incident} \times 1 \text{ incident/day} \times 1 \text{ kg chemical/kg additive}$$

$$EXP_{\text{dermal}} = 3\,100 \text{ mg/day}$$

Exposure During Transport Container Cleaning (Exposure B)

Dermal Exposure:

The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure during container cleaning operations.

$$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad [5-4]$$

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

$EXP_{\text{dermal}} = 1\,764 \text{ mg/cm}^2\text{-incident}$ for high end and $588 \text{ mg/cm}^2\text{-incident}$ for low end

Exposure During Equipment Cleaning (Exposure C)

¹⁵ These inputs are used in ChemSTEER. ChemSTEER is a Chemical Screening Tool for Exposures and Environmental Releases developed by the EPA. It enables to estimates workplace exposures and releases to a chemical.

Dermal Exposure:

The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure during equipment cleaning operations.

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [5-4] \\ &= \left[\frac{0.7 \text{ to } 2.1 \text{ mg form.}}{\text{cm}^2 - \text{incident}} \right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{1 \text{ mg chem.}}{\text{mg form.}} \\ \text{EXP}_{\text{dermal}} &= 1\,764 \text{ mg/cm}^2\text{-incident for high end and } 588 \text{ mg/cm}^2\text{-incident for low end} \end{aligned}$$

*Exposure During Coating Operations (Exposure D)**Inhalation Exposure:*

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.

$$\begin{aligned} \text{EXP}_{\text{inhalation}} &= C_{\text{part_air}} \times \text{TIME}_{\text{exposure}} \times \text{RATE}_{\text{breathing}} \times F_{\text{chem_form}} / F_{\text{particulate_prod}} \quad [5-6] \\ &= 0.04 \text{ to } 0.26 \frac{\text{mg}}{\text{m}^3} \times 8 \frac{\text{hr}}{\text{d}} \times 1.25 \frac{\text{m}^3}{\text{hr}} \times 0.02 \frac{\text{mg}}{\text{mg}} / 0.25 \frac{\text{mg}}{\text{mg}} \\ \text{EXP}_{\text{inhalation}} &= 0.032 \text{ mg/day for high end and } 0.21 \text{ mg/day for low end} \end{aligned}$$

Dermal Exposure:

The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure during coating operations.

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_form}} \quad [5-7] \\ &= \left[\frac{0.7 \text{ to } 2.1 \text{ mg form.}}{\text{cm}^2 - \text{incident}} \right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.02 \text{ mg chem.}}{\text{mg form.}} \\ \text{EXP}_{\text{dermal}} &= 35.3 \text{ mg/cm}^2\text{-incident for high end and } 11.8 \text{ mg/cm}^2\text{-incident for low end} \end{aligned}$$

Exposure to Particulates During Product Finishing (Exposure E)

Workers may be exposed while trimming and finishing the products.

Inhalation Exposure:

As a conservative estimate, a concentration of 3.0 mg of product/m³ may be used to estimate inhalation exposure using Equation 5-8.

$$\begin{aligned} \text{EXP}_{\text{inhalation}} &= C_{\text{part_finish}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \times F_{\text{chem_prod}} \\ \text{EXP}_{\text{inhalation}} &= 3.0 \text{ mg/m}^3 \times 1.25 \text{ m}^3/\text{hr} \times 8 \text{ hr/day} \times 0.002 \text{ kg chemical/kg product} \\ \text{EXP}_{\text{inhalation}} &= 0.06 \text{ mg chemical/worker-day} \\ &\quad \dots \text{over 250 days/year} \end{aligned}$$

Dermal Exposure:

As a conservative estimate, the *EPA/OPPT 2-Hand Dermal Contact with Solids Model* may be used to estimate dermal exposure during product finishing.

