



Use of Additive in Plastic Compounding-
Generic Scenario for Estimating Occupational
Exposures and Environmental Releases
-Draft-

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Explanatory Notes

Purpose and background

This OECD draft Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns, and potential release pathways of chemical additives used in compounded thermoplastic resins. It also is intended to serve as a preliminary screening tool for assessing such chemicals. The reader should note that this document does not cover the subsequent conversion of compounded plastic resins into finished articles, which is covered separately in the *ESD on the Use of Additives in Plastics Converting*. The document presents standard approaches for estimating the environmental releases of and occupational exposures to additive chemicals used by the plastics compounding industry. 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.

OECD previously published an ESD providing information on the sources, use patterns, and release pathways of chemicals used as additives in plastics (OECD, 2009). Similar to this document, the 2009 ESD provides methods for estimating releases to the environment from plastics compounding. In addition, the 2009 ESD also provides estimation methods for converting operations, the service life of finished plastic products, and end-of-life disposal. The models presented in the 2009 ESD are based on industry information from the United Kingdom but are applicable to all European Union Member States.

The ESD presented herein complements the previous ESD by providing environmental release models for plastics compounding operations that are based on information representative of the United States plastics industry. It also provides exposure models for estimating occupational exposures to chemical additives during plastics compounding operations.

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

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to non-volatile chemical additives used in compounded thermoplastics. The reader should note that the estimation methods provided in this

document may result in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in real world practice. This is because the ESD makes conservative assumptions about facility operations and workplace practices. For example, the ESD defaults to the most conservative facility throughput values if the end use is unknown. For occupational exposures, the ESD methodology does not account for the use of personal protective equipment.

The users of this draft ESD should consider how the information contained in the document emulates 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

EPA developed this draft ESD using relevant data¹ and information on the plastics industry, including process descriptions, operating information, chemicals used, wastes generated, waste treatment, worker activities, and exposure information. EPA supplemented the collected data with standard models² to develop the environmental release and occupational exposure estimating approaches presented in this ESD.

The primary sources of information cited in this draft ESD include information published by the U.S. Census Bureau, and various EPA and other government sources (e.g., CEB, OECD, and regional/state pollution prevention organizations). Additional information on the sources investigated and the references cited in this document are presented in Section 8.0.

This draft ESD includes methods for estimating environmental releases of and occupational exposures to non-volatile chemical additives used in compounded thermoplastics. For EPA new chemical assessments, volatile chemicals are considered to be those whose vapor pressures are above 0.001 torr (CEB, 2008). The volatilization of chemicals with vapor pressures below 0.001 torr, for the purposes of estimating screening-level inhalation exposures and air releases, is considered negligible (CEB, 1994 and 1995).

A review of Premanufacture Notices (PMNs) submitted to EPA under section 5 of the Toxic Substances Control Act (TSCA) for chemicals used as plastics additives indicates that vapor pressures typically are below 0.001 torr. Based on a sample of 71 PMNs, 98% had vapor pressures below 0.001 torr. Only one of the reviewed PMNs was for a chemical with a vapor pressure greater than 0.001 torr.

PMN submissions submitted to EPA generally represent a distinct chemical substance that may be entering commerce in the United States. EPA maintains a database of the

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

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

functions and uses of chemicals reviewed under the PMN program (i.e., EPA's new chemicals review program).

The scope of the ESD covers any non-volatile plastics additive chemicals, as used in compounded thermoplastic resins. These chemicals can be classified into one of several types of plastics additives such as fillers, flame retardants, plasticizers, and slip promoters. Table 1-1 provides additional examples of the types of plastics additives applicable to the ESD. Compounding sites can incorporate plastics additives into various types of polymers (e.g., polyethylene and poly(vinyl chloride)). Table 1-2 provides additional examples of the types of polymers associated with plastics additives.

An illustration of the scope of this document within the context of the life cycle of the chemical of interest is provided below.

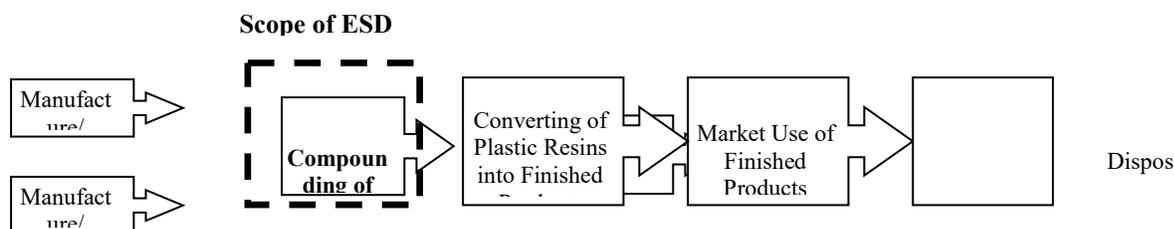


Figure 1. Scope of the ESD on the Use of Additives in Thermoplastics Compounding

It is important to note the ESD only covers plastics additives compounding into thermoplastic polymer resins. Although plastics additives serve similar functions in both thermoplastic and thermoset polymers, the processes by which they are incorporated into polymers are not similar. Unlike thermoplastics, where additives are compounded into polymer resins then converted into plastic articles in a separate process, thermosets incorporate additives in a single step during production of finished articles. Since thermoset polymers are not compounded into resins, they are outside the scope of the ESD.

Overall, plastics additives comprise solid and non-volatile liquids. The release estimation methods presented in this document apply to both solid and non-volatile liquid plastics additives.

The methods for estimating the following facility operating parameters and releases and exposures to chemical additives used in compounded plastic are discussed in the draft ESD:

- Number of sites in the United States that compound plastic resins;
- Releases from dust emissions during container transfers into the process (e.g., storage or process vessels);

- Releases from spillage during raw material handling;
- Releases from transport container residue (via container cleaning or direct disposal of empty containers);
- Releases during the blending/compounding process (from dust and fugitive air emissions);
- Releases from equipment cleaning;
- Number of workers that may come into contact with the chemical additive during compounding operations;
- Inhalation and dermal exposures during container unloading/transferring;
- Dermal exposures during container cleaning and disposal;
- Dermal exposures during the equipment cleaning; and
- Inhalation exposures to dusts generated during blending/compounding processes.

The estimation methods in this draft ESD apply to any non-volatile plastics additive chemicals, as used in compounded thermoplastic resins, regardless of their function within the plastic resin.

How this document was developed

The U.S. Environmental Protection Agency (EPA), with support from Eastern Research Group, Inc. (ERG), has developed this draft emission scenario document on the use of additives in plastics compounding.

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1.0 PLASTICS COMPOUNDING INDUSTRY SUMMARY AND BACKGROUND

The plastics manufacturing industry can be divided into three distinct phases: manufacturing of polymer resins and chemical additives, compounding of polymer resins and chemical additives, and converting of the compounded plastic into finished products. Polymer resin manufacturers synthesize polymer resin blends that are subsequently compounded and converted into the finished plastic products. Compounders receive the polymer resins from these manufacturers and produce master batches of plastic resins with specific properties by blending the polymer resin with plastics additives (e.g., fillers, reinforcements). Converters receive the master batch of plastic resin from compounders and convert it into the finished plastic product. Compounding and converting can take place at the same facility (i.e., “in-house” manufacturing) or at separate facilities.

The following section provides an overview of the terminology used in this document, as well as background on the plastics additive industry and market.

1.1 Terminology

Plastics are produced through chemical reactions in which monomers, the fundamental building blocks, cross-link to form oligomers and polymers, as shown in Figure 1-1. Monomers covalently bond (i.e., polymerize) to form oligomers, which are a subset of polymer molecules comprising relatively few monomers. The oligomers shown in Figure 1-1 comprise two, three, or four monomers, and can be referred to as dimers, trimers, and tetramers, respectively.

It is important to note that some terms, while ubiquitous in industry, have meanings that are rather ambiguous. For example, there is no concrete definition setting oligomers and polymers apart. In fact, the International Union of Pure and Applied Chemistry (IUPAC) simply defines an oligomer as a molecule having “a small plurality of units derived...from molecules of lower relative molecular mass.” IUPAC provides an explanatory note indicating that the addition or removal of one or more units would affect the physical properties of the oligomer significantly, while it would have a negligible effect on a polymer molecule (IUPAC, 1996).

Also, the conventional use of the term “polymer” provides room for additional ambiguity, as it can refer to individual polymer molecules or to the polymer substance (i.e., the plastic resin). To avoid any potential confusion, EPA has adopted in this document the conventions proposed by IUPAC. This document uses the term “macromolecule” when referring to individual polymer molecules and “polymer” when referring to the bulk substance composed of the macromolecules (i.e., the plastic resin).

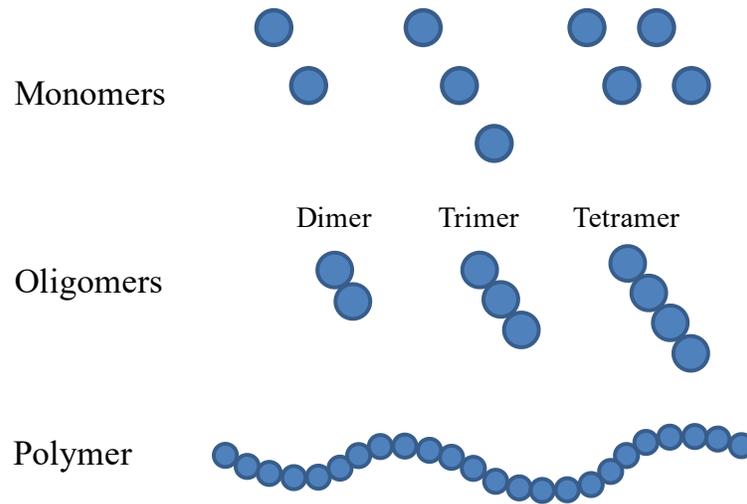


Figure 1-1. Visualizing Monomer Polymerization at the Molecular Level

1.2 Additives Used in Plastics Processing

Polymer resins can be classified into the two following polymer types:

- *Thermoplastic polymers* are melted and become fluid when heat and pressure are applied. The molten polymers are formed into finished products via pressure. Thermoplastics solidify when cooled, and the heating and cooling process can be repeated many times with little loss in properties.
- *Thermosetting polymers (e.g., foam, epoxy)* are formed into finished products during a chemical reaction under pressure and heat. This process creates permanent cross-linking, and the product retains its shape during subsequent cooling and heating. Thermosetting polymers are not within the scope of this generic scenario and are not discussed further.

The facility throughput of plastics additives associated with compounding operations will vary according to both the type of additive and the type of plastic resin blended together by compounders. Additives typically are added to polymer resins to adjust various properties of the plastic resin, and can be added during polymer production, compounding, or converting. However, it is most common for additives to be added during the compounding process in order to produce a custom “masterbatch” of compounded resin.

Additive components include, but are not limited to, antioxidants, antistatics, blowing agents, colorants, coupling agents, fillers, flame retardants, heat stabilizers, impact modifiers, lubricants, plasticizers, preservatives, slip promoters, and ultraviolet stabilizers. Table

1-1 presents an overview of several types of additives used in plastics processing, including their function, the types of chemicals used, and the weight fraction of that additive that could be compounded into plastic resins.

The types and quantities of plastics additives that compounding sites incorporate into polymer resins will depend on desired properties for the finished article. Table 1-2 summarizes typical weight fractions of various plastics additives for several thermoplastic resins. Table 1-3 provides examples of the types of plastic articles produced from the resins in Table 1-2. For each of the listed articles, EPA also has included product categories associated with the EPA Chemical Data Reporting (CDR) program that are applicable to the ESD. Manufacturers are required to report these product categories to CDR for any chemical substances listed in the TSCA Inventory used in quantities that meet or exceed the program's reporting thresholds.

Table 1-1. Summary of Additives and Weight Fractions Used in Plastic Resins Compounding

Additive Type	Function	Types of Chemicals	Typical Physical State	Minimum Weight Fraction In Plastic Resin	Maximum Weight Fraction In Plastic Resin	Average Weight Fraction In Plastic Resin
Antioxidants	Inhibit the oxidation of plastic materials that are exposed to oxygen or air at normal or high temperatures.	Alkylated phenols, amines, organic phosphites and phosphates, esters	Solid powder or pellets	0.001	0.005	0.003
Antistatics	Impart a minimal to moderate degree of electrical conductivity to the plastic compound, preventing electrostatic charge accumulation on the finished product.	Quaternary ammonium compounds, anionics, amines	Solid	0.001	0.01	0.005
Blowing agents	Releases gas during heating to produce a cellular form of plastic (typically used in thermosetting resins).	Carbon dioxide, acetone, sodium bicarbonate, organic nitrogen compounds	Solids, liquids, compressed liquids, gases	0.04	0.06	0.05
Colorants	Impart color to the plastic resin.	Titanium dioxides, iron oxides, anthraquinones, carbon black	Fine powder (pigments) and liquid or waxy solid (dyes)	0.01	0.2	0.04
Coupling Agent	Interface between filler and plastic, bonding with both phases to improve interfacial adhesion. Typically introduced during the treatment stage of filler manufacture.	Organometallic compounds, silanes	Low viscosity liquid or low melting point solid	0.005	0.005	0.005
Curing agent	Assist in the curing of thermosetting materials.	Peroxides, amines, organotin compounds	Solids and liquids	0.03	0.03	0.03
Fillers	Inert materials which reduce polymer cost, improve processability, and improve mechanical properties.	NA	Solid (fiber or powder)	0.1	0.55	0.35
Flame Retardants	Reduce the tendency of the plastic product to burn.	Antimony trioxide, chlorinated paraffins, bromophenols	Solid	0.05	0.4	0.18
Heat Stabilizers	Assist in maintaining the chemical and physical properties of the plastic, such as color changes, undesirable surface changes, and decreases in electrical and mechanical properties, by protecting it from the effects of heat.	Lead, barium-cadmium, tin, calcium zinc	Solid (sometimes liquid)	0.0015	0.05	0.014

Table 1-1. Summary of Additives and Weight Fractions Used in Plastic Resins Compounding

Additive Type	Function	Types of Chemicals	Typical Physical State	Minimum Weight Fraction In Plastic Resin	Maximum Weight Fraction In Plastic Resin	Average Weight Fraction In Plastic Resin
Impact Modifiers	Prevent brittleness and increase the resistance of the plastic to cracking.	Natural rubber, acrylonitrile, ethylene as copolymers	Granular solid	Not Available		
Lubricants	Assist in easing the flow of the plastic in molding and extruding processes by lubricating the metal surfaces that come into contact with the plastic.	Stearic acid, waxes, fatty acid esters, fatty acid amines	Waxy solid or soft powder	0.001	0.012	0.009
Plasticizers	Increase the plastic product's flexibility and workability.	Adipates, azelates, trimellitates, DOP/DIOP/DIDP	Liquids or waxy solids (i.e., chemicals with low melting points)	0.01	0.5	0.15
Preservatives	Protects against fungi and bacteria.	Organotin, organomercury compounds	Solid	Not Available		
Slip promoters	Improve surface lubrication during processing and use.	Calcium and zinc stearates, waxes and fatty acid amines or esters	Soft powders or waxy solids	0.0005	0.25	0.13
Ultraviolet Stabilizers	Absorb or screen out ultra-violet radiation, thereby preventing premature degradation of the plastic product.	Benzophenones, benzotriazole, salicates	Solid	0.002	0.05	0.015

Sources: Kirk-Othmer, 2003; OECD, 2009

Table 1-2. Typical Weight Fractions of Plastics Additives in Various Thermoplastic Resins

Additive Type	Typical Fraction of Additive in Each Type of Plastic Resin												
	LDPE	HDPE	Poly-propylene	Rigid PVC	Flexible PVC	Poly-styrene	Expanded Poly-styrene	ABS	PET	Poly-amides	Acrylics	Acetals	Poly-carbonate
Antioxidants	0.001	0.0025	0.005	0.002	-	-	-	-	-	-	-	-	-
Antistatics	0.001	0.003	-	-	-	-	-	-	-	-	-	0.01	-
Blowing agents	0.04	-	-	0.04	-	-	0.06	-	-	-	-	-	0.04
Colorants	0.03	0.03	0.03	0.005-0.03	0.02	0.01	-	0.05	0.03	0.2	0.01	0.02	0.03
Coupling agents	-	-	0.005	-	-	-	-	-	-	0.005	0.005	0.005	0.005
Curing agents	0.03	-	-	-	-	-	-	-	-	-	-	-	-
Fillers	-	-	0.4	0.1	0.1-0.3	-	-	-	0.55	0.4	0.35	0.3	0.4
Flame Retardants	0.2	0.2	0.05-0.4	-	0.05	0.2	0.15	0.2	0.15	0.15-0.25	-	-	-
Heat Stabilizers	-	-	-	0.01-0.05	0.02-0.05	-	-	0.0075-0.01	-	0.005	-	0.002	0.0015-0.0025
Impact Modifiers ^a	Unknown												
Lubricants	-	-	-	0.01	0.001-0.003	0.012	-	-	-	-	-	-	0.012
Plasticizers	-	-	-	-	0.3-0.45	-	-	-	0.05	0.01	-	-	-
Preservatives ^a	Unknown												
Slip promoters	0.0005	-	-	-	-	-	-	-	-	-	-	0.25	-
UV Stabilizers	-	-	0.05	0.005	-	0.005	-	0.005	0.005	0.03	0.002	0.03	0.003
Total Weight Fraction (F _{all additives_resin})	0.30	0.24	0.49	0.17-0.24	0.49-0.87	0.23	0.21	0.26-0.27	0.79	0.80-0.90	0.37	0.62	0.49
Minimum F _{all additives_resin}	0.17												
Maximum F _{all additives_resin}	0.90												
Average F _{all additives_resin}	0.46												

Source: OECD, 2009

LDPE – Low density polyethylene

HDPE – High density polyethylene

PVC – Poly(vinyl chloride)

ABS – Acrylonitrile-butadiene-styrene copolymer

PET – Poly(ethylene terephthalate)

^a Weight fraction data were not identified for this additive type.