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= \text{up to } 3100 \text{ mg additive/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_prod}} \quad [5-9] \\ \text{EXP}_{\text{dermal}} &= 3100 \text{ mg additive/incident} \times 1 \text{ incident/day} \times 0.002 \text{ kg chemical/kg product} \\ \text{EXP}_{\text{dermal}} &= 6.2 \text{ mg/day} \end{aligned}$$

7. DATA GAPS/UNCERTAINTIES AND FUTURE WORK

- Industry-specific information for acid developer formulation steps in thermal paper manufacturing was not available to the same level of detail as for CCP (see Section 2.1).
- Information on all specific components of thermal paper coating formulation was not available. Therefore, a table for “Physical Properties of Example Thermal Paper Chemicals” is not included (see Table 2-3).
- CEB commented on the November 2006 version of this scenario, referring to the reported wastewater treatment data provided by industry: “...was this annual information?” As discussed in the Product Review Meeting in the EPA, no specific time period was included with the treatment data submitted.

8. REFERENCES

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

- United States Environmental Protection Agency (EPA),
- United States Occupational Safety and Health Administration (OSHA),
- United States National Institute for Occupational Safety and Health (NIOSH),
- United States Census Bureau and
- Environment Canada.

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

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APPENDIX A

ESTIMATION EQUATION SUMMARY AND DEFAULT VALUE DOCUMENTATION

Summary of Release and Exposure Estimation Equations

Table A-1 summarizes the equations introduced in Section 3.0, which are used to calculate the general facility parameters. Tables A-2 and A-3 summarize the equations used in evaluating releases of and exposures to chemicals used in the formulation and application of thermal and carbonless copy paper coatings. Table A-4 summarizes the parameters for each equation, the default value if applicable and the source. The default values for standard EPA/OPPT models are presented in Appendix B.

Table A-1. General Facility Parameter Calculation Summary

General Facility Estimates	
Days of Operation per Year:	
$TIME_{\text{working_days}} = 250 \text{ days/year (default)}$	(See Section 3.1)
Weight Fraction of the Chemical of Interest:	
$F_{\text{chem_form}} = F_{\text{chem_additive}} \times F_{\text{additive_form}}$	(3-1a)
$F_{\text{chem_prod}} = F_{\text{chem_form}} \times F_{\text{form_prod}}$	(3-1b)
Daily Use Rate of Formulation per Facility:	
$Q_{\text{chem_site_day}} = \frac{Q_{\text{chem_yr}}}{N_{\text{sites}} \times TIME_{\text{working_days}}}$	(3-3)
Number of Sites:	
$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{CCP_yr}} \times F_{\text{form_site}} \times F_{\text{chem_prod}}}$	(3-2a, 3-2b)

Environmental Release Calculations		
Source	Media of Release	Calculations
Control Technologies		$E_{\text{local}}_{\text{water_WWT}} = E_{\text{local}}_{\text{coating_losses}} \times (1 - F_{\text{eff_WWT}}) \quad (4-9a)$ $E_{\text{local}}_{\text{concentrate}} = E_{\text{local}}_{\text{coating_losses}} \times F_{\text{eff_WWT}} \quad (4-9b)$
Release 1 Container Residue	Water, Incineration, or Landfill	<p>For Liquids:</p> $N_{\text{cont_site_yr}} = \frac{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{working_days}}}{V_{\text{container}} \times \text{RHO}_{\text{additive}} \times F_{\text{chem_additive}}} \quad (4-1)$ <p>If the number of containers is less than the days of operation, the days of release is equal to the number of containers, and the daily release is calculated based on the following equation:</p> $E_{\text{local}}_{\text{container_residue_disp}} = V_{\text{container}} \times \text{RHO}_{\text{additive}} \times F_{\text{chem_additive}} \times F_{\text{container_residue}} \times 1 \frac{\text{container}}{\text{site-day}} \quad (4-2)$ <p>If the number of containers is greater than the days of operation, the days of release is equal to the days of operation, and the daily release is calculated based on the following equation (Note: most sites should use less than one container per day):</p> $E_{\text{local}}_{\text{container_residue_disp}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}} \quad (4-3)$ <p>For Solids:</p> <p>The <i>EPA/OPPT Solids Residual in Transport Containers Model</i> may be utilized to estimate container residue releases from raw materials received in bags or supersacks. Information from two facilities indicates that all bags are disposed at a third party permitted landfill facility (Glatfelter, 2005). As conservative, CEB assumes these wastes may also be incinerated. The daily release may be estimated using the following equation:</p> $E_{\text{local}}_{\text{container_residue_disp}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}} \quad (4-4)$
Release 2 Dust Generation from Transfer Operations	Air, Water, Incineration, or Landfill	<p>For liquid non-volatile chemicals: $E_{\text{local}}_{\text{dust_fugitive}} = \text{negligible}$</p> <p>For solid chemicals:</p> $E_{\text{local}}_{\text{dust_fugitive}} = Q_{\text{chem_day}} \times F_{\text{dust_generation}} \quad (4-5)$
Release 3 Cleaning Mixing Vessels	On-site treatment	$E_{\text{local}}_{\text{equip_cleaning}} = Q_{\text{chem_site_day}} \times F_{\text{equip_cleaning}} \quad (4-6)$
Release 4 Coating Process Losses	On-site treatment	$E_{\text{local}}_{\text{coating_losses}} = Q_{\text{chem_site_day}} \times F_{\text{coating_losses}} \quad (4-7)$