Table 1-3. Plastic Articles Produced from Thermoplastic Resins and Associated CDR Product Categories/Codes

Thermoplastic Resin	Plastic Articles^a	CDR Product Categories^a	CDR Product Codes^a
LDPE	Squeeze bottles	Plastic and rubber products	C303
	Toys	Toys, playground, and sporting equipment	C304
	Carrier bags	Plastic and rubber products	C303
	High frequency insulation	Building/Construction materials not covered elsewhere	C204
	Chemical tank linings	No applicable product category.	
	Heavy-duty sacks	Plastic and rubber products	C303
	General packaging	Plastic and rubber products	C303
	Gas and water pipes	Building/Construction materials not covered elsewhere	C204
HDPE	Chemical drums, jerricans, carboys	No applicable product category.	
	Toys	Toys, playground, and sporting equipment	C304
	Picnic ware	Plastic and rubber products	C303
	Household and kitchenware	Plastic and rubber products	C303
	Cable insulation	Electrical and electronic products	C205
	Carrier bags	Plastic and rubber products	C303
	Food wrapping material	Food packaging	C301
Polypropylene	Coffee pot parts	Plastic and rubber products	C303
	Washing machine parts	Electrical and electronic products	C205
	Drink vending machines	Electrical and electronic products	C205
	Microwave components	Electrical and electronic products	C205
PVC	Window frames	Building/Construction materials not covered elsewhere	C204
	Drainage pipe	Building/Construction materials not covered elsewhere	C204
	Water service pipe	Building/Construction materials not covered elsewhere	C204
	Medical devices	No applicable product category.	
	Blood storage bags	No applicable product category.	
	Cable and wire insulation	Electrical and electronic products	C205
	Resilient flooring	Floor coverings	C101
	Roofing membranes	Building/Construction materials not covered elsewhere	C204
	Automotive interiors and seat coverings	No applicable product category.	
	Fashion and footwear	Plastic and rubber products	C303
	Packaging	No applicable product category.	
	Cling film	Food packaging	C301
	Credit cards	No applicable product category.	
	Synthetic leather and other coated fabrics	Fabric, Textile, and leather products not elsewhere covered	C104
Polystyrene.	Toys	Toys, playground, and sporting equipment	C304
	Rigid packaging	No applicable product category.	
	Refrigerator trays and boxes	Plastic and rubber products	C303
	Cosmetic packs	Plastic and rubber products	C303
	Costume jewelry	Plastic and rubber products	C303
	Lighting diffusers	Plastic and rubber products	C303

Thermoplastic Resin	Plastic Articles ^a	CDR Product Categories ^a	CDR Product Codes ^a
	Audio cassette and CD cases	Plastic and rubber products	C303
	Yogurt containers	Food packaging	C301
	Refrigerator linings	Electrical and electronic products	C205
	Vending cups	Plastic and rubber products	C303
	Bathroom cabinets	Plastic and rubber products	C303
	Toilet seats and tanks	Plastic and rubber products	C303
	Instrument control knobs	Electrical and electronic products	C205
ABS	Telephone handsets	Plastic and rubber products	C303
	Rigid luggage	Plastic and rubber products	C303
	Domestic appliance housings (e.g., food mixers)	Electrical and electronic products	C205
	Computer housings	Electrical and electronic products	C205
	Radiator grills	No applicable product category.	
PET	Automotive window wiper holders	No applicable product category.	
	Automotive exterior mirror housing	No applicable product category.	
Polyamides	Fishing line	Plastic and rubber products	C303
	Carpets	Plastic and rubber products	C303
	High-temperature food packaging	Food packaging	C301
Acrylics	Drinking tumblers	Plastic and rubber products	C303
	Lenses	Plastic and rubber products	C303
	Water jugs	Plastic and rubber products	C303
	Toothbrush handles	Plastic and rubber products	C303
	Kitchen and picnic ware	Plastic and rubber products	C303
	Radio dials	Electrical and electronic products	C205
	TV set screens	Electrical and electronic products	C205
	Washing machine trims	Electrical and electronic products	C205
Acetals	Business machine parts	Electrical and electronic products	C205
	Clock and watch parts	Plastic and rubber products	C303
	Plumbing systems	Building/Construction materials not covered elsewhere	C204
	Shoe components	Plastic and rubber products	C303
Polycarbonate	Compact discs	Plastic and rubber products	C303
	Riot shields	Plastic and rubber products	C303
	Baby feeding bottles	Plastic and rubber products	C303
	Safety helmets	Plastic and rubber products	C303
	Headlamp lenses	Plastic and rubber products	C303

Sources: Plastipedia, no date and EPA, 2012

^a CDR product categories are based on the end use market associated with a given product. CDR does not provide any information about the products themselves. The products identified above for each CDR product category is based on supplemental research conducted by EPA. The information is not intended to be exhaustive. It is intended to provide examples of common products and associated CDR consumer product categories (based on engineering judgment).

1.3 Market Profile

The plastics manufacturing industry can be divided into three stages: polymer manufacturing, compounding, and converting. The compounding and converting stages typically occur at separate sites, although they also may occur at the same site. As stated previously, this

document focuses on release and exposure assessments during compounding operations. Therefore, polymer manufacturing and converting operations are outside the scope of this document.

Compounders produce masterbatches of plastic resins with specific properties by blending the polymer (i.e., the plastic resin), additives, fillers, and reinforcements. Converters receive the masterbatch of plastic resin from these compounders and convert the compounded resin into finished plastic articles or products. A separate generic scenario covers the conversion of plastic resins into finished articles.

The plastics compounding industry is made up of the North American Industrial Classification System (NAICS) code 325991 (Custom Compounding of Purchased Resins). This NAICS code comprises establishments primarily engaged in custom mixing and blending of plastics resins made elsewhere or reformulating plastic resins from recycled plastics products. Table 1-4 summarizes U.S. Census data for the number of sites associated with the plastics compounding NAICS code. The data reflects all sites that reported the plastics compounding primary NAICS code to the U.S. Census Bureau; therefore, some of the sites in Table 1-4 also may conduct converting operations in addition to compounding (no NAICS code exists that is specific to sites where both compounding and converting occur).

Table 1-4. Number of Compounding Sites Based on 2011 U.S. Census Data

NAICS Code	NAICS Code Description	Sites
325991	Custom compounding of purchased resins	468
<i>Total Compounding Sites</i>		<i>468</i>

Source: USCB, 2011a

Market data (Freedonia, 2013a) indicate that the demand for plastics additives in the U.S. totaled approximately 1.5 billion kilograms in 2012. The market data, which are reproduced below in Table 1-5, provide historical and forecasted U.S. demand for plastics additives (aggregated by resin type). Note that the market data defines “demand” as being the total U.S. production of additives including imports and exports. Table 1-5 shows that the total U.S. demand for plastics additives in 2012 was 1,463 million kg, of which most (approximately 60 percent) were incorporated into poly(vinyl chloride) resins. The industry forecast expects demand to increase over the next ten years and attributes the rise to a strong rebound in construction activity, which they anticipate will generate over two thirds of new demand for plastics additives (Freedonia, 2013b).

Table 1-5. Historical and Forecasted U.S. Demand for Plastics Additives by Resin Type

Resin Type	Plastics Additives (million kg)				
	2002	2007	2012	2017	2022
Poly(vinyl chloride)	1,229	1,149	862	1,104	1,234
Polyethylene	114	127	120	147	168
Polypropylene	108	115	111	134	150
Polyurethane	64	64	53	64	72

Resin Type	Plastics Additives (million kg)				
	2002	2007	2012	2017	2022
Polystyrene	51	49	40	45	49
Other Resins	305	327	277	331	378
<i>Total Demand</i>	<i>1,872</i>	<i>1,831</i>	<i>1,463</i>	<i>1,826</i>	<i>2,050</i>

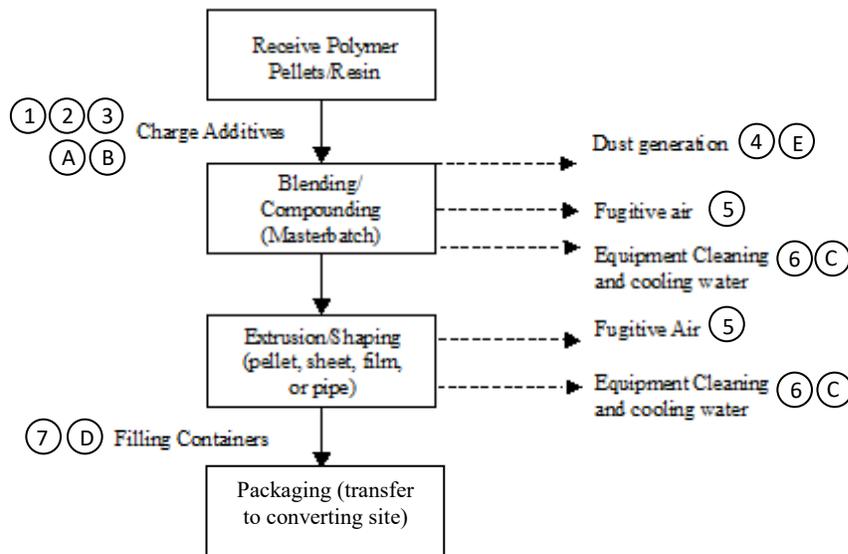
Source: Freedonia, 2013a

2.0 PROCESS DESCRIPTION

Compounding consists of blending polymer resins with chemical additives to form a master batch for further converting into finished articles. Additives also can be added during the resin manufacturing process as well as during the converting process. However, they most commonly are added during compounding in order to impart the desired properties into the master batch.

Figure 2-1 illustrates the general plastics additives compounding processes and their associated environmental release sources and occupational exposure activities. Releases and exposures specific to each application method are discussed in greater detail in Section 4.0 and 5.0, respectively.

Figure 2-1. Typical Release and Exposure Points during Plastics Compounding



Environmental Releases:

1. Transfer operations losses to air, water, incineration, or landfill from container transfers of additives
2. Spillage from raw material handling to water, landfill, or incineration
3. Container residue cleaning/disposal losses to water, landfill, or incineration
4. Dust emissions from blending/compounding to air, landfill, or water (includes disposal of captured dusts)
5. Fugitive emissions from blending/compounding to air and water
6. Equipment cleaning residue losses to water, landfill, or incineration
7. Release of additives during unloading

Occupational Exposure:

- A. Inhalation exposure to solids and dermal exposure to liquids and solids during unloading/transferring of additive chemicals
- B. Inhalation exposure to solids and dermal exposure to liquids and solids during container cleaning
- C. Dermal exposure to liquids during equipment cleaning
- D. Inhalation and dermal exposures to solids during packaging of plastic resins containing additive chemical
- E. Inhalation exposure to dusts generated during blending/compounding process operations

EPA expects most plastics additives to be non-volatile liquids or solids. For EPA new chemical assessments, volatile chemicals are considered to be those whose vapor pressures are above 0.001 torr (CEB, 2008). Based on a review of 71 PMNs submitted to EPA between 2007 and 2012, EPA found that 98% had vapor pressures below 0.001 torr. Only one PMN was for a chemical with a vapor pressure greater than 0.001 torr. The review also indicates that plastics additives are typically solids. Of the 71 PMNs, 65% were for solid plastics additives while the remaining 35% were for liquids.

The first step of the overall compounding process is the handling of the shipping containers. The type of shipping container used largely will depend on the physical properties of the additive chemical. Solid additives will be received as powders, pills, flakes or granules, which typically are shipped in boxes, bags, or fiber drums (Clariant, 2013). Liquid additives most typically are received in steel drums (Clariant, 2013).

Shipping containers are unloaded into mixing vessels. Environmental releases may result during this transfer activity, particularly for powdered solids due to the generation of airborne particulates. Depending on process controls, the dusts may be released directly to the atmosphere or it may be captured by engineering controls (e.g., bag filters). The portion captured by the bag filters are disposed to incineration or landfill. Particulate emissions within the facility that are not captured by emission controls will settle, resulting in losses to landfill or wastewater during wash downs (OECD, 2009). Environmental releases also may occur from spillage during container transfers and similarly may result in releases to water, incineration or landfill. Exposures also are expected; specifically dust inhalation (solid additives only) and dermal exposures to liquid or solid additives.

Empty containers either are immediately disposed of or they are cleaned prior to disposal, depending on the type of container. Based on engineering judgment, boxes and bags are not likely to be cleaned prior to disposal, whereas cleaning would be much more likely for steel drums. Container cleaning activities may result in worker inhalation exposures to solids (solid additives only) and dermal exposures to liquid or solid additives.

Once unloaded, blends of plastics additives, polymer resins, and other raw materials are mixed to produce the compounded resin masterbatch. There are numerous methods used to blend resin master batches, and can include:

Closed Processes

1. Tumble Blenders: Used for pre-blending solids of similar particle size. Polymer powders and dry additives are charged to a closed container that is rotated/tumbled.
2. Ball Blenders: Used for dry or liquid polymer systems. These are similar to tumble blenders, but with mills to enhance fine dispersion.
3. Gravity Mixer: Used for dry or liquid polymer systems. Materials are cascaded downwards through a series of baffles. Repeated passes are possible with an elevator or auger.

4. Paddle/Double Arm Mixer: Used for high viscosity mastics, pastes, elastomers, dough molding compounds, and materials with high filler content. Contra-rotating blades knead and fold the materials.
5. Intensive Vortex Action Mixers: Used for dry or liquid polymer systems. Materials are preheated and mixed with high-speed stirrers.
6. Banbury Internal Mixers: Used for dry or liquid polymer systems. A ram presses the polymer and additives against revolving rotor blades in an enclosed chamber. Temperature control is necessary to avoid degradation of materials. The resin is typically sent to secondary mixing or extrusion processes.

Partially Open Processes

7. Two Roll Mill: Used for dry or liquid polymer systems. Two rollers contra-rotate at different speeds, generating a shearing action. Polymer and additives are introduced to the rollers, which knead the materials.
8. Extruders: Polymer and additives are pre-blended in a hopper or tumbler then the mixture is fed into an extruder containing one or two screws. The material is heated in the extruder and the screws shear the material and transport it through the extruder.

Closed processes predominate in the plastics industry and comprise systems where the compounding process is almost completely enclosed (OECD, 2009). Open processes are those where compounding occurs in an open environment at ambient conditions. Tumble blenders, ball blenders, gravity mixers, paddle/double arm mixers, intensive vortex action mixers, and banbury internal mixers are all closed systems and are considered to be blending processes. Two roll mills and extruders are partially open systems and represent all-in-one processes that perform blending and forming of the final compounded plastic (e.g. pellets, sheets).

The process activities described above for closed and open compounding process are likely to generate dusts. If occurring at elevated temperatures, volatile releases may occur as well. EPA did not find information on typical process temperatures; however, based on the melting temperatures of various thermoplastics (Kirk-Othmer, 2003), temperatures are expected to range from 65°C to 365°C. For closed processes, air releases from dusts or volatilization are most likely released as stack emissions. Release from open processes can include both fugitive and stack emissions, depending on the extent of engineering controls used at the site, and may include a potential pathway for dust inhalation exposures. Note that, although inhalation exposures to volatilized additives are possible, the ESD does not provide methods for estimating such exposures given that additives most typically are compounded in closed processes (OECD, 2009) and the additives have negligible vapor pressures well below the 0.001 torr, as observed during EPA's review of the PMN submissions.

Once resin compounding is completed, the solid masterbatch is transferred into an extruder where it is converted into pellets, sheets, films, or pipes. The extruder is a long, heated chamber that utilizes a continuously revolving screw to transfer the molten compounded resin through the extruder and into the die. The shape of the die determines the final form of the extrudate. The extruded plastic is then cooled in air or by direct immersion in water. Upon drying, the extrudate is packaged and shipped to downstream converting sites. Exposures during packaging are expected to be negligible. Workers then will clean the equipment at the end of the compounding run, and is expected to generate environmental releases to water, incineration, or landfill as well as dermal exposures to liquids.

The engineering controls utilized during the compounding process are described in detail in Section 4.1. Air pollution control methods include mechanical separation, settling/clarification, scrubber, incineration, condenser, or adsorption (EPA, 2011). Process waters generated from heating and cooling water, cleaning rinsates, and finishing water are discharged to publicly owned treatment works (POTW), where the concentration of additives in the wastewater is reduced by settling or clarification, neutralization, sludge treatment and/or dewatering, biological treatment, chemical precipitation, phase separation, adsorption, or other treatment processes (EPA, 2011).

3.0 OVERALL APPROACH AND GENERAL FACILITY ESTIMATES FOR THE USE OF ADDITIVES IN PLASTICS COMPOUNDING

This methodology review draft presents EPA's standard approach for estimating environmental releases of and worker exposures to plastics additives during compounding operations. Although there are several types of compounding processes, their associated release and exposure points are expected to be the same.

The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible. However, EPA acknowledges several areas in which additional industry data would enhance the estimates presented herein. These data needs are summarized in Section 7.0. It should be noted that the default values cited throughout this document are intended to be used only when appropriate site-specific or industry-specific information is not available.

This section of the methodology review draft presents general facility calculations for the plastics compounding industry, which include estimates of the daily use rates of plastics additives, the number of operating days at these sites, and the number of compounding sites using the plastics additives.

Section 4.0 of the methodology review draft presents environmental release assessments from the use of plastics additives during compounding operations. Section 4.0 utilizes the general facility estimates presented in this section to determine the quantity of chemical additive released from various points in the compounding process, and the most likely media of release for each source.

Section 5.0 of the methodology review draft presents occupational exposure assessments from the use of plastics additives during compounding operations. Section 5.0 utilizes both the general facility estimates presented in this section and the release estimates from Section 4.0 to estimate the number of workers potentially exposed while performing various compounding process activities and their corresponding potential exposure level (quantity) and routes of exposures.

3.1 Introduction to the General Facility Estimates

Throughout the remainder of this section, EPA utilized available industry and U.S. Census data to estimate the number of plastics compounding sites in the U.S. This section also describes the methods and assumptions used to estimate typical daily use rates of the chemical of interest at a plastics compounding site. The daily use rate can be estimated using several facility parameters, including the annual facility use rate of the chemical of interest ($Q_{\text{chem_site_yr}}$), days of operation ($\text{TIME}_{\text{operating_days}}$), and the number of compounding sites using the chemical of interest (N_{sites}). Industry data on U.S. demand for plastics additives is provided in Table 1-5. Additional information on the number of compounding sites was obtained from the 2011 U.S. Census (USCB, 2011a).

Table 3-1 summarizes the parameters that this document uses to develop general facility estimates and identifies the corresponding sections in which they are discussed in detail. In addition, Table A-2 (Appendix A) presents a detailed summary of the default values used as inputs to each of the general facility estimates, accompanied by their references. Combined, market data, Census data, and the parameters in Table 3-1 allow for calculation of annual and daily use rates on a per site basis, as well as determining the number of shipping containers used annually.

Table 3-1: Summary of General Facility Parameters for Plastics Compounding Sites

Parameter	Description	Section
$TIME_{operating\ days}$	Number of operating days at the compounding site (days/yr)	3.2
$Q_{all\ additives\ site\ yr}$	Annual facility use rate of all plastics additives (kg all additives/site-year)	3.3
$F_{chem\ additive}$	Mass fraction of chemical of interest in the plastics additive (kg chemical of interest/kg additive containing chemical of interest)	3.4
$F_{additive\ resin}$	Mass fraction of the plastics additive containing the chemical of interest in the plastic resin (kg additive/kg resin)	3.5
$F_{chem\ resin}$	Mass fraction of chemical of interest in the plastic resin (kg chemical/ kg resin)	3.6
$F_{all\ additives\ resin}$	Mass fraction of all additives in the plastic resin (kg all additives/kg resin)	3.7
$Q_{chem\ site\ yr}$	Annual facility use rate of the chemical of interest (kg chemical of interest/site-yr)	3.8
$Q_{chem\ site\ day}$	Daily facility use rate of the chemical of interest (kg chemical of interest/site-day)	0
$N_{chem\ bt}$	Daily number of batches of the chemical of interest used at each site (batches/site-day)	3.10
$N_{bt\ site\ yr}$	Annual number of batches at each site (batches/site-yr)	
N_{sites}	Number of sites using the chemical of interest (sites)	3.11
$Q_{chem\ yr}$	Annual production volume of the chemical of interest (kg chemical of interest/yr).	
$N_{containers\ unloaded\ site\ yr}$	Number of transport containers unloaded per site per year (containers/site-yr)	3.12
$Q_{container}$	Mass of the plastics additive in the transport container (kg plastics additive/container)	
$V_{container}$	Volume of plastics additive in the transport container (L plastics additive)	
$RHO_{plastics\ additive}$	Density of the plastics additive (kg plastics additive/L plastics additive)	

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

3.2 Days of Operation ($TIME_{operating\ days}$)

Table 3-2 summarizes the number of production workers and production hours for resin compounding facilities as reported in the 2011 Annual Survey of Manufacturers (USCB,

2011a). Dividing the total production worker hours by the average number of production workers (each aggregated over all sites) results in an average of 264 worker days/year, assuming a worker works eight hours per day. EPA often estimates a work frequency per worker of 250 days/year, assuming a work schedule of five days per week and 50 weeks per year (allowing for a vacation time of two weeks per year). The compounding industry-specific data estimate a work frequency per worker similar to CEB's default assumption.

Table 3-2. Number of Workers, Worker Hours, and Worker Days for Plastics Compounding Facilities

NAICS Code	Industry Description	Number of Production Workers ^a	Number of Production Worker Hours ^a	Calculated Worker Days/Year ^b
325991	Custom Compounding of Purchased Resins	11,031	23,285,000	264

^a USCB, 2011a

^b Calculated by dividing the number of production worker hours by the number of production workers and assuming eight hours worked per day.

For supplemental information on the number of operating days, EPA also conducted a review of Premanufacture Notices (PMNs) submitted under section 5 of the Toxic Substances Control Act (TSCA). The PMNs were submitted to EPA between 2007 and 2012. During the review, EPA assumed that the reported number of operating days per year was equal to the number of exposure days per year reported in the PMN submissions. Table 3-3 presents the results of the review and shows that the number of operating days at a given site can range from a minimum of 10 days per year to a maximum of 365 days per year. The average of the reported values is 148 days per year.

If site-specific information is not available to estimate the days of operation ($TIME_{\text{operating_days}}$) at compounding sites, the days of operation should be assumed based on assessment concerns. For environmental release concerns, EPA typically minimizes the number of operating days when assessing releases. This yields the most conservative daily environmental release estimates. For occupational exposure concerns, EPA typically maximizes the number of operating days, in this case up to a maximum of 264 days per year since it is known from Table 3-2 that the typical worker works up to 264 days per year. For both environmental and exposure concerns, EPA recommends assuming the average value for $TIME_{\text{operating_days}}$ (i.e., 148 days per year).

Table 3-3. Number of Operating Days Reported in PMN Submissions for Plastics Compounding Facilities

Submission	Operating Days per Year ^a
1	333
2	19
3	19
4	19
5	19

Submission	Operating Days per Year^a
6	50
7	100
8	350
9	40
10	19
11	250
12	200
13	230
14	186
15	20
16	153
17	50
18	10
19	220
20	220
21	80
22	122
23	200
24	10
25	20
26	250
27	62
28	288
29	200
30	250
31	365
32	295
33	200
34	180
Minimum	10
Maximum	365
Average	148

^a EPA assumes the reported number of operating days per year is equal to the number of exposure days per year reported in the PMN submissions.

3.3 Annual Facility Use Rate of Plastics Additives ($Q_{\text{all additives site yr}}$)

The annual facility use rate of plastics additives can be estimated using plastics additives market data (Table 1-5) and data on the number of compounding sites obtained from the 2011 Census (USCB, 2011a). Table 3-4 presents the market and Census data inputs and the resulting estimated default value for the annual facility use rate of plastics additives. It is important to note that the market data utilized in Table 3-4 aggregates plastics additives of all types. Therefore, the use rate in Table 3-4 represents the use of *all* plastics additives incorporated into the resin, not just the specific additive containing the chemical of interest. For this reason, it is critical that the use rate estimate accounts for the chemical-, additive-, and plastic resin-related mass fractions presented in Sections 3.4, 3.5, and 3.7, respectively.

Table 3-4. Input Data and Resulting Annual Facility Use Rate of Plastics Additives at Compounding Sites

Annual U.S. Demand for Plastics Additives (kg additives/year) ^a	Number of Sites ^b	Default $Q_{\text{all additives site yr}}$ (kg all additives/site-year)
1,463,000,000	468	3,126,068

^a Freedonia, 2013a (data reproduced in Table 1-5)

^b USCB, 2011a

3.4 Mass Fraction of the Chemical of Interest in the Plastics Additive ($F_{\text{chem additive}}$)

The chemical of interest may only be a fraction of the plastics additive that is incorporated into plastic resins. If the concentration of the chemical of interest within the plastics additive ($F_{\text{chem additive}}$) is not known, EPA recommends a conservative-case assumption of 100 percent when performing the calculations in this assessment:

$$F_{\text{chem additive}} = \text{Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest)}$$

3.5 Mass Fraction of the Plastics Additive of Interest in the Plastic Resin ($F_{\text{additive resin}}$)

This value represents the mass fraction of the specific plastics additive within the plastic resin that contains the chemical of interest (hereafter referred to as the “additive of interest”). If $F_{\text{additive resin}}$ is not known, EPA recommends referencing the most appropriate value from Table 1-1 or Table 1-2. Which table is used will depend on what is known about the additive of interest and the resin into which it will be compounded.

If both additive type and resin type are known, EPA recommends referencing Table 1-2 for the corresponding value of $F_{\text{additive resin}}$. For example, if the additive of interest is a flame retardant compounded into low density polyethylene resins, then EPA recommends using the corresponding value of 0.2 from Table 1-2. Note that if the value from Table 1-2 is a range, then the assessor should select a value within that range that most suitably addresses the assessment concerns for the chemical of interest (i.e., whether environmental releases,

occupational exposures, or both are of concern). Figure 3-1 presents a logic diagram that should be used to determine the appropriate default value for $F_{\text{additive_resin}}$.

If neither the additive type nor resin type is unknown, EPA instead recommends referencing Table 1-1 for the most appropriate value. Table 1-1 summarizes the minimum, maximum, and average mass fractions typical of each additive type. The most appropriate value will depend on the assessment concerns for the chemical of interest (i.e., whether environmental releases, occupational exposures, or both are of primary concern); therefore, the assessor should use the logic diagram (Figure 3-1) to determine the appropriate default value for $F_{\text{additive_resin}}$.

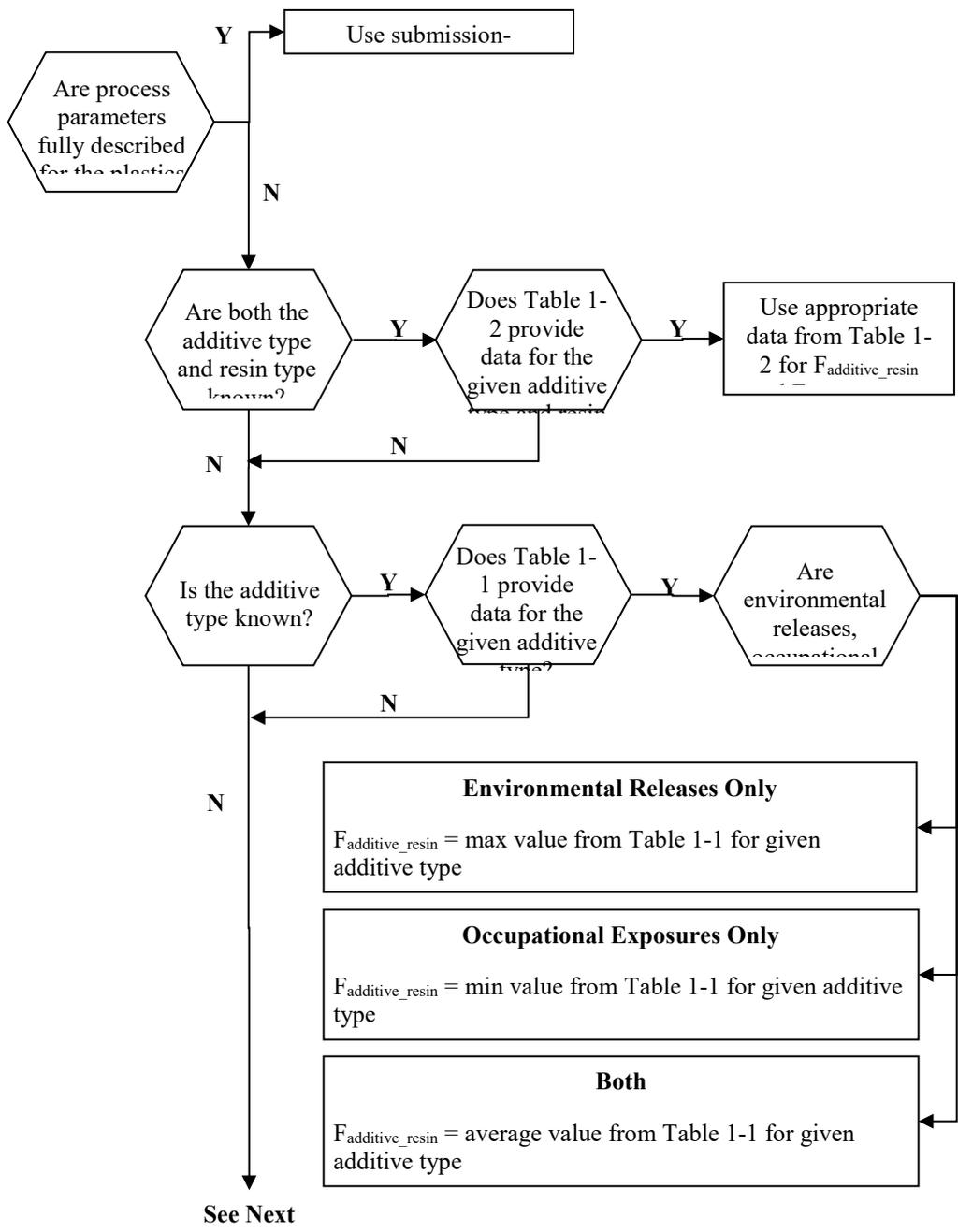


Figure 3-1. Logic Diagram for Determining Appropriate Defaults for $F_{\text{additive_resin}}$ and $F_{\text{all_additives_resin}}$

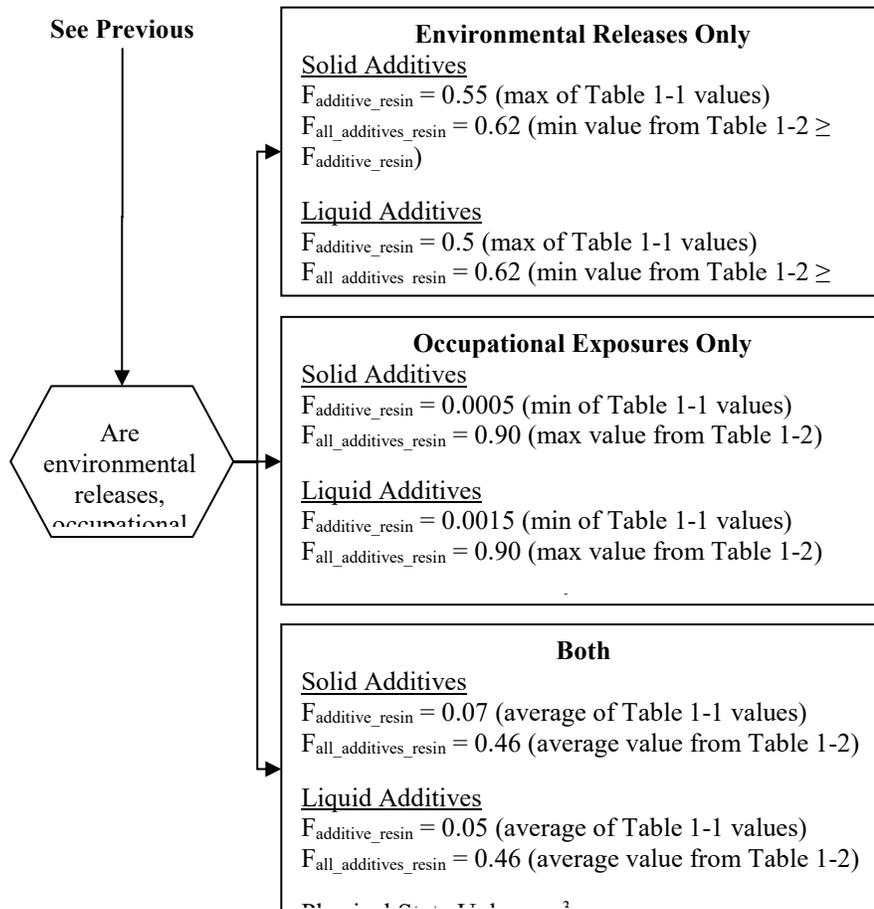


Figure 3-1. Logic Diagram for Determining Appropriate Defaults for $F_{\text{additive_resin}}$ and $F_{\text{all_additives_resin}}$ (Continued)

Footnotes:

- 1) If the compounding operation is fully described in the PMN submission (e.g., additive concentrations, number of sites, days of operation per year) then submission data should be used.
- 2) If additive type or resin type is unknown, assumptions must be made based on assessment concerns. EPA typically uses the following methodology to make conservative assessments:
 - a. Environmental release assessments: for a conservative release assessment, maximize the facility throughput rate of the chemical of interest. This is achieved by maximizing $F_{\text{additive_resin}}$ while minimizing $F_{\text{all_additives_resin}}$.
 - b. Occupational exposure assessments: for a conservative occupational exposure assessment, minimize the facility throughput rate of the chemical of interest. This maximizes the number of use sites and therefore maximizes the number of workers. This is achieved by minimizing $F_{\text{additive_resin}}$ while maximizing $F_{\text{all_additives_resin}}$.