Environmental Release Calculations		
Source	Media of Release	Calculations
Release 5 Trimblings and Off-spec Product	On-site treatment after broke recycle	$E_{\text{local}_{\text{broke_release}}} = Q_{\text{chem_site_day}} \times F_{\text{broke_generation}} \quad (4-8)$

Occupational Exposure Estimates
<p>Number of Exposed Workers per Site (Section 5.2):</p> <p>See Table 5-2. Number of Workers Exposed During CCP Manufacturing for specific exposures during raw material unloading, coating operations and product finishing.</p>
<p>Exposure from Unloading Solid or Liquid Chemicals (Exposure A)</p> <p>Default Number of Exposed Workers: up to 12 workers/site</p> <p><u>Inhalation:</u></p> <p><i>Liquids:</i></p> <p>If non-volatile (VP <0.001 torr):</p> $EXP_{inhalation} = \text{Negligible}$ <p>If volatile (VP >0.001 torr):</p> <p>Outside the scope of this scenario</p> <p><i>Solids:</i></p> <p>If $Q_{\text{facility_day}} > 54$ kg of additive/site-day:</p> $EXP_{inhalation} = C_{\text{particulate}} \times RATE_{\text{breathing}} \times TIME_{\text{exposure}} \times F_{\text{chem_additive}} \quad (5-1)$ <p><u>Dermal:</u></p> <p><i>Liquids:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad (5-2)$ <p><i>Solids:</i></p> $EXP_{\text{dermal}} = \text{up to } 3,100 \text{ mg-incident/day} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad (5-3)$
<p>Exposure from Transport Container Cleaning (Exposure B)</p> <p>Default Number of Exposed Workers: up to 12 workers/site</p> <p><u>Dermal:</u></p> <p><i>Liquids:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad (5-4)$
<p>Exposure from Equipment Cleaning (Exposure C)</p> <p>Default Number of Exposed Workers: up to 12 workers/site</p> <p><u>Dermal:</u></p> <p><i>Liquids:</i></p> $EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad (5-5)$

Occupational Exposure Estimates	
Exposure During Coating Operations (Exposure D) Default Number of Exposed Workers: 30 workers/site <u>Inhalation:</u> $EXP_{inhalation} = C_{part_air} \times TIME_{exposure} \times RATE_{breathing} \times F_{chem_particulate} \quad (5-6)$ If volatile (VP >0.001 torr): Outside the scope of this generic scenario <u>Dermal:</u> $EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_formn} \quad (5-7)$	
Exposure to Particulates During Product Finishing (Exposure E) Default Number of Exposed Workers: up to 48 workers/site <u>Inhalation:</u> $EXP_{inhalation} = C_{part_finish} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_prod} \quad (5-8)$ <u>Dermal:</u> Dermal typically not assessed for the handling of chemical coated onto a solid surface. However, in instances of product trimming: $EXP_{dermal} = \text{up to 3,100 mg additive/incident} \times N_{exp_incident} \times F_{chem_additive} \quad (5-9)$	

Variable	Variable Description	Default Value	Data Source
AREA _{surface}	Surface area of contact (cm ²)	840 (2 hands)	(CEB, 2000)
C _{part_finish}	Concentration of particulate in the workers breathing zone in the finishing area (mg/m ³)	3.0	(Glatfelter, 2005)
C _{particulate}	Concentration of particulate in the workers breathing zone (mg/m ³)	15	29 CFR 1910.1000
F _{additive_form}	Weight fraction of the additive in formulation (kg additive/kg formulation)	CCP: 0.23 Thermal: 0.10	Tables 2-1 and 2-2
F _{broke_generation}	Fraction of chemical lost from trimming and off-spec product (kg chem in broke/kg chem applied)	0.4	(Glatfelter, 2005)
F _{broke_release}	Fraction of chemicals in broke released to on-site wastewater treatment (kg chem released/kg chem in broke)	0.1	(Glatfelter, 2005)

Variable	Variable Description	Default Value	Data Source
$F_{\text{chem_additive}}$	Weight fraction of the chemical of interest in additive.	1	CEB assumption
$F_{\text{coating_loss}}$	Fraction of chemical lost during the coating process (kg chem released/kg chem formulated)	CCP: 0.15 Thermal: 0.15	CEB assumption
$F_{\text{container_residue}}$	Fraction of chemical remaining in the container as residue (kg container residue/kg in container)	Liquids: 0.002 Solids: 0.01 (for bulk shipping containers)	(CEB, 1992)
$F_{\text{dust_generation}}$	Fraction of chemical lost during transfer/unloading of solid powders (kg released/kg handled)	0.005	(CEB, 2007)
$F_{\text{eff_WWT}}$	Wastewater treatment efficiency	0.891 (COD)	(Glatfelter, 2005)
$F_{\text{equipment_cleaning}}$	Fraction of chemical remaining in the formulation vessel as residue (kg chem remaining/kg chem. f Formulated)	0.02	CEB assumption
$F_{\text{form_prod}}$	Weight fraction of the formulation in the final product.	0.1 kg formulation/kg product	(Glatfelter, 2005) (Schmidt, 2000)
$F_{\text{form_site-}}$	Fraction of formulations used per site containing the chemical of interest	1	CEB assumption
$N_{\text{exp_incident}}$	Number of exposure incidents per day (incidents/day)	1	CEB assumption
$Q_{\text{CCP_yr}}, Q_{\text{thermal_yr}}$	Average annual production volume of product (kg product/site-yr)	CCP: 103.75×10^6 Thermal : 45×10^6	(Fisher, 2008)
$Q_{\text{liquid_skin}}$	Quantity of liquid remaining on skin (mg/cm ² -incident)	Routine or incidental contact: 2.1 (high-end) 0.7 mg/cm ² (low-end) Routine immersion: 10.3 (high-end) 1.3 (low-end)	(CEB, 2000)
$\text{RATE}_{\text{breathing}}$	Typical worker breathing rate (m ³ /hr)	1.25	(CEB, 1991)
$\text{RHO}_{\text{additive}}$	Density of additive (kg formulation/L)	1	CEB assumption
$\text{TIME}_{\text{exposure}}$	Duration of exposure (hr/day)	8	the default value for $C_{\text{particulate}}$ is an 8-hr TWA
$\text{TIME}_{\text{working_days}}$	Operating days (days/yr)	Default = 250 days/yr	CEB assumption (Glatfelter, 2005)
$V_{\text{container}}$	Volume of product container (L/container)	190,00 L/container	CEB assumption

APPENDIX B

BACKGROUND INFORMATION AND EQUATIONS/DEFAULTS FOR THE STANDARD EPA ENVIRONMENTAL RELEASE AND WORKER EXPOSURE MODELS

B.1 Introduction

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

- Section B.2: Chemical Vapor Releases & Associated Inhalation Exposures;
- Section B.3: Container Residue Release Models (non-air);
- Section B.4: Process Equipment Residue Release Models (non-air);
- Section B.5: Dust Emissions from Transferring Solids Model;
- Section B.6: Chemical Particle Inhalation Exposure Models;
- Section B.7: Dermal Exposure Models; and
- Section B.8: Chemical Mist Inhalation Exposure Model.