- c. Releases and Exposures: use the average facility throughput rate of the chemical of interest. This is achieved by using the average values presented above for $F_{\text{additive_resin}}$ and $F_{\text{all_additives_resin}}$.
- 3) Care should be taken to select values from Table 1-1 that are consistent with the physical state of the chemical of interest (i.e., solid or liquid). If the physical state of the additive is unknown, EPA recommends assuming the additive is a solid. This assumption will provide the most conservative environmental release and occupational exposure assessments. It also is consistent with the results of EPA's review of PMNs submissions, where approximately 65% of the additives were reported to be solids.

3.6 Mass Fraction of the Chemical of Interest in the Plastic Resin ($F_{\text{chem_resin}}$)

This value represents the mass fraction of the chemical of interest that is incorporated into the plastic resin. This value is calculated using the following equation:

$$F_{\text{chem_resin}} = F_{\text{chem_additive}} \times F_{\text{additive_resin}} \quad (3-1)$$

Where:

$F_{\text{chem_resin}}$	=	Mass fraction of chemical of interest in the plastic resin (kg chemical/kg resin)
$F_{\text{chem_additive}}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/kg additive containing chemical of interest) (See Section 3.4)
$F_{\text{additive_resin}}$	=	Mass fraction of the plastics additive containing the chemical of interest in the plastic resin (Defaults: 0.55 kg additive/kg resin (release concerns only), 0.0005 kg additive/kg resin (exposure concerns only), or 0.07 kg additive/kg resin (both concerns)) (See Section 3.5)

The defaults provided above for $F_{\text{additive_resin}}$ assumes no information on the chemical of interest is available. If additive or resin type is known, reference the logic diagram in Figure 3-1 to determine the most appropriate default for $F_{\text{additive_resin}}$.

3.7 Mass Fraction of All Plastics Additives Contained in the Plastic Resin ($F_{\text{all_additives_resin}}$)

Typically, several types of plastics additives are compounded into a given resin. $F_{\text{all_additives_resin}}$ represents the mass fraction of all plastics additives within the compounded resin, including the additive of interest. It is important to note that this fraction will vary according to resin type and intended purpose of the final compounded resin, as these parameters dictate what additives must be incorporated into the resin. If $F_{\text{all_additives_resin}}$ is not known, EPA recommends referencing the most appropriate value from Table 1-2. The value will depend on the assessment concerns for the chemical of interest (i.e., whether environmental releases, occupational exposures, or both are of concern).

If the resin type is known, EPA recommends referencing Table 1-2 for the corresponding value. For example, if the resin type is known to be a rigid PVC, then EPA recommends using the corresponding value of 0.17 to 0.24 from Table 1-2. Since the value is a range, the assessor should select a value within that range that most suitably addresses the

assessment concerns for the chemical of interest (i.e., whether environmental releases, occupational exposures, or both are of concern). Figure 3-1 presents a logic diagram that should be used to determine the appropriate default value for $F_{\text{all_additives_resin}}$.

Care should be taken when selecting a value for $F_{\text{all_additives_resin}}$, particularly if $F_{\text{additive_resin}}$ is known but assumptions must be made about $F_{\text{all_additives_resin}}$. When selecting a value for $F_{\text{all_additives_resin}}$, the resulting value must be less than $F_{\text{additive_resin}}$. If, when using the logic diagram, $F_{\text{additive_resin}}$ is greater than $F_{\text{all_additives_resin}}$, the assessor instead must assume $F_{\text{additive_resin}}$ and $F_{\text{all_additives_resin}}$ are equal.

3.8 Annual Facility Use Rate of the Chemical of Interest ($Q_{\text{chem_site_yr}}$)

The annual use rate of the chemical of interest during compounding is estimated using the following equation, based on the annual facility use rate of all plastics additives ($Q_{\text{all_additives_site_yr}}$) and the mass fractions of the chemical of interest, the plastics additive of interest, and of all plastics additives contained in the plastic resin.

$$Q_{\text{chem_site_yr}} = Q_{\text{all_additives_site_yr}} \frac{F_{\text{chem_additive}} \times F_{\text{additive_resin}}}{F_{\text{all_additives_resin}}} \quad (3-2)$$

Where:

$Q_{\text{chem_site_yr}}$	=	Annual facility use rate of the chemical of interest (kg chemical of interest/site-yr)
$Q_{\text{all_additives_site_yr}}$	=	Annual facility use rate of plastics additives (Default: 3,126,068 kg all additives/site-year) (See Section 3.3)
$F_{\text{chem_resin}}$	=	Mass fraction of chemical of interest in the plastic resin (kg chemical/kg resin) (See Section 3.6)
$F_{\text{all_additives_resin}}$	=	Mass fraction of all additives in the plastic resin (Default: 0.62 kg all additives/kg resin (release concerns only), 0.90 kg all additives/kg resin (exposure concerns only), or 0.46 kg all additives/kg resin (both concerns)) (See Section 3.7)

The defaults provided above for $F_{\text{all_additives_resin}}$ assume no information is available for the chemical of interest. If additive or resin type is known, reference the logic diagram in Figure 3-1 to determine the most appropriate defaults.

3.9 Daily Facility Use Rate of the Chemical of Interest ($Q_{\text{chem_site_day}}$)

The daily use rate of the chemical of interest during compounding is estimated using the following equation, based on the annual facility use rate of the chemical of interest and the number of operating days.

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

Where:

$Q_{chem_site_day}$	=	Daily facility use rate of the chemical of interest (kg chemical of interest/site-day)
$Q_{chem_site_yr}$	=	Annual facility use rate of the chemical of interest (kg chemical of interest/site-yr) (See Section 3.8)
$TIME_{operating_days}$	=	Number of operating days at the compounding site (Default: 10 days/yr (release concerns only), 264 days/yr (exposure concerns only), or 148 days/yr (both concerns)) (See Section 3.2)

3.10 Annual Number of Batches ($N_{bt_site_yr}$)

To estimate the annual number of batches, a batch size must be calculated. The batch size can be estimated using the following equation, assuming the number of batches used per site per day is one:

$$N_{bt_site_yr} = TIME_{operating_days} \times N_{chem_bt} \quad (3-4)$$

Where:

$N_{bt_site_yr}$	=	Annual number of batches at each site (batches/site-yr)
$TIME_{operating_days}$	=	Number of operating days at the compounding site (Default: 10 days/yr (release concerns only), 264 days/yr (exposure concerns only), or 148 days/yr (both concerns)) (See Section 3.2)
N_{chem_bt}	=	Daily number of batches of the chemical of interest used at each site (Default: 1 batch/site-day)

3.11 Number of Sites (N_{sites})

The following calculation estimates the number of compounding sites (N_{sites}) that utilize the chemical of interest by dividing the annual use volume of the chemical of interest (Q_{chem_yr}) by the annual facility use rate of the chemical of interest ($Q_{chem_site_yr}$):

$$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_site_yr}} \quad (3-5)$$

Where:

N_{sites}^3	=	Number of sites using the chemical of interest (sites)
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³ The value for N_{sites} , calculated using Equation 3-5, should be rounded to the nearest non-zero integer value. Then, to avoid errors due to rounding, $TIME_{operating_days}$ and $Q_{chem_site_yr}$ should be adjusted to reflect the integer value for N_{sites} while maintaining the same value of $Q_{chem_site_day}$ calculated in Section 0.

First, $TIME_{operating_days}$ is recalculated using $Q_{chem_site_day}$ and the rounded number of sites:

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

$Q_{\text{chem_yr}}$	=	Annual production volume of the chemical of interest (kg chemical of interest/yr)
$Q_{\text{chem_site_yr}}$	=	Annual facility use rate of the chemical of interest (kg chemical of interest/site-yr) (See Section 3.8)

Note that the calculated value of N_{sites} should not exceed the total number of compounding sites known to operate in the U.S. (i.e., 468 sites, see Table 3-4).

Summary of the Relationship between General Facility Parameters

It is important to recognize that the days of operation ($\text{TIME}_{\text{operating_days}}$), the daily facility use rate of the chemical of interest ($Q_{\text{chem_site_day}}$), and the number of compounding sites (N_{sites}) are interrelated. This methodology review draft presents a method for estimating N_{sites} using the annual production volume of the chemical of interest ($Q_{\text{chem_yr}}$) and the estimated default value for the annual facility use rate of the chemical of interest ($Q_{\text{chem_site_yr}}$).

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

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

If N_{sites} is known but $\text{TIME}_{\text{operating_days}}$ is unknown, EPA recommends using the default assumptions discussed in Section 3.2 for $\text{TIME}_{\text{operating_days}}$. $Q_{\text{chem_site_day}}$ then is calculated using the above equation.

EPA recommends calculating the daily facility use rate ($Q_{\text{chem_site_day}}$) using the methodology presented in Section 0, and then comparing it to the throughput based on number of sites and operating days, as calculated above.

3.12 Number of Transport Containers Unloaded per Site ($N_{\text{containers unloaded site yr}}$)

Solid plastics additives are shipped to compounding sites in 50-lb (22.7-kg) paper or plastic bags. Cartons, which are lined with plastic bags, also may be used, and have a capacity of 1,200 to 1,500 lb (544 to 680 kg). On occasion, plastics additives suppliers may use bulk trucks or rail cars for shipping; however, plastics additives typically are not ordered in sufficient bulk quantities to warrant transport via trucks or rail cars (ERG, 2013).

The number of transport containers unloaded annually per site can be estimated based on the daily facility use rate ($Q_{\text{chem_site_day}}$), the container size, and the concentration of the chemical of interest in the plastics additive ($F_{\text{chem_additive}}$), as shown below.

Next, $\text{TIME}_{\text{operating_days}}$ is rounded to the nearest non-zero integer. Then, $Q_{\text{chem_site_yr}}$ is recalculated using the rounded number of operating days:

$$Q_{\text{chem_site_yr}} = Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}$$

In the absence of site-specific information, EPA recommends assuming a default transportation container size of 22.7 kg for solids and 208 L (55 gal) for liquids. If the density of a liquid formulation is not known, the density of water can be used as a default (1 kg/L).

$$N_{\text{container_unloaded_site_yr}} = \frac{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}}{F_{\text{chem_additive}} \times Q_{\text{container}}} \quad (3-6)$$

Where:

$N_{\text{container_unloaded_site_yr}}$	=	Number of transport containers unloaded per site per year (containers/site-yr)
$Q_{\text{chem_site_day}}$	=	Daily facility use rate of the chemical of interest (kg chemical of interest/site-day) (See Section 0)
$\text{TIME}_{\text{operating_days}}$	=	Number of operating days at the compounding site (Default: 10 days/yr (release concerns only), 264 days/yr (exposure concerns only), or 148 days/yr (both concerns)) (See Section 3.2)
$F_{\text{chem_additive}}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/kg additive containing chemical of interest) (See Section 3.4)
$Q_{\text{container}}^4$	=	Mass of the additive in the transport container (Defaults: solids, 22.7 kg additive/container; liquids 208 kg additive/container)

⁴ If the mass of the plastics additive in each container ($Q_{\text{container}}$) is not known, it can be calculated using the known volume of plastics additive per container and its density:

$$Q_{\text{container}} = V_{\text{container}} \times \text{RHO}_{\text{additive}}$$

Where:

$V_{\text{container}}$	=	Volume of additive in the transport container (L additive)
$\text{RHO}_{\text{additive}}$	=	Density of the additive (kg additive/ L additive) (Default: 1 kg/L for liquid)

4.0 ENVIRONMENTAL RELEASE ASSESSMENTS FOR THE USE OF ADDITIVES IN PLASTICS COMPOUNDING

This section presents approaches for estimating the amount of additives released during the compounding process. The release sources are presented in the order discussed in Section 2.0 (see Figure 2-1) and include the most likely receiving media (i.e., water, landfill, or incineration). The primary sources of release include: transfer of solid additive formulations, container residue, dust emissions from blending/compounding, fugitive emissions from blending/compounding, and process equipment cleaning. Key default values used for the release estimates, accompanied by their respective references, are provided in Table A-1, Appendix A.

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

All release equations estimate daily rates for a given site. To estimate annual releases for all sites for a given source, the release rates must be multiplied by the number of days of the release and by the total number of sites using additives (N_{sites}) (see Section 3.11).

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

Many of the environmental release estimates presented in this document are based on standard EPA release models. Table 4-1 summarizes the release estimation methods used in this methodology review draft.

Note that the standard model default values cited are current as of the date of this methodology review draft; however, EPA may update these models as additional data become available. It is recommended that the most current version of the models be used in these calculations.

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

Table 4-1. Summary of Use of Additives in Plastics Compounding Scenario Release Models

Release Source #	Description	Model Name or Description	Standard EPA Model (✓)
1	Dust emissions from unloading solid powder disposed to water, air, incineration, or landfill (if solid)	<i>EPA/OPPT Dust Emissions from Solid Transfers Model</i>	✓
2	Spillage from raw material handling to water, incineration, or landfill	<i>Loss from this operation is estimated based on readily-available industry specific data</i>	
3	Container residue losses to water, incineration, or land	Specific model used is based on the type and size of the containers, and on the physical state of the formulation: <ul style="list-style-type: none"> • <i>EPA/OPPT Bulk Transport Residual Model</i> • <i>EPA/OPPT Drum Residual Model</i> • <i>EPA/OPPT Small Container Residual Model</i> • <i>EPA/OPPT Solids Residual Model</i> 	✓
4	Dust emissions from blending/compounding to air and water	<i>Loss from this operation is estimated based on readily-available industry specific data</i>	
5	Fugitive emissions from blending/compounding to air or water	<i>Loss from this operation is estimated based on readily-available industry specific data</i>	
6	Equipment cleaning residue disposed to water, landfill, or incineration	<i>EPA/OPPT Multiple Process Vessel Residual Model</i>	✓
7	Release of additives during loading	<i>Exposure from this operation expected to be negligible</i>	

OPPT – Office of Pollution Prevention and Toxics.

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

4.1 Control Technologies

The plastics industry may employ various types of control technologies to reduce the amount of waste generated during plastics compounding. This subsection discusses some of the control technologies identified from the literature search and their effects on environmental releases.

The majority of waste streams generated at plastics compounding sites are air or water. Air control technologies may be used to reduce worker exposure and environmental releases due to dust generation or fugitive emissions. Air pollution control methods include mechanical separation, settling/clarification, scrubber, incineration, condenser, or adsorption (EPA, 2011).

Most plastics compounding facilities are indirect dischargers to POTWs (EPA, 1995). Process water generated at plastic compounding sites may include heating and cooling

water, cleaning rinsate, and finishing water. Downstream wastewater treatment processes are used to reduce the concentration of additives in the wastewater. Treatment processes may include settling or clarification, neutralization, sludge treatment and/or dewatering, biological treatment, chemical precipitation, phase separation, adsorption, or other treatment processes (EPA, 2011).

The efficiencies of the control technologies used to break down or capture the additives are presented in Table 4-2. Note, since facilities are not required to report waste quantities treated on site within their TRI submission, it is not possible to use this data to develop facility-level environmental release estimates that are directly attributable to on-site waste treatment.

Table 4-2. Summary of Waste Streams and Treatment Methods and Efficiencies for the NAICS Code Associated with Plastics Compounding

Waste Treatment Method, by Waste Stream	No. of Facilities	Treatment Method Distribution (%)	Minimum Reported Treatment Efficiency (%) ^a		Maximum Reported Treatment Efficiency (%) ^a	
			Lower Limit	Upper Limit	Lower Limit	Upper Limit
Plastics Compounding Industry	130					
<i>Gaseous (gases, vapors, airborne particulates)</i>	<i>66</i>					
Mechanical Separation	46	69.7	0	50	>99.99	99.9999
Other Air Emission Treatment	12	18.2	>50	95	>99	99.99
Settling or clarification	3	4.5	>99	99.99	>99.99	99.9999
Scrubber	2	3.0	>50	95	>50	95
Incineration - thermal destruction other than use as a fuel	1	1.5	>50	95	>50	95
Condenser	1	1.5	>95	99	>95	99
Adsorption	1	1.5	>99.99	99.9999	>99.99	99.9999
<i>Wastewater (aqueous waste)</i>	<i>51</i>					
Settling or clarification	20	39.2	0	50	>99.9999	100
Neutralization	6	11.8	>95	99	>95	99
Sludge treatment and/or dewatering	6	11.8	>95	99	>99.9999	100
biological treatment with or without precipitation	6	11.8	0	50	>99	99.99
Other chemical precipitation with or without pre-treatment	6	11.8	>50	95	>99.9999	100
Other treatment	4	7.8	0	50	>99	99.99
Phase separation	2	3.9	>95	99	>95	99
Adsorption	1	2.0	>50	95	>50	95
<i>Solid waste streams (including sludges and slurries)</i>	<i>7</i>					
Settling or clarification	5	71.4	>95	99	>99	99.99
Stabilization or chemical fixation prior to disposal	1	14.3	>99.99	99.9999	>99	99.9999
Other treatment	1	14.3	0	50	0	50

Waste Treatment Method, by Waste Stream	No. of Facilities	Treatment Method Distribution (%)	Minimum Reported Treatment Efficiency (%) ^a		Maximum Reported Treatment Efficiency (%) ^a	
			Lower Limit	Upper Limit	Lower Limit	Upper Limit
<i>Liquid waste streams (non-aqueous waste)</i>	6					
Stabilization or chemical fixation prior to disposal	4	66.7	>99.9999	100	>99.9999	100
Incineration - thermal destruction other than use as a fuel	1	16.7	>99.9999	100	>99.9999	100
Other treatment	1	16.7	>99.9999	100		>99.9999

^a Minimum and maximum treatment efficiencies are reported to TRI as ranges, hence the lower- and upper-end values presented herein.