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:

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*¹⁶ 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

¹⁶ Similar air releases from surfaces located at *outdoor* locations (air speeds > 100 ft/min) are calculated using the *Mass Transfer Coefficient Model* (see the description provided in this section of Appendix B).

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:

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

Where:

$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical/sec)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default = 1) ¹⁷
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{\text{air_speed}}$	=	Air speed (EPA default = 100 feet/min; value must be ≤ 100 feet/min for this model)
$AREA_{\text{opening}}$	=	Surface area of the static pool or opening (cm^2 ; $B \times D_{\text{opening}}^2 / 4$)
$TEMP_{\text{ambient}}$	=	Ambient temperature (EPA default = 298 K)
D_{opening}	=	Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)
P_{ambient}	=	Ambient pressure (EPA default = 1 atm)

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

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

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

Where:

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

¹⁷The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

References:

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

B.2.1.2 EPA/OPPT Mass Transfer Coefficient Model

Model Description and Rationale:

The *EPA/OPPT Mass Transfer Model* estimates releases to air from the evaporation of a chemical from an open, exposed liquid surface. This model is appropriate for determining this type of volatile release from activities that are performed *outdoors*¹⁸ 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).

¹⁸ Similar air releases from surfaces located at *indoor* locations (air speeds ≤ 100 ft/min) are calculated using the *Penetration Model* (see the description provided in this section of Appendix B).

Model Equations:

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

[B-3]

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

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) ¹⁹
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{\text{air_speed}}$	=	Air speed (EPA default = 440 feet/min; value must be > 100 feet/min for this model)
$AREA_{\text{opening}}$	=	Surface area of the static pool or opening (cm ² ; $B \times D_{\text{opening}}^2 / 4$)
$TEMP_{\text{ambient}}$	=	Ambient temperature (EPA default = 298 K)
D_{opening}	=	Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)

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

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

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

Where:

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

¹⁹ The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

References:

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

B.2.1.3 EPA/OAQPS AP-42 Loading Model

Model Description and Rationale:

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

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

Model Equations:

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

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

Where:

$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical/sec)
$F_{\text{saturation_factor}}$	=	Saturation factor (See Table B-1 for appropriate EPA default values)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$V_{\text{cont_empty}}$	=	Volume of the container (gallons; see Table B-1 for appropriate EPA default values)
$\text{RATE}_{\text{fill}}$	=	Fill rate (containers/hour; see Table B-1 for appropriate EPA default values)
$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default = 1) ²⁰
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:

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

Where:

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

Reference:

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

²⁰ The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

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

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

Activity Type (Location)	$V_{\text{cont empty}}$ (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 \times 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.

B-9 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) ²¹
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 = $24.45 \text{ L}/\text{mol}$ 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 ($\text{mg chemical}/\text{worker-day}$)
$C_{\text{chem_mass}}$	=	Mass concentration of the chemical vapor in air (mg/m^3 ; see Equation B-9)
$RATE_{\text{breathing}}$	=	Typical worker breathing rate (EPA default = $1.25 \text{ m}^3/\text{hr}$)

²¹ The 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.

$TIME_{\text{exposure}}$ = 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.²². “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.

²² Note: This reference is currently not available for viewing in the ChemSTEER Help System.

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

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

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

a - If the appropriate vapor generation rate model is the *EPA/OAQPS AP-42 Loading Model* (see Equation B-5) for an outdoor activity, the RATE_{air_speed} should be set to 440 feet/min, as a default in determining the worst case RATE_{ventilation}. **B.3 Container Residue Release Models (non-air)**

Model Description and Rationale:

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

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

Model Equation:

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

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

Where:

$E_{\text{local_container_residue_disp}}$	=	Daily release of the chemical residue to water, incineration, or landfill from the cleaning or disposal of empty shipping containers (kg/site-day)
$F_{\text{container_residue}}$	=	Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table B-3 for appropriate EPA default values)
$Q_{\text{total_daily_container}}$	=	Total (daily) quantity of the chemical contained in the shipping containers prior to emptying (kg of chemical/site-day; see Table B-4 for appropriate EPA default values)

Each model, however, utilizes unique default values within that equation based upon the relative size of the container and the physical form of the chemical residue. These default values are summarized in Table B-3 and Table B-4. The following models are the standard EPA models for estimating container residues:

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

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

containers ($Q_{\text{total_daily_container}}$) used in calculating the daily release. Thus, Table B-4 also contains the appropriate EPA default values for $\text{TIME}_{\text{days_container_residue}}$.