4.2 Transfer Operations Losses to Air, Water, Incineration, or Landfill from Unloading Plastic Additives (Release 1)

When solid powders are unloaded, dust may be generated. The OECD ESD on Plastic Additives estimates a loss factor of up to 0.5% for fine particles and 0.1% for coarse particles (particle size >40 µm) based on expert judgment (OECD, 2009). The *EPA/OPPT Dust Emissions from Transferring Solids Model* may be used to estimate dust releases generated during the transfer of solid additives. This model assumes that up to 0.5 percent of the transferred quantity may be released to the environment (consistent with the worst case presented in OECD, 2009). The rationale, defaults, and limitations of these models are further explained in Appendix B.

Most facilities utilize some type of control device(s) to collect fugitive dust 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 are originally released to air, but may also settle to facility floors and be disposed of when floors are cleaned (water if the floors are rinsed, or land or incineration if the floors are swept). Therefore, the lost quantity of dust should conservatively be assessed as released to air, water, incineration, or landfill.

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, the assessor should utilize the alternate equations presented in Appendix B.

$$E_{\text{local}}_{\text{dust_generation}} = Q_{\text{chem_site_day}} \times F_{\text{dust_generation}} \quad (4-1)$$

Where:

$$E_{\text{local}}_{\text{dust_generation}} = \text{Daily release of dust from transfers/unloading (kg chemical/site-day)}$$

$Q_{\text{chem_site_day}}$	=	Daily use rate of the chemical of interest per site-day (kg/site-day)
$F_{\text{dust_generation}}$	=	Fraction of the chemical of interest lost during transfers/unloading of solid powders (Default = 0.005 kg chemical released/kg handled)

4.3 Spillage from Raw Material Handling to Water, Incineration, or Landfill (Release 2)

When liquid plasticizers are unloaded, spillage may occur resulting in a worst case scenario loss of 0.01% of the transported material (EU, 2002). The source further estimates that a worst case approach is to assess the spillage loss to wastewater. It has been noted that passive controls, such as closed sinks and basins, can be used to mitigate spillage releases to wastewater as well as surface water (INEOS, 2010). Due to the lack of industry-specific information regarding the media of release for other plastics additives, EPA recommends assessing spillage releases to water, incineration, or landfill using a loss fraction of 0.01%.

The following equation may be utilized to estimate potential releases from spillage during transfer operations.

$$E_{\text{local spillage}} = Q_{\text{chem_site_day}} \times F_{\text{spillage}} \quad (4-2)$$

Where:

$E_{\text{local spillage}}$	=	Daily release of spillage from transfers/unloading (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily facility use rate of the chemical of interest (kg chemical/site-day) (See Section 0)
F_{spillage}	=	Fraction of the chemical of interest lost during transfers/unloading of liquids (Default = 0.0001 kg chemical released/kg handled)

4.4 Container Residue Losses to Water, Incineration, or Landfill (Release 3)

Additives can be received as liquids or solids. If the physical state of the component is unknown, EPA recommends using engineering judgment to determine if additives should be assumed a solid or liquid for the purposes of the assessment.

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

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

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

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

EPA/OPPT Solid Residuals in Transport Containers Model may be used for containers of all sizes containing solids.

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

Solid additives are typically shipped in 50-lb paper or plastic bags for solid components (ERG, 2013). 1,200- to 1,500-lb cartons may also be used; however, bulk trucks or rail cars are used infrequently. If the size of the container is not known, EPA recommends assuming a default transportation container size of 55-gallon drums for liquid additives and a 50-lb (27.7-kg) bag for solid additives.

Containers are likely to be disposed of as solid waste (OECD, 2009; EC, 2007). Typical industrial container handling may include rinsing the container with water or solvent prior to disposal. The residual is then released to water or incineration. Therefore, the container residue loss should conservatively be assessed as released to water, incineration, or landfill.

The annual number of containers used per year ($N_{\text{container_unloaded_site_yr}}$) is estimated based on the daily use rate of additives and the container size (see Section 3.12). EPA recommends assuming a default transportation container size of 22.7 kg for solids and 208 L (55 gal) for liquids. If the density of a liquid formulation is not known, the density of water can be used as a default (1 kg/L).

Liquids:

If the $N_{\text{container_unloaded_site_yr}}$ value is fewer than the days of operation ($\text{TIME}_{\text{operating_days}}$), the days of release equal $N_{\text{container_unloaded_site_yr}}$ and the daily release is calculated based on the following equation:

$$E_{\text{local_container_residue_disp}} = V_{\text{container}} \times \text{RHO}_{\text{additive}} \times F_{\text{chem_additive}} \times F_{\text{container_residue}} \times N_{\text{container_unloaded_site_day}} \quad (4-3a)$$

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

Where:

$E_{\text{local_container_residue_disp}}$ = Daily release of the chemical of interest from container residue (kg chemical/site-day)

$V_{\text{container}}$	=	Volume of additive formulation in the transport container (Default: 208 L formulation/container (55-gallon drum; see Table B-1 in Appendix B for alternative default container volumes)
RHO_{additive}	=	Density of additive (kg/L additive formulation; Default: 1 kg/L for liquid ⁵)
$F_{\text{chem_additive}}$	=	Mass fraction of the chemical of interest in the additive (kg chemical/kg additive) (See Section 3.6)
$F_{\text{container_residue}}$	=	Fraction of the chemical of interest remaining in the container as residue (Default: 0.03 kg chemical remaining/kg shipped (for drums) (CEB, 2002); see Appendix B for defaults used for other container types)
$N_{\text{container_unloaded_site_day}}$ ⁶	=	Number of containers unloaded per site, per day

If $N_{\text{container_unloaded_site_yr}}$ is greater than $TIME_{\text{operating_days}}$ (See Section 3.2), more than one container is unloaded per day (i.e., $N_{\text{container_unloaded_site_yr}} > 1$). The days of release should equal the days of operation, and the average daily release can be estimated based on the following equation:

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

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

Where:

$E_{\text{local_container_residue_disp}}$	=	Daily release of the chemical of interest from container residue (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily use rate of the chemical of interest (kg chemical/site-day) (See Section 0)
$F_{\text{container_residue}}$	=	Fraction of the chemical of interest remaining in the container as residue (Default: 0.03 kg chemical remaining/kg shipped (for drums) (CEB, 2002); see Appendix B for defaults used for other container types)

⁵ Default value based on the density of water.

⁶ The daily number of containers unloaded per site may be estimated as:

$$N_{\text{container_unloaded_site_day}} = \frac{N_{\text{container_unloaded_site_yr}}}{TIME_{\text{operating_days}}}$$

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

Where:

$N_{\text{container_unloaded_site_yr}}$	=	Number of transport containers unloaded per site per year (containers/site-yr) (See Section 3.12)
$TIME_{\text{operating_days}}$	=	Annual number of days the additive is used (days/yr) (See Section 3.2)

Solids:

The *EPA/OPPT Solids Residual in Transport Containers Model* may be utilized to estimate container residue releases from solids. If the $N_{\text{container_unloaded_site_yr}}$ value is fewer than the days of operation ($\text{TIME}_{\text{operating_days}}$), the days of release equal $N_{\text{container_unloaded_site_yr}}$ and the daily release is calculated based on the following equation:

$$E_{\text{local_container_residue_disp}} = Q_{\text{container}} \times F_{\text{chem_additive}} \times F_{\text{container_residue}} \times N_{\text{container_unloaded_site_day}} \quad (4-4a)$$

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

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

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

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

Where:

$E_{\text{local_container_residue_disp}}$	=	Daily release of the chemical of interest from container residue (kg chemical/site-day)
$Q_{\text{container}}$	=	Mass of the additive in the transport container (Default: 22.7 kg additive/container) (See Section 3.12)
$F_{\text{chem_additive}}$	=	Mass fraction of the chemical of interest in the additive (kg chemical/kg additive) (See Section 3.4)
$F_{\text{container_residue}}$	=	Fraction of the chemical of interest remaining in the container as residue (Default: 0.01 kg chemical remaining/kg shipped) (CEB, 2002) (See Appendix B for defaults used for other container types))
$N_{\text{cont_unloaded_site_day}}$	=	Number of containers unloaded per site, per day (Default: 1 container/site-day)
$Q_{\text{chem_site_day}}$	=	Daily use rate of chemical of interest (kg chemical/site-day) (See Section 0)

4.5 Dust Emissions from Blending/Compounding to Air, Landfill, or Water (Release 4)

Dust generation is expected during blending/compounding operations for solid additives due to the susceptibility of dust generation during the process of mixing fine particles into polymer solutions (as discussed in Section 2.0). Potential losses due to blending/compounding are expected to occur early in the mixing cycle and be at least an order of magnitude less than the loss fraction from transferring and handling operations. Therefore, the release of solid additives during blending/compounding operations can be estimated by a loss fraction of 0.05% for fine (<40 μm) particles and 0.01% for coarse (>40 μm) particles (OECD,

2009). EPA recommends assessing dust emissions from blending/compounding using a loss fraction of 0.05%, as conservative.

Fugitive dust emissions are originally lost to air, which may result in the dust settling to facility floors and being disposed of when floors are cleaned. The settled dust may be released to landfill for dusts captured within vacuum cleaner bags and filters (OECD, 2009). Additionally, the particles can undergo subsequent condensation upon release, resulting in losses to water. EPA recommends conservatively assessing releases to air, landfill, and water.

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

Where:

$E_{\text{local fugitive_dust_emissions}}$	=	Daily release of the chemical of interest from fugitive dust emissions during blending/compounding (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily use rate of the chemical of interest (kg chemical/site-day) (See Section 0)
$F_{\text{fugitive_dust_emissions}}$	=	Fraction of the chemical of interest lost during blending/compounding operations (Default: 0.0005 kg chemical released/kg blended) (OECD, 2009)

4.6 Fugitive Emissions from Blending/Compounding to Air and Water (Release 5)

For liquid additives with a low adjusted vapor pressure, (e.g., those with a vapor pressure of < 0.001 torr), releases to air are expected to be negligible. However, due to the elevated temperatures at which blending/compounding operations may be performed, volatilization may occur. Fugitive emission loss rates are based on the volatility at 200°C for typical plasticizers: high – 0.05%; medium – 0.01 %; and low – 0.002% (OECD, 2009). EPA recommends assessing fugitive emissions from blending/compounding using a loss fraction of 0.05%, as conservative.

Fugitive emissions are originally lost to air (50%), but subsequent condensation may result in losses to water (50%) (OECD, 2009). Emission sources and pathways associated with fugitive emissions are discussed in greater detail in Section 2.0. Therefore, EPA recommends assuming fugitive air emissions from blending/compounding processes are assessed to water (50%) and air (50%). The following equation can be used to estimate these releases:

$$E_{\text{local fugitive_emissions}} = Q_{\text{chem_site_day}} \times F_{\text{fugitive_emissions}} \quad (4-6)$$

Where:

$E_{\text{local fugitive_emissions}}$	=	Daily release of the chemical of interest from fugitive emissions during blending/compounding (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily use rate of the chemical of interest (kg chemical/site-day) (See Section 0)
$F_{\text{fugitive_emissions}}$	=	Fraction of the chemical of interest lost during blending/compounding operations (Default: 0.0005 kg chemical released/kg blended) (OECD, 2009)

4.7 Equipment Cleaning Losses to Water, Landfill, or Incineration (Release 6)

Limited information was found regarding standard equipment cleaning practices within the plastics compounding industry. This methodology review draft assumes this release includes rinsate and process water (i.e. cooling and heating water, finishing water) used during equipment cleaning and compounding (CEB, 2004). The *EPA/OPPT Multiple Vessel Residual Model* assumes that no more than two percent of the batch size or capacity of the process remains in the equipment as residue and is released as equipment cleaning waste. The *Multiple Vessel Residual Model* is recommended, as opposed to the *Single Vessel Residual Model*, because cooling lines will also have to be cleaned. Equipment cleaning may occur at the end of each campaign or as needed to maintain proper compounding.

Water is primarily used for cooling equipment and cleaning purposes onsite. Therefore, there is the potential for water releases (OECD, 2009). Cooling water would contribute to this release only if it is contact cooling water; non-contact cooling water would not contain the chemical of interest. Equipment may be rinsed with water or organic solvent resulting in equipment residue potentially being released to water, incineration, or landfill. EPA recommends assessing equipment cleaning releases to water, incineration, or landfill.

If $N_{bt_site_yr}$ or known number of cleanings is fewer than the days of operation ($TIME_{operating_days}$), the days of release equal $N_{bt_site_yr}$ (as calculated in Section 3.10) and the daily release of additive residue in the process equipment is calculated using the following equation:

$$E_{local_equipment_cleaning} = Q_{chem_bt} \times F_{chem_resin} \times N_{bt_site_day} \times F_{equipment_cleaning} \quad (4-7a)$$

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

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

$$E_{local_equipment_cleaning} = Q_{chem_site_day} \times F_{equipment_cleaning} \quad (4-7b)$$

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

Where:

$E_{local_equipment_cleaning}$	=	Daily release of the chemical of interest from equipment cleaning (kg chemical/site-day)
Q_{chem_bt}	=	Mass of the chemical of interest used per batch (kg chemical/batch) (See Section 3.10)
F_{chem_resin}	=	Mass fraction of chemical of interest in the plastic resin (kg chemical/kg resin) (See Section 3.6)

$N_{bt_site_day}^7$	=	Daily number of batches compounded at each site (batches/site-day)
$F_{equipment_cleaning}$	=	Fraction of polymer resin containing the chemical of interest released as residual in process equipment (Default: 0.02 kg product released/kg batch holding capacity (CEB, 1992))
$Q_{chem_site_day}$	=	Daily use rate of chemical of interest in the polymer resin (kg chemical/site-day) (See Section 0)

4.8 Release of Additives during Loading (Release 7)

Compounded plastics are transported as pellets, sheets, films or pipes (Kirk-Othmer, 1991), which consist of large particle sizes. Dust generation is not expected during this activity, and therefore, the expected release of particulates during product loading is negligible.

⁷ The daily number of batches compounded at each site may be estimated as:

$$N_{bt_site_day} = \frac{N_{bt_site_yr}}{TIME_{operating_days}}$$

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

Where:

$N_{bt_site_yr}$	=	Annual number of batches at each site (batches/ site-yr) (See Section 3.10)
$TIME_{operating_days}$	=	Annual number of days the additive is used (days/yr) (See Section 3.2)

5.0 OCCUPATIONAL EXPOSURE ASSESSMENTS FOR THE USE OF ADDITIVES IN PLASTICS COMPOUNDING

The following section presents estimation methods for worker exposures to additives during the compounding process. Figure 2-1 illustrates the occupational activities performed within the process that have the greatest potential for worker exposure to additives. Table 5-1 summarizes the exposure estimation methods used in this methodology review draft.

Note that the standard model default values cited are current as of the date of this methodology review draft; however, EPA may update these models as additional data becomes available. It is recommended that the most current version of the models be used in the calculations.

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

Table 5-1. Summary of Additive Use Scenario Exposure Models

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description ^a	Standard EPA Model (✓)
A	Exposure to additive formulations during unloading or transferring	Inhalation of solid powder dust emissions	Specific model is based on the total volume of material handled: <ul style="list-style-type: none"> • <i>EPA Small Volume Handling Model</i> • <i>OSHA Total PNOR PEL-Limiting Model</i> 	✓
		Dermal exposure to liquid or solid additive formulations	Specific model is based on the physical form of the material: <ul style="list-style-type: none"> • <i>EPA/OPPT 2-Hand Dermal Contact with Liquids Model</i> • <i>EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model</i> 	✓
B	Exposure to additive during container cleaning	Inhalation of solid powder dust emissions	Specific model is based on the total volume of material handled: <ul style="list-style-type: none"> • <i>EPA Small Volume Handling Model</i> • <i>OSHA Total PNOR PEL-Limiting Model</i> 	✓

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description ^a	Standard EPA Model (✓)
		Dermal exposures to liquid or solid additive containing the chemical	Specific model is based on the physical form of the material: <ul style="list-style-type: none"> EPA/OPPT 2-Hand Dermal Contact with Liquids Mode EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model 	✓
C	Exposure to liquids during equipment cleaning	Dermal exposure to liquids containing the chemical	Specific model is based on the physical form of the material: <ul style="list-style-type: none"> EPA/OPPT 2-Hand Dermal Contact with Liquids Model 	✓
D	Exposure to additives during loading	Inhalation of solid powder dust emissions	<i>Exposure from this operation expected to be negligible</i>	
E	Exposure to dusts generated from compounding processes	Inhalation of solid powder dust emissions	<i>OSHA Total PNOR PEL-Limiting Model</i>	✓

^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

No specific information was identified about the typical PPE used during compounding processes. According to AP-42, most plants use forced ventilation techniques to reduce worker exposure to vapors (EPA, 2008). Please note that EPA does not assess the effectiveness of PPE at mitigating occupational exposures in this methodology review draft. The exposure mitigation by PPE is affected by many factors including availability, cost, worker compliance, impact on job performance, chemical and physical properties of the substance and protective clothing, and the use, decontamination, maintenance, storage, and disposal practices applicable to the industrial operation (CEB, 1997). Therefore, the conservative, screening-level occupational exposure estimates presented in this methodology review draft do not account for PPE. Actual occupational exposure may be significantly less than the estimates presented in this methodology review draft.

5.2 Number of Workers Exposed Per Site

Limited industry-specific data on the number of workers potentially exposed while performing each of the compounding activities were found in the references reviewed for this methodology review draft (refer to Section 8.0). Table 5-2 summarizes data collected from the U.S Census Bureau for the plastics compounding industry.

In combination with use rate information provided in Section 3.0, the total number of workers can be estimated by end-use market; however, not all workers are expected to work in the production areas. The Census also provides estimates for *production workers* (USCB, 2011b), which are defined by the U.S. Census Bureau to include...

...workers (up through the line-supervisor level) engaged in fabricating, processing, assembling, inspecting, receiving, storing, handling, packing, warehousing, shipping (but not delivering), maintenance, repair, janitorial and guard services, product development, auxiliary production for plant's own use (e.g., power plant), record keeping, and other services closely associated with these production operations at the establishment (USCB, 2011b).

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

...those engaged in supervision above the line-supervisor level, sales (including driver-salespersons), sales delivery (highway truck drivers and their helpers), advertising, credit, collection, installation and servicing of own products, clerical and routine office functions, executive, purchasing, financing, legal, personnel (including cafeteria, medical, etc.), professional, technical employees, and employees on the payroll of the manufacturing establishment engaged in the construction of major additions or alterations utilized as a separate work force (USCB, 2011b).

The Census data does not provide information that could provide bases for estimating the specific numbers of production workers that perform each of the exposure activities discussed in this section. In the absence of data, the number of workers potentially exposed to additives during each activity should be conservatively estimated as 24 workers per site; however, the total number of workers per site does not equal the sum of the number of workers assumed to be exposed during each activity.

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

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

NAICS Code	Description	Number of Establishments ^a	Number of Production Workers ^b	Average Number of Workers per Facility ^c
325991	Custom Compounding of Purchased Resins	468	11,031	24

^a USCB, 2011a

^b USCB, 2011b

^c Calculated by dividing the number of production workers by the number of establishments.

5.3 Exposure from Unloading and Transferring Additives (Exposure A)

Workers may connect transfer lines or manually unload additives from transport containers into process equipment or storage. If the concentration of the chemical of interest

within the plastics additive ($F_{\text{chem_additive}}$) is not known, EPA recommends assuming 100 percent as a conservative default, as previously discussed in Sections 3.4.

Inhalation Exposure:

The transfer of solid additives from containers to storage or process equipment generates particulates. The degree of inhalation exposure to particulates depends on the concentration of the chemical of interest in the plastics additive ($F_{\text{chem_additive}}$), the potential concentration of additive containing the chemical of interest in the worker’s breathing zone ($C_{\text{particulate}}$), and the total amount of additive containing the chemical of interest that the worker is exposed to per day in performing this activity ($Q_{\text{additive_site_day}}$).

The daily transfer rate of the additive containing the chemical of interest may be estimated using the following equation:

$$Q_{\text{additive_site_day}} = \frac{Q_{\text{chem_site_day}}}{F_{\text{chem_additive}}} \quad (5-1)$$

Where:

- $Q_{\text{additive_site_day}}$ = Daily amount of the additive containing the chemical of interest transferred into the process (kg additive/site-day)
- $Q_{\text{chem_site_day}}$ = Daily use rate of the chemical of interest (kg chemical/site-day) (See Section 0)
- $F_{\text{chem_additive}}$ = Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

In lieu of airborne concentration data that is specific to the chemical of interest, EPA typically references personal monitoring data collected by the Occupational Safety and Health Administration (OSHA) for particulates not otherwise regulated (PNOR) for both respirable and total dust (OSHA, 2011). The personal monitoring data, which was sampled between 2006 and 2010, was collected using the primary NAICS codes associated with the plastics compounding industry. Table 5-3 summarizes the OSHA monitoring data for the NAICS code associated with the plastics compounding industry. This data includes the number of facilities, number of monitoring samples taken, and statistics on low-end, high-end, and average exposure concentrations for PNOR (respirable fraction and total dust). The average exposure concentration at compounding sites for PNOR (respirable fraction) is 0.72 mg/m³ and for PNOR (total dust) is 3.8 mg/m³. It is important to note that the monitoring data presented is not activity-specific, and therefore, it is not possible to directly correlate the exposure data to unloading and transfer activities.

Table 5-3. Summary of OSHA Monitoring Data for the NAICS Code Associated with the Plastics Compounding Industry

Industry	Substance	No. of Facilities	No. of Samples	Low End	High End	Average	OSHA PEL	Units
Compounding	PNOR (Respirable Fraction)	2	11	0.133	1.88	0.723	5	mg/m ³
	PNOR (Total Dust)	1	6	0.226	10.7	3.80	15	mg/m ³

The *OSHA Total PNOR PEL-Limiting Model* presented in the following sections conservatively assumes an airborne particulate concentration equal to that of the OSHA PEL for PNOR (total dust). As the monitoring data in Table 5-3 show, this approach yields conservative exposure estimates since actual dust concentrations of the chemical of interest are likely to be reduced by utilization of process enclosures and engineering controls. As an example of this, sampling data for medium-chained chlorinated paraffins (MCCPs), as measured at two sites in the European Union (EU), yielded minimum and maximum dust exposure values of 0.02 and 0.44 mg/m³, respectively (ECHA, 2008). The report containing this data indicates that operations at these sites are believed to be representative of compounding operations presented in the EU, but it did not include specific information about site process enclosures and engineering controls associated with the sampling data. These values are approximately one order of magnitude lower than the OSHA monitoring data presented above.

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

Note that the two estimation methods provided below are defaults. If using the *OSHA Total PNOR PEL-Limiting Model*, the data presented in Table 5-3 can be used to develop typical and high-end exposure estimates by setting $C_{\text{particulate}}$ equal to the respective average or high-end values.

If the daily amount of the solid formulation component containing additives ($Q_{\text{additive_site_day}}$) is *greater than* 54 kg/site-day; EPA recommends using the *OSHA Total PNOR PEL-Limiting Model*:

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

This exposure will occur over the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{operating_days}}$.

Where:

$EXP_{\text{inhalation}}$ = Inhalation exposure to chemical per day (mg chemical/day)
 $C_{\text{particulate}}$ = Concentration of particulate in the worker breathing zone (Default: 15 mg/m³; based on OSHA PEL for particulates not otherwise regulated)

RATE _{breathing}	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
TIME _{exposure}	=	Duration of exposure (Default: 8 hr/day)
F _{chem_additive}	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

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

If the daily amount of solid additive containing the chemical of interest (Q_{additive_site_day}) is *less than or equal to* 54 kg/site-day, EPA recommends using the *EPA/OPPT Small Volume Solids Handling Inhalation Model*:

$$EXP_{inhalation} = Q_{additive_site_day} \times F_{chem_additive} \times F_{exposure} \quad (5-2b)$$

This exposure will occur over the lesser of N_{bt_site_yr} or TIME_{operating_days}.

Where:

EXP _{inhalation}	=	Inhalation exposure to chemical per day (mg chemical/day)
Q _{additive_site_day}	=	Quantity of additive containing the chemical of interest handled during container transfers (kg additive/site-day) (See Equation 5-1)
F _{chem_additive}	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)
F _{exposure}	=	Weight fraction of the total particulate in the worker breathing zone (Default: 0.0477 (typical) to 0.161 (worst) mg chemical/kg chemical handled (CEB, 1992))

Dermal Exposure:

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

Liquids

The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the liquid additive in the formulation during these activities. Appendix B discusses the rationale, defaults, and limitation of these models.

To estimate the potential worker exposure to the chemical of interest for this activity, the following equation may be used:

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

This exposure will occur over the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{operating_days}}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid final product remaining on skin (Defaults: 2.1 mg product/cm ² -incident (high-end) and 0.7 mg product/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000))
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 1,070 cm ² for 2 hands (CEB, 2013))
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{\text{chem_additive}}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

Solids

The *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* may be used to estimate dermal exposure to additives in a solid powder formulation component. The rationale, defaults, and limitations of these models are further explained in Appendix B.

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

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

This exposure will occur over the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{operating_days}}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to chemical of interest per day (mg chemical/day)
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{\text{chem_additive}}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

5.4 Exposure from Container Cleaning (Exposure B)

Workers may be exposed while rinsing containers used to transport the plastics additive containing the chemical of interest. If the concentration of the chemical in the additive is unknown ($F_{\text{chem_additive}}$), 100 percent concentration may be assumed as a conservative default (see Section 3.4).

Inhalation Exposure:

Liquids

The method used to calculate inhalation exposure ($EXP_{\text{inhalation}}$) depends on the volatility and the physical state of the composite formulation. Inhalation exposure is assumed negligible for non-volatile liquids (i.e., vapor pressure < 0.001 torr).

Solids

The cleaning of solid powders from transport containers may generate dust particulate. The degree of inhalation to particulates depends on the concentration of the chemical of interest in the additive ($F_{\text{chem_additive}}$), the potential concentration of additive containing the chemical of interest in the worker's breathing zone ($C_{\text{particulate}}$), and the total amount of the additive residual containing the chemical of interest removed from the containers ($Q_{\text{additive_residue_site_day}}$). EPA recommends using the following equation to estimate the amount of additive residual handled by a worker during container cleaning:

$$Q_{\text{additive_residue_site_day}} = \frac{E_{\text{local}}_{\text{container_residue_disp}}}{F_{\text{chem_additive}}} \quad (5-4)$$

$Q_{\text{additive_residue_site_day}}$	=	Quantity of chemical handled during container cleaning (kg chemical/site-day)
$E_{\text{local}}_{\text{container_residue_disp}}$	=	Daily release of the chemical of interest from container residue (kg chemical/site-day) (See Section 4.4)
$F_{\text{chem_additive}}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

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

If the $Q_{\text{additive_residue_site_day}}$ is *greater than* 54 kg/site-day; EPA recommends using the *OSHA Total PNOR PEL-Limiting Model*:

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

This exposure will occur over the lesser of $N_{container_unloaded_site_yr}$ or $TIME_{operating_days}$.

Where:

$EXP_{inhalation}$	=	Inhalation exposure to chemical per day (mg chemical/day)
$C_{particulate}$	=	Concentration of particulate in the worker breathing zone (Default: 15 mg/m ³ (average); based on OSHA PEL for particulates not otherwise regulated)
$RATE_{breathing}$	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
$TIME_{exposure}$	=	Duration of exposure (Default: 8 hr/day)
$F_{chem_additive}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

The accuracy of solid component inhalation estimates are limited by the estimated airborne concentration of the chemical of interest and the assumed breathing rate. Note that the OSHA monitoring data presented in Table 5-3 can be used to develop typical and high-end exposure estimates by setting $C_{particulate}$ equal to the respective average or high-end values.

If $Q_{additive_residue_site_day}$ is less than or equal to 54 kg/site-day, EPA recommends using the *EPA/OPPT Small Volume Solids Handling Inhalation Model*:

$$EXP_{inhalation} = Q_{additive_residue_site_day} \times F_{chem_additive} \times F_{exposure} \quad (5-5b)$$

This exposure will occur over the lesser of $N_{container_unloaded_site_yr}$ or $TIME_{operating_days}$.

Where:

$EXP_{inhalation}$	=	Inhalation exposure to chemical per day (mg chemical/day)
$Q_{additive_residue_site_day}$	=	Quantity of additive handled during container cleaning (kg additive/site-day)
$F_{chem_additive}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)
$F_{exposure}$	=	Weight fraction of the total particulate in the worker breathing zone (Default: 0.0477 (typical) to 0.161 (worst) mg chemical/kg chemical handled (CEB, 1992))

Dermal Exposure:

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

Liquids

To estimate the potential worker exposure to a liquid additive containing the chemical of interest for this activity, EPA recommends using the following equation:

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

This exposure will occur over the lesser of $N_{\text{container_unloaded_site_yr}}$ or $TIME_{\text{operating_days}}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid final product remaining on skin (Defaults: 2.1 mg product/cm ² -incident (high-end) and 0.7 mg product/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000))
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 1,070 cm ² for 2 hands (CEB, 2013))
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{\text{chem_additive}}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

Solids

The *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* may be used to estimate dermal exposure to additives in a solid powder formulation component. To estimate the potential worker exposure to chemical of interest in a solid component for this activity, EPA recommends using the following equation (CEB, 2000):

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

This exposure will occur over the lesser of $N_{\text{container_unloaded_site_yr}}$ or $TIME_{\text{operating_days}}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to chemical of interest per day (mg chemical/day)
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{\text{chem_additive}}$	=	Mass fraction of chemical of interest in the plastics additive (Default: 1 kg chemical of interest/ kg additive containing chemical of interest) (See Section 3.4)

5.5 Exposure from Equipment Cleaning (Exposure C)

Workers may be exposed while cleaning the process equipment with water or organic solvents. Since some equipment cleaning may be performed manually, exposures during equipment cleaning should be assessed.

Inhalation Exposure:

The method used to calculate inhalation exposure ($EXP_{\text{inhalation}}$) depends on the volatility and the physical state of the composite formulation. Inhalation exposure is assumed negligible for non-volatile liquids (i.e., vapor pressure < 0.001 torr) and for solids during equipment cleaning.

Dermal Exposure:

Dermal exposure to liquids is expected during the cleaning of process equipment. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to additives in the liquid. EPA assumes the concentration of the additive in the cleaning solution is 50% the concentration of additive in resin (CEB, 2004). Note dermal contact with cooling water is not expected because of elevated temperatures. Appendix B discusses the rationale, defaults, and limitations of these models.

To estimate the potential worker exposure to the resin containing the chemical of interest during this activity, the following equation may be used:

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

This exposure will occur over the lesser of $N_{\text{bt_site_yr}}$ or $TIME_{\text{operating_days}}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid final product remaining on skin (Defaults: 2.1 mg product/cm ² -incident (high-end) and 0.7

		mg product/cm ² -incident (low-end) for routine or incidental contact (CEB, 2000))
AREA _{surface}	=	Surface area of contact (Default: 1,070 cm ² for 2 hands (CEB, 2013))
N _{exp_incident}	=	Number of exposure incidents per day (Default: 1 incident/day)
F _{cleaning} ⁸	=	Fraction of chemical of interest in the cleaning solution (Default: 0.5 kg resin/kg solution) (CEB, 2004)

5.6 Exposure from Loading Plastic Resin Containing Additive (Exposure D)

Compounded plastics are transported as pellets, sheets, films or pipes (Kirk-Othmer, 1991), which consist of large particle sizes. Inhalation exposure during loading is negligible as dust generation is not expected during this activity. Although some surface contact may occur due to the incorporation of the additive into the plastic material, dermal exposure is non-quantifiable (CEB, 2004).

5.7 Exposure from Dusts Generated from Compounding Processes (Exposure E)

Workers may be exposed to dust generated during the compounding process.

Inhalation Exposure:

EPA recommends conservatively estimating exposures associated with dust generation from compounding activities using the OSHA PEL for particulates not otherwise regulated, 15 mg/m³. The *OSHA Total PNOR PEL-Limiting Model* may be used to determine inhalation exposure estimates as follows:

$$EXP_{inhalation} = C_{particulate} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_resin} \quad (5-8)$$

This exposure will occur over the lesser of N_{bt_site_yr} or TIME_{operating_days}.

Where:

EXP _{inhalation}	=	Inhalation exposure to chemical per day (mg chemical/day)
C _{particulate}	=	Concentration of particulate in the worker breathing zone (Default: 15 mg/m ³ ; based on OSHA PEL for particulates not otherwise regulated)

⁸ F_{cleaning} is calculated as follows:

$$F_{cleaning} = F_{chem_resin} \times 0.5 \frac{\text{kg resin}}{\text{kg soln}}$$

Where:

F _{chem_resin}	=	Mass fraction of chemical of interest in the plastic resin (kg chemical/kg resin) (See Section 3.6)
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$RATE_{\text{breathing}}$	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
$TIME_{\text{exposure}}$	=	Duration of exposure (Default: 8 hr/day)
$F_{\text{chem_resin}}$	=	Mass fraction of chemical of interest in the plastic resin (kg chemical/kg resin) (See Section 3.6)

Note that the OSHA monitoring data presented in Table 5-3 can be used to develop typical and high-end exposure estimates by setting $C_{\text{particulate}}$ equal to the respective average or high-end values.

6.0 SAMPLE CALCULATIONS

This section presents an example of how the equations introduced in Sections 3.0 through 5.0 can be used to estimate releases of and exposures to additives during compounding processes. The default values used in these calculations are presented in Sections 3.0 through 5.0 and should be used only in the absence of site-specific information. The following data are used in the example calculations:

1. The production volume for the chemical of interest ($Q_{\text{chem_yr}}$) is *100,000 kg chemical/yr*.
2. The chemical of interest is a *solid that* is compounded into plastic resins (type of additive and resin are unknown).
3. The chemical assessment must address environmental release and occupational exposure concerns.

6.1 General Facility Estimates

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

If specific information is not available to estimate the days of operation ($\text{TIME}_{\text{operating_days}}$) at a compounding site, assume a default value based on chemical assessment concerns, as discussed in Section 3.2. To address both environmental release and occupational exposure concerns, it is necessary to assume a value of 148 days per year.

6.1.2 Annual Facility Use Rate of Plastics Additives ($Q_{\text{all_additives_site_yr}}$)

Aside from the annual production volume and physical state of the chemical of interest, no other site-specific information or data are known. Therefore, it is necessary to use default assumptions to determine site throughputs of the chemical of interest. The first step is to assume an annual facility use rate for plastics additives ($Q_{\text{all_additives_site_yr}}$). This rate subsequently is used to calculate the corresponding site throughput of the chemical of interest. Per Section 3.3, the default annual facility use rate is 3,126,068 kg all additives/site-yr.

6.1.3 Mass Fraction of the Chemical of Interest in the Plastics Additive ($F_{\text{chem_additive}}$)

If the weight fraction of the chemical of interest in the plastics additive is not known, assume the additive contains no other chemicals besides the chemical of interest (i.e., 1 kg chemical/kg additive containing chemical).

6.1.4 Mass Fraction of the Plastics Additive of Interest in the Plastic Resin ($F_{\text{additive_resin}}$)

Little is known about the chemical of interest outside of its physical state (i.e., solid); therefore, it is necessary to reference the logic diagram in Figure 3-1. Since both

environmental releases and occupational exposures are of concern, EPA recommends assuming a weight fraction of 0.07 kg additive/kg resin.

6.1.5 Mass Fraction of the Chemical of Interest in the Plastic Resin ($F_{\text{chem_resin}}$)

This value can be calculated using Equation 3-1:

$$\begin{aligned}
 F_{\text{chem_resin}} &= F_{\text{chem_additive}} \times F_{\text{additive_resin}} \\
 &= 1 \frac{1 \text{ kg chemical}}{\text{kg additive containing chemical}} \times 0.07 \frac{\text{kg additive containing chemical}}{\text{kg resin}} \\
 &= 0.07 \frac{\text{kg chemical}}{\text{kg resin}}
 \end{aligned}$$

6.1.6 Mass Fraction of All Plastics Additives Contained in the Plastic Resin ($F_{\text{all_additives_resin}}$)

If this value is not known and both environmental releases and occupational exposures are of concern, assume the default value of 0.46 kg all additives/kg resin (per Figure 3-1).

6.1.7 Annual Facility Use Rate of the Chemical of Interest ($Q_{\text{chem_site_yr}}$)

The annual use rate of the chemical of interest can be estimated using the following equation. To address environmental release and occupational exposure assessment concerns, assume $F_{\text{all_additives_resin}}$ is equal to 0.46 kg all additives/kg resin (per Figure 3-1).

$$\begin{aligned}
 Q_{\text{chem_site_yr}} &= Q_{\text{all_additives_site_yr}} \frac{F_{\text{chem_resin}}}{F_{\text{all_additive_resin}}} \\
 &= 3,126,068 \frac{\text{kg all additives}}{\text{site - yr}} \times \frac{0.07 \frac{\text{kg chemical}}{\text{resin}}}{0.46 \frac{\text{kg all additives}}{\text{kg resin}}} \\
 &= 475,706 \text{ kg/site - yr}
 \end{aligned}$$

6.1.8 Daily Facility Use Rate of the Chemical of Interest ($Q_{\text{chem_site_day}}$)

The daily use rate of the chemical of interest can be estimated using the following equation:

$$\begin{aligned}
 Q_{\text{chem_site_day}} &= \frac{Q_{\text{chem_site_yr}}}{\text{TIME}_{\text{operating_days}}} \\
 &= \frac{475,706 \frac{\text{kg chemical}}{\text{site - yr}}}{148 \frac{\text{days}}{\text{yr}}} \\
 &= 3,214 \text{ kg/site - day}
 \end{aligned}$$

6.1.9 Annual Number of Batches ($N_{\text{bt_st_yr}}$)

The following calculation estimates the batch size, assuming the number of batches used per site per day ($N_{\text{chem_bt}}$) is one:

$$\begin{aligned}
 Q_{\text{chem_bt}} &= \frac{Q_{\text{chem_site_yr}}}{\text{TIME}_{\text{operating_days}} \times N_{\text{chem_bt}}} \\
 &= \frac{475,706 \frac{\text{kg chemical}}{\text{site - yr}}}{148 \frac{\text{days}}{\text{yr}} \times 1 \frac{\text{batch}}{\text{site - day}}} \\
 &= 3,214 \text{ kg chemical/batch}
 \end{aligned}$$

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

$$\begin{aligned}
 N_{\text{bt_site_yr}} &= \frac{Q_{\text{chem_site_yr}}}{Q_{\text{chem_bt}}} \\
 &= \frac{475,706 \frac{\text{kg chemical}}{\text{site - yr}}}{3,214 \frac{\text{kg chemical}}{\text{batch}}} \\
 &= 148 \text{ batches/site - yr}
 \end{aligned}$$

The annual number of batches per year is consistent with the number of operating days per year (i.e., 148). This will be the case when assuming $N_{\text{chem_bt}}$ is equal to one batch/site-day.

6.1.10 Number of Sites (N_{sites})

The number of sites can be estimated using the following equation:

$$\begin{aligned}
 N_{\text{sites}} &= \frac{Q_{\text{chem_yr}}}{Q_{\text{chem_site_yr}}} \\
 &= \frac{100,000 \frac{\text{kg chemical}}{\text{yr}}}{475,706 \frac{\text{kg chemical}}{\text{site - yr}}} \\
 &= 0.21 \text{ sites}
 \end{aligned}$$

N_{sites} must be rounded to the nearest non-zero integer value (i.e., 1 site). To avoid errors due to rounding, $Q_{\text{chem_site_day}}$ must be recalculated as follows:

$$\begin{aligned}
 Q_{\text{chem_site_day}} &= \frac{Q_{\text{chem_yr}}}{N_{\text{sites}} \times \text{TIME}_{\text{operating_days}}} \\
 &= \frac{100,000 \frac{\text{kg chemical}}{\text{yr}}}{1 \text{ site} \times 148 \frac{\text{days}}{\text{yr}}} \\
 &= 676 \text{ kg/site - day}
 \end{aligned}$$

6.1.11 Number of Transport Containers Unloaded per Site ($N_{\text{container_unloaded_site_yr}}$)

The number of transport containers can be estimated using the following equation:

$$\begin{aligned}
 N_{\text{container_unloaded_site_yr}} &= \frac{Q_{\text{chem_site_day}} \times \text{TIME}_{\text{operating_days}}}{F_{\text{chem_additive}} \times Q_{\text{container}}} \\
 &= \frac{676 \frac{\text{kg chemical}}{\text{site - day}} \times 148 \frac{\text{days}}{\text{yr}}}{1 \frac{\text{kg chemical}}{\text{kg additive}} \times 22.7 \frac{\text{kg additive}}{\text{container}}} \\
 &= 4,407 \text{ containers/site - yr}
 \end{aligned}$$

6.2 Environmental Releases

6.2.1 Release to Air, Water, Incineration, or Landfill from Unloading Plastic Additives (Release 1)

$$E_{\text{local}}_{\text{dust_generation}} = Q_{\text{chem_site_day}} \times F_{\text{dust_generation}}$$

$$\begin{aligned}
&= 676 \frac{\text{kg}}{\text{site-day}} \times 0.005 \frac{\text{kg released}}{\text{kg handled}} \\
&= 3.38 \text{ kg/site-day}
\end{aligned}$$

...over 148 days/year from 1 site.

Fugitive dust emissions are originally released to air, but may also settle to facility floors and be disposed of when floors are cleaned (water if the floors rinsed or land or incineration if the floors are swept). Therefore, the lost quantity of dust should conservatively be assessed as released to air, water, incineration, or landfill.

6.2.2 Release to Water, Incineration, or Landfill from Spillage during Raw Material Handling (Release 2)

$$\begin{aligned}
E_{\text{local spillage}} &= Q_{\text{chem_site_day}} \times F_{\text{spillage}} \\
&= 676 \frac{\text{kg}}{\text{site-day}} \times 0.0001 \frac{\text{kg released}}{\text{kg handled}} \\
&= 0.0676 \text{ kg/site-day}
\end{aligned}$$

...over 148 days/year from 1 site.

Spillage releases should conservatively be assessed to water, incineration, or landfill.

6.2.3 Release to Water, Incineration, or Landfill from Container Residues (Release 3)

The default container size for solids is 22.7 kg. For solids, the *EPA/OPPT Solid Residuals in Transport Containers Model* may be used to estimate container residue releases. Since $N_{\text{container_unloaded_site_yr}}$ is greater than $\text{TIME}_{\text{operating_days}}$, the days of release should equal days of operation, and the average daily release can be estimated using the following equation:

$$\begin{aligned}
E_{\text{local container_residue_disp}} &= Q_{\text{chem_site_day}} \times F_{\text{container_residue}} \\
&= 676 \frac{\text{kg}}{\text{site-day}} \times \frac{0.01 \text{ kg chemical remaining}}{\text{kg shipped}} \\
&= 6.76 \text{ kg/site-day}
\end{aligned}$$

...over 148 days/year from 1 site.

Containers are likely to be disposed of as solid waste (OECD, 2009; EC, 2007). Typical industrial container handling may include rinsing the container with water or solvent prior to disposal. The residual wash is then released to water or incineration. Therefore, the container residue loss should conservatively be assessed as released to water, incineration, or landfill.

6.2.4 Release to Air, Landfill, or Water from Dust Emissions during Blending/Compounding (Release 4)

$$\begin{aligned} E_{\text{local}}_{\text{fugitive_dust_emissions}} &= Q_{\text{chem_site_day}} \times F_{\text{fugitive_dust_emissions}} \\ &= 676 \frac{\text{kg}}{\text{site-day}} \times \frac{0.0005 \text{ kg released}}{\text{kg blended/compounded}} \\ &= 0.338 \text{ kg/site-day} \end{aligned}$$

...over 148 days/year from 1 site.

Fugitive dust emissions are originally lost to air, which may result in the dust settling to facility floors and being disposed of when floors are cleaned. The settled dust may be released to landfill for dusts captured within vacuum cleaner bags and filters (GS, 2009; OECD, 2009). Additionally, the particles can undergo subsequent condensation upon release, resulting in losses to water. EPA recommends conservatively assessing releases to air, landfill, or water.

6.2.5 Release to Air or Water from Fugitive Emissions during Blending/Compounding (Release 5)

$$E_{\text{local}}_{\text{fugitive_emissions}} = Q_{\text{chem_site_day}} \times F_{\text{fugitive_emissions}}$$

Per OECD 2009, fugitive air emissions result in a 50% release to water and 50% release to air.

$$\begin{aligned} E_{\text{local}}_{\text{fugitive_emissions_air}} &= 676 \frac{\text{kg}}{\text{site-day}} \times \frac{0.0005 \text{ kg released}}{\text{kg blended/compounded}} \times 0.5 \\ &= 0.169 \text{ kg/site-day released to air} \end{aligned}$$

$$\begin{aligned} E_{\text{local}}_{\text{fugitive_emissions_water}} &= 676 \frac{\text{kg}}{\text{site-day}} \times \frac{0.0005 \text{ kg released}}{\text{kg blended/compounded}} \times 0.5 \\ &= 0.169 \text{ kg/site-day released to water} \end{aligned}$$

...over 148 days/year from 1 site.

Fugitive emissions are originally lost to air, but subsequent condensation may result in losses to water. Therefore, EPA recommends assuming fugitive air emissions from blending/compounding processes are released to water or air.

6.2.6 Release to Water, Landfill, or Incineration from Equipment Cleaning Residue (Release 6)

$$\begin{aligned} E_{\text{local}_{\text{equipment_cleaning}}} &= Q_{\text{chem_site_day}} \times F_{\text{equipment_cleaning}} \\ &= 676 \frac{\text{kg}}{\text{site - day}} \times \frac{0.02 \text{ kg released}}{\text{kg batch holding capacity}} \\ &= 13.5 \text{ kg/site - day} \end{aligned}$$

...over 148 days/year from 1 site.

Water is primarily used for cooling equipment and cleaning purposes onsite and therefore water releases are expected (OECD, 2009). Equipment may be rinsed with water or organic solvent resulting in equipment residue potentially being released to water, incineration, or landfill. EPA recommends assessing equipment cleaning releases to water, incineration, or landfill.

6.3 Occupational Exposures

6.3.1 Total Number of Workers Potentially Exposed to the Chemical

It is assumed that 24 workers are potentially exposed to the chemical of interest at each site, per Section 5.2; therefore, the total number of workers is calculated as:

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

Note that all 48 workers are assumed to be exposed during each of the exposure activities performed at the 2 compounding sites.

6.3.2 Exposure from Unloading and Transferring Additives (Exposure A)

Inhalation Exposure:

The potential worker exposure to the chemical of interest is calculated using the *OSHA Total PNOR PEL-Limiting Model* or the *EPA/OPPT Small Volume Solids Handling Inhalation Model*. To determine the appropriate model to estimate exposure from unloading and transferring activities, the use of the additive containing the chemical of interest per site day must be calculated.

$$\begin{aligned} Q_{\text{additive_site_day}} &= \frac{Q_{\text{chem_site_day}}}{F_{\text{chem_additive}}} \\ &= 676 \frac{\text{kg chemical}}{\text{site - day}} \Big/ 1 \frac{\text{kg chemical}}{\text{kg additive}} \\ &= 676 \text{ kg additive/site - day} \end{aligned}$$

Since the daily amount of solid additives containing the chemical of interest ($Q_{\text{additive_site_day}}$) is *greater than* 54 kg/site-day; use the *OSHA Total PNOR PEL-Limiting Model*:

$$\begin{aligned} \text{EXP}_{\text{inhalation}} &= C_{\text{particulate}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \times F_{\text{chem_additive}} \\ &= 15 \frac{\text{mg}}{\text{m}^3} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} \times 1.25 \frac{\text{m}^3}{\text{hr}} \times 8 \frac{\text{hr}}{\text{day}} \times 1 \frac{\text{kg chemical}}{\text{kg additive}} \\ &= 0.00015 \frac{\text{kg chemical}}{\text{day}} \end{aligned}$$

...over 148 days/year

Dermal Exposure:

Since the chemical of interest is a solid, dermal exposure during unloading is calculated using the following equation:

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= \text{up to } 3,100 \text{ mg additive/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \\ &= \text{up to } 3,100 \text{ mg additive/incident} \times \frac{1 \text{ kg additive}}{10^6 \text{ mg additive}} \times 1 \frac{\text{incident}}{\text{day}} \times 1 \frac{\text{kg chemical}}{\text{kg additive}} \\ &= 0.0031 \frac{\text{kg chemical}}{\text{day}} \end{aligned}$$

...over 148 days/year

6.3.3 Exposure from Container Cleaning (Exposure B)

Inhalation:

The potential worker exposure to the chemical of interest is calculated using the *OSHA Total PNOR PEL-Limiting Model* or the *EPA/OPPT Small Volume Solids Handling Inhalation Model*. To determine the appropriate model to estimate exposure from container cleaning activities, the use of the additive residual containing the chemical of interest handled per site day must be calculated.

$$\begin{aligned} Q_{\text{additive_residue_site_day}} &= \frac{E_{\text{local}}_{\text{container_residue_disp}}}{F_{\text{chem_additive}}} \\ &= \frac{6.76 \text{ kg chemical/site - day}}{1 \text{ kg chemical/kg additive}} \\ &= 6.76 \text{ kg additive/s ite - day} \end{aligned}$$

Since the daily amount of solid additive residuals containing the chemical of interest ($Q_{\text{additive_residue_site_day}}$) is *less than* 54 kg/site-day; use the *EPA/OPPT Small Volume Solids Handling Inhalation Model*, assuming the worst-case value for F_{exposure} (see Section 5.4):

$$\begin{aligned} \text{EXP}_{\text{inhalation}} &= Q_{\text{additive_residue_site_day}} \times F_{\text{chem_additive}} \times F_{\text{exposure}} \\ &= 6.76 \frac{\text{kg additive}}{\text{site - day}} \times \frac{1 \text{ kg chemical}}{\text{kg additive}} \times \frac{0.161 \text{ mg chemical}}{\text{kg chemical handled}} \\ &= 1.09 \text{ mg chemical/s ite - day} \\ &\dots\text{over 148 days/year from 1 site} \end{aligned}$$

Dermal:

Since the chemical of interest is a solid, dermal exposure during cleaning is calculated using the following equation:

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= \text{up to 3,100 mg additive/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \\ &= \text{up to 3,100 mg additive/incident} \times \frac{1 \text{ kg additive}}{10^6 \text{ mg additive}} \times 1 \frac{\text{incident}}{\text{day}} \times 1 \frac{\text{kg chemical}}{\text{kg additive}} \\ &= 0.0031 \frac{\text{kg chemical}}{\text{day}} \\ &\dots\text{over 148 days/year} \end{aligned}$$

6.3.4 Exposure from Equipment Cleaning (Exposure C)

The potential worker exposure to the chemical of interest is calculated using the *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*. EPA assumes the concentration of the additive in the cleaning solution is 50% the concentration of additive in resin (CEB, 2004). Therefore, F_{cleaning} is taken to be the product of $F_{\text{chem_resin}}$ (i.e., 0.07 kg chemical/kg resin) and 0.5 kg resin/kg soln as shown below.

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{cleaning}} \\ &= 2.1 \frac{\text{mg soln}}{\text{cm}^2 - \text{incident}} \times \frac{1 \text{ kg soln}}{10^6 \text{ mg soln}} \times 1,070 \text{ cm}^2 \times 1 \frac{\text{incident}}{\text{day}} \times \left(0.07 \frac{\text{kg chemical}}{\text{kg resin}} \times 0.5 \frac{\text{kg resin}}{\text{kg soln}} \right) \\ &= 0.00008 \text{ kg chemical/day} \\ &\dots\text{over 148 days/year} \end{aligned}$$

6.3.5 Exposure from Loading Plastic Resin Containing Additive (Exposure D)

As discussed in Section 5.6, compounded plastics are transported as pellets, sheets, films or pipes (Kirk-Othmer, 1991), which consist of large particle sizes. Therefore, inhalation exposures during this activity are expected to be negligible. For dermal exposures, although some surface contact may occur, the resulting exposure is non-quantifiable (CEB, 2004) since the additive is incorporated into the plastic resin.

6.3.6 Exposure from Dusts Generated from Compounding Processes (Exposure E)

The potential worker exposure to the chemical of interest is calculated using the *OSHA Total PNOR PEL-Limiting Model*:

$$\begin{aligned} \text{EXP}_{\text{inhalation}} &= C_{\text{particulate}} \times \text{RATE}_{\text{breathing}} \times \text{TIME}_{\text{exposure}} \times F_{\text{chem_resin}} \\ &= 15 \frac{\text{mg}}{\text{m}^3} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} \times 1.25 \frac{\text{m}^3}{\text{hr}} \times 8 \frac{\text{hr}}{\text{day}} \times 0.07 \frac{\text{kg chemical}}{\text{kg resin}} \\ &= 0.00001 \frac{\text{kg chemical}}{\text{day}} \end{aligned}$$

...over 148 days/year

7.0 DATA GAPS/UNCERTAINTIES AND FUTURE WORK

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

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

1. The ESD estimates typical annual facility use rate of plastics additives ($Q_{\text{all_additives_site_yr}}$) by averaging U.S. consumption of plastics additives over the number of compounding sites in the U.S., using market and U.S. Census data, respectively. The quality of the annual facility use rate could be improved with additional, site-specific data on annual use rates (e.g., kg/site-day, kg/site-bt). This would allow the ESD to present low- and high-end estimates, in addition to the typical-case estimate presented in the ESD.
2. Activity-specific data for number of workers exposed were not identified in the literature; therefore, the ESD assumes all workers at a given facility perform each activity. Data on the number of workers associated with each activity would further enhance ESD exposure estimates.
3. Specific input on the reasonableness of the default values used in the general facility estimates (e.g., batch duration, number of operating days per year) would enhance the quality of the calculations.
4. Industry-specific monitoring data for operations involving dusts emissions would enhance estimates for vented or fugitive dust releases and associated worker inhalation exposures.
5. Industry-specific dermal monitoring data for all operations involving workers handling plastics additives would enhance dermal exposure estimates.

8.0 REFERENCES

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Appendix A

ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES

Summary of Release and Exposure Estimation Equations for Plastics Compounding Sites

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

Table A-1. Plastics Compounding Release and Exposure Calculation Summary

General Facility Estimates	
Mass Fraction of Chemical in the Plastic Resin (F_{chem_resin}):	
$F_{chem_resin} = F_{chem_additive} \times F_{additive_resin} \quad (3-1)$	
Annual Facility Use Rate of the Chemical of Interest ($Q_{chem_site_yr}$):	
$Q_{chem_site_yr} = Q_{all_additives_site_yr} \frac{F_{chem_additive} \times F_{additive_resin}}{F_{all_additives_resin}} \quad (3-2)$	
Daily Facility Use Rate of the Chemical of Interest ($Q_{chem_site_day}$):	
$Q_{chem_site_day} = \frac{Q_{chem_site_yr}}{TIME_{operating_days}} \quad (3-3)$	
Annual Number of Batches ($N_{bt_site_yr}$):	
$N_{bt_site_yr} = TIME_{operating_days} \times N_{chem_bt} \quad (3-4)$	
Number of Sites (N_{sites}):	
$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_site_yr}} \quad (3-5)$	
Number of Transport Containers Unloaded per Site ($N_{containers_unloaded_site_yr}$):	
$N_{container_unloaded_site_yr} = \frac{Q_{chem_site_day} \times TIME_{operating_days}}{F_{chem_additive} \times Q_{container}} \quad (3-6)$	

Release Calculations		
Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Transfer Operations (Dust Emissions)	Air	EPA/OPPT Dust Emissions from Solid Transfers Model (See Section 4.2) $Elocal_{dust_generation} = Q_{chem_site_day} \times F_{dust_generation} \quad (4-1)$...released over [Time _{operating_days}] days/year from [N _{sites}]

Table A-1 (Continued)

Release Calculations		
Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Spillage	Water Incineration Landfill	$E_{\text{local}}_{\text{spillage}} = Q_{\text{chem_site_day}} \times F_{\text{spillage}} \quad (4-2)$ <p align="center">...released over [Time_{operating_days}] days/year from [N_{sites}]</p>
Container Residue (Liquids)	Water Incineration Landfill	<p>If N_{container_unloaded_site_yr} is fewer than TIME_{operating_days}:</p> $E_{\text{local}}_{\text{container_residue_disp}} = V_{\text{container}} \times \text{RHO}_{\text{additive}} \times F_{\text{chem_additive}} \times F_{\text{container_residue}} \times N_{\text{container_unloaded_site_day}} \quad (4-3a)$ <p align="center">...released over [N_{container_unloaded_site_yr}] days/year from [N_{sites}]</p> <p>If N_{container_unloaded_site_yr} is greater than TIME_{operating_days}:</p> $E_{\text{local}}_{\text{container_residue_disp}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}} \quad (4-3b)$ <p align="center">...released over [Time_{operating_days}] days/year from [N_{sites}]</p>
Container Residue (Solids)	Water Incineration Landfill	<p>If N_{container_unloaded_site_yr} is fewer than TIME_{operating_days}:</p> $E_{\text{local}}_{\text{container_residue_disp}} = Q_{\text{container}} \times F_{\text{chem_additive}} \times F_{\text{container_residue}} \times N_{\text{container_unloaded_site_day}} \quad (4-4a)$ <p align="center">...released over [N_{container_unloaded_site_yr}] days/year from [N_{sites}]</p> <p>If N_{container_unloaded_site_yr} is greater than TIME_{operating_days}:</p> $E_{\text{local}}_{\text{container_residue_disp}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}} \quad (4-4b)$ <p align="center">...released over [Time_{operating_days}] days/year from [N_{sites}]</p>
Blending/ Compounding (Dust Emissions)	Air Landfill Water	$E_{\text{local}}_{\text{fugitive_dust_emissions}} = Q_{\text{chem_site_day}} \times F_{\text{fugitive_dust_emissions}} \quad (4-5)$ <p align="center">...released over [Time_{operating_days}] days/year from [N_{sites}]</p>
Blending/ Compounding (Fugitive Emissions)	Air Water	$E_{\text{local}}_{\text{fugitive_emissions}} = Q_{\text{chem_site_day}} \times F_{\text{fugitive_emissions}} \quad (4-6)$ <p align="center">...released over [Time_{operating_days}] days/year from [N_{sites}]</p> <p>The releases can be partitioned to multi-media:</p> <p align="center">%_{air} = 50 %_{water} = 50</p>

Table A-1 (Continued)

Release Calculations		
Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Equipment Cleaning	Water Landfill Incineration	<p>If $N_{bt_site_yr}$ is fewer than $TIME_{operating_days}$:</p> $E_{local_equipment_cleaning} = Q_{chem_bt} \times F_{chem_resin} \times N_{bt_site_day} \times F_{equipment_cleaning} \quad (4-7a)$ <p>...released over $[N_{bt_site_yr}]$ days/year from $[N_{sites}]$</p>
		<p>If $N_{bt_site_yr}$ is greater than $TIME_{operating_days}$:</p> $E_{local_equipment_cleaning} = Q_{chem_site_day} \times F_{equipment_cleaning} \quad (4-7b)$ <p>...released over $[Time_{operating_days}]$ days/year from $[N_{sites}]$</p>

Occupational Exposure Calculations
<p>Number of Workers Exposed Per Site: See Section 5.2.</p>
<p>Exposures from Unloading and Transferring Solid Additives:</p> <p><i>Inhalation:</i></p> <p>The daily transfer rate of the additive containing the chemical of interest may be estimated using the following equation:</p> $Q_{additive_site_day} = \frac{Q_{chem_site_day}}{F_{chem_additive}} \quad (5-1)$ <p>If $Q_{additive_site_day}$ is greater than 54 kg/site-day: OSHA Total PNOR PEL-Limiting Model (See Section 5.3)</p> <p>If $Q_{additive_site_day}$ is less than or equal to 54 kg/site-day: EPA/OPPT Small Volume Handling Inhalation Model (See Section 5.3)</p> <p><i>Dermal:</i></p> $EXP_{dermal} = \text{up to 3,100 mg additive/incident} \times N_{exp_incident} \times F_{chem_additive} \quad (5-3b)$ <p>... over the lesser of $N_{bt_site_yr}$ or $TIME_{operating_days}$.</p>
<p>Exposures from Unloading and Transferring Liquid Additives:</p> <p><i>Dermal:</i></p> $EXP_{dermal} = Q_{liquid_skin} \times AREA_{surface} \times N_{exp_incident} \times F_{chem_additive} \quad (5-3a)$ <p>... over the lesser of $N_{bt_site_yr}$ or $TIME_{operating_days}$</p>

Table A-1 (Continued)

Occupational Exposure Calculations	
Exposure from Container Cleaning (Solid Additives):	
<i>Inhalation:</i>	
The amount of additive residual containing the chemical of interest handled by a worker during container cleaning may be estimated using the following equation:	
$Q_{\text{additive_residue_site_day}} = \frac{E_{\text{local}}_{\text{container_residue_disp}}}{F_{\text{chem_additive}}} \quad (5-4)$	
If $Q_{\text{additive_residue_site_day}}$ is greater than 54 kg/site-day:	
OSHA Total PNOR PEL-Limiting Model (See Section 5.4)	
If $Q_{\text{additive_residue_site_day}}$ is less than or equal to 54 kg/site-day:	
EPA/OPPT Small Volume Handling Inhalation Model (See Section 5.4)	
<i>Dermal:</i>	
$\text{EXP}_{\text{dermal}} = \text{up to } 3,100 \text{ mg additive/incident} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad (5-6b)$ <p align="center">... over the lesser of $N_{\text{container_unloaded_site_yr}}$ or $\text{TIME}_{\text{operating_days}}$.</p>	
Exposure from Container Cleaning (Liquid Additives):	
<i>Dermal:</i>	
$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_additive}} \quad (5-6a)$ <p align="center">... over the lesser of $N_{\text{container_unloaded_site_yr}}$ or $\text{TIME}_{\text{operating_days}}$.</p>	
Exposure from Equipment Cleaning:	
<i>Dermal:</i>	
$\text{EXP}_{\text{dermal}} = Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{cleaning}} \quad (5-7)$	
Exposure from Dusts Generated from Compounding Processes:	
<i>Inhalation:</i>	
OSHA Total PNOR PEL-Limiting Model (See Section 5.7)	

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

Variable	Variable Description	Default Value	Data Source
AREA _{surface}	Surface area of contact (cm ²)	1,070 (2 hands) 535 (1 hand)	CEB, 2013
C _{particulate}	Mass concentration of particulate in air (mg/m ³)	15	OSHA
F _{chem_additive}	Mass fraction of the chemical of interest in the plastics additive (kg chemical/kg additive)	1	EPA assumption
F _{additive_resin}	Mass fraction of the plastics additive containing chemical of interest in the plastic resin (kg additive/kg resin)	0.55 kg additive/kg resin (release concerns only), 0.0005 kg additive/kg resin (exposure concerns only), or 0.07 kg additive/kg resin (both concerns)	EPA assumption. See Section 3.5.
F _{all_additives_resin}	Mass fraction of all additives in the plastic resin (kg all additives/kg resin)	0.62 kg all additives/kg resin (release concerns only), 0.90 kg all additives/kg resin (exposure concerns only), or 0.46 kg all additives/kg resin (both concerns)	EPA assumption. See Section 3.7.
F _{dust_generation}	Fraction of the chemical of interest lost during transfers/unloading of solid powders (kg chemical released/kg handled)	0.005	EPA assumption
F _{spillage}	Fraction of the chemical of interest lost during transfers/unloading of liquids (kg chemical released/kg handled)	0.0001	EU, 2002
F _{container_residue}	Fraction of the chemical of interest remaining in the container as residue (kg chemical remaining/kg additive)	solids, 0.01 liquids, 0.03	CEB, 2002
F _{fugitive_dust_emissions}	Fraction of the chemical of interest lost during blending/compounding operations (kg chemical released/kg blended)	0.0005	OECD, 2009
F _{fugitive_emissions}	Fraction of the chemical of interest lost during blending/compounding operations (kg chemical released/kg blended)	0.0005	OECD, 2009
F _{equipment_cleaning}	Fraction of polymer resin containing the chemical of interest released as residual in process equipment	0.02	CEB, 1992
F _{exposure}	Weight fraction of the total particulate in the worker breathing zone (mg chemical/kg chemical handled)	0.0477 (typical) 0.161 (worst)	CEB, 1992
F _{cleaning}	Fraction of chemical of interest in the cleaning solution (kg resin/kg solution)	0.5	CEB, 2004
N _{exp_incident}	Number of exposure incidents per day (incidents/day)	1	CEB, 2000
Q _{all_additives_site_yr}	Annual facility use rate of plastics additives (kg all additives/site-yr)	3,126,068	U.S. Census and industry data. See Section 3.3.

Table A-2 (Continued)

Variable	Variable Description	Default Value	Data Source
$Q_{\text{liquid_skin}}$	Quantity of liquid component or product remaining on skin (mg/cm ² -incident)	0.7 - 2.1 (dermal contact)	CEB, 2000
$\text{RATE}_{\text{breathing}}$	Typical worker breathing rate (m ³ /hr)	1.25	CEB, 1991a
$\text{RHO}_{\text{formulation}}$	Density of the adhesive formulation (kg/L)	1	EPA assumption
$\text{TIME}_{\text{exposure}}$	Duration of exposure (hrs/day)	8	EPA assumption
$\text{TIME}_{\text{operating_days}}$	Annual number of days the plastic resin is compounded at each facility (days/yr)	148	PMN data. See Section 3.2.

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: Dust Emissions from Transferring Solids Model;
- Section B.3: Container Residue Release Models (non-air);
- Section B.4: Process Equipment Residue Release Models (non-air);
- Section B.5: Particle Inhalation Exposure Models; and
- Section B.6: Dermal Exposure Models.

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

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

www.epa.gov/oppt/exposure/pubs/chemsteerdl.htm

B.2. DUST GENERATION

Model Description and Rationale:

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).

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-1 provides estimated efficiencies for common control technologies.

Table B-1. 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

Control Technology	Default Control Technology Capture Efficiency (%)	Notes/Source	Default Media of Release for Controlled Release
Scrubber	Varies 95 may be assumed	Consult Table 7-1 of the CEB Engineering Manual.	Water

Model Equation:

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

$$E_{\text{local}_{\text{dust_fugitive}}} = Q_{\text{transferred}} \times F_{\text{dust_generation}} \times (1 - F_{\text{dust_control}}) \quad (\text{B-1})$$

Where:

$E_{\text{local}_{\text{dust_fugitive}}}$	=	Daily amount not captured by control technology from transfers or unloading (kg