References:

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

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

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

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

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

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

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

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

B.4 Process Equipment Residue Release Models (non-air)

Model Description and Rationale:

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

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

Model Equation:

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

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

Where:

- | | | |
|---|---|---|
| $E_{\text{local}_{\text{equip_cleaning}}}$ | = | Daily release of the chemical residue to water, incineration, or landfill from cleaning of empty process equipment (kg/site-day) |
| $F_{\text{equip_residue}}$ | = | Fraction of the amount of the total chemical in the process equipment remaining in the emptied vessels, transfer lines, and/or other pieces (dimensionless; see Table B-5 for appropriate EPA default values) |
| $Q_{\text{equip_chem_capacity}}$ | = | Total capacity of the process equipment to contain the chemical in question, prior to emptying (kg of chemical/site-day; see Table B-6 for appropriate EPA default values) |

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

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

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

References:

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

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

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

Model Title	F _{equip residue} ^a
<i>EPA/OPPT Single Process Vessel Residual Model</i>	<p>Conservative: 0.01 (for <u>pumping</u> process materials from the vessel)</p> <p>*Alternative defaults: Central Tendency: 0.0007 High End to Bounding: 0.002 (alternative defaults for <u>gravity-draining</u> materials from the vessel)</p>
<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”. July 2007.
- U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (page 4-11). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.
- Plinke, Marc A.E., et al. “Dust Generation from Handling Powders in Industry.” *American Industrial Hygiene Association Journal*. Vol. 56: 251-257, March 1995.

B.6 Chemical Particle Inhalation Exposure Models

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

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

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

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

For amounts up to (and including) 54 kg/worker-shift, the *EPA/OPPT Small Volume Solids Handling Inhalation Model* is used, as it more accurately predicts worker exposures to particulates within this range than the *OSHA Total PNOR PEL-Limiting Model*. The *Small Volume Solids 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*²³ (i.e., ≤ 54 kg/worker-shift) of solid/powdered materials containing the chemical of interest. The handling of these small volumes is presumed to include scooping, weighing, and pouring of the solid materials.

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

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

Model Equation:

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

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

Where:

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

²³ Worker inhalation exposures to particulates handled in amounts *greater than 54 kg/worker-shift* are calculated using the *OSHA Total PNOR PEL-Limiting Model* (see the description provided in this section of Appendix B).

N_{shifts} ²⁴	=	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_{daily_handled} in the EPA/OPPT Small Volume Solids Handling Inhalation Model

Activity Type	Default $Q_{\text{shift_handled}}$ ²⁵ (kg/worker-day)
Loading and Unloading Containers	Quantity of material in each container (kg/container) × Number of containers/worker-shift
Container Cleaning	Quantity of residue in each container (kg/container) × Number of container/worker-shift
Process-Related Activity (equipment cleaning, sampling):	
Continuous process:	Daily throughput of material / Number of shifts per day
Batch process (<1 batch per day):	Quantity of material per batch
Batch process (>1 batch per day):	Quantity of material per batch × Number of batches per shift

References:

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

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

U.S. EPA Economics, Exposure and Technology Division²⁶. *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.

²⁴ Note that this value is the number of shifts worked by *each worker* per day. This value would only be greater than one if a worker worked for over eight hours in a given day.

²⁵ The appropriate quantity of material handled by each worker on each day may vary from these standard CEB defaults, per the particular scenario. Be sure to consult the discussion presented in the ESD activity description in determining the most appropriate default value for $Q_{\text{daily_handled}}$.

²⁶ Note: 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*²⁷. 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 mg/m ³ , based on the OSHA Total PNOR PEL, 8-hr TWA)
F_{chem}	=	Weight fraction of the chemical of interest in the particulate material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)

²⁷ Worker inhalation exposures to particulates handled in amounts *up to and including 54 kg/worker-shift* are calculated using the *EPA/OPPT Small Volume Handling Inhalation Model* (see the description provided in this section of Appendix B).

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

$$\text{EXP}_{\text{inhalation}} = C_{\text{chem_mass}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \quad [\text{B-17}]$$

Where:

$\text{EXP}_{\text{inhalation}}$	= Inhalation exposure to the airborne particulate chemical per day (mg chemical/worker-day)
$C_{\text{chem_mass}}$	= Mass concentration of the particulate chemical in air (mg/m ³ ; see Equation B-17)
$\text{RATE}_{\text{breathing}}$	= Typical worker breathing rate (EPA default = 1.25 m ³ /hr)
$\text{TIME}_{\text{exposure}}$	= Duration of exposure for the activity (EPA default = 8 hours/worker-day ²⁸)

References:

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

B.7 Dermal Exposure Models

Model Description and Rationale:

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

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

Model Equation:

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

²⁸ Since the OSHA Total PNOR PEL is an 8-hr TWA, the exposure duration must be assumed as 8 hours/worker-day for the model defaults to apply.

$$\text{EXP}_{\text{dermal}} = \text{AREA}_{\text{surface}} \times \text{Q}_{\text{remain_skin}} \times \text{F}_{\text{chem}} \times \text{N}_{\text{event}} \quad [\text{B-18}]$$

Where:

$\text{EXP}_{\text{dermal}}$	=	Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)
$\text{AREA}_{\text{surface}}$	=	Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm^2 ; see Table B-9 for appropriate EPA default values)
$\text{Q}_{\text{remain_skin}}$	=	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)
$\text{N}_{\text{event}}^{29}$	=	Frequency of events for the activity (EPA default = 1 event/worker-day)

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

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

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

References:

U.S. EPA. Chemical Engineering Branch. *Options for Revising CEB's Method for Screening-Level Estimates of Dermal Exposure – Final Report.* U.S. Environmental

²⁹ Only one contact per day ($\text{N}_{\text{event}} = 1$ event/worker-day) is assumed because $\text{Q}_{\text{remain_skin}}$, 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.

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>	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>	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>	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>	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>	Solid sampling activities Filling/dumping containers of powders, flakes, granules Weighing powder/scooping/mixing (i.e., dye weighing) Cleaning solid residues from process equipment Handling wet or dried material in a filtration and drying process	No defaults	No defaults	< 3,100 ²³

a - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citations of this sources) and are the mean values for men taken from the EPA Exposure Factors Handbook, 1997.

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

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

Table B-10. EPA Default Qualitative Assessments for Screening-Level Estimates of Dermal Exposure

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

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

B.8 Chemical Mist Inhalation Exposure Models

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.

Model Description and Rationale:

Limited personal samples were obtained from a monitoring study of workers exposed to “ink fly” in a facility using offset lithographic printing of cartonboard using UV-curable ink, which may be applied to similar roll coating operations. This model assumes that the exposure concentration is the same as the concentration of the chemical in the non-volatile portion of the coating mixture.

Model Equations:

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

$$EXP_{inhalation} = C_{part_air} \times TIME_{exposure} \times RATE_{breathing} \times F_{chem_particulate} \quad [B-19]$$

Where:

$EXP_{inhalation}$	= Inhalation exposure to the airborne particulate chemical per day (mg chemical/worker-day)
C_{part_air}	= Mass concentration of the particulate chemical in air (EPA default = 0.04 mg/m ³ , high end; 0.26 mg/m ³ , low end)
$RATE_{breathing}$	= Typical worker breathing rate (EPA default = 1.25 m ³ /hr)
$TIME_{exposure}$	= Duration of exposure for the activity (EPA default = 8 hours/worker-day)

$F_{\text{chem_particulate}}$ = Weight fraction of chemical in particulate or non-volatiles
fraction of mist (EPA default = 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.
- U.S. EPA. Chemical Engineering Branch. Generic Scenario: *Roll Coating of UV-Curable Coatings*. No date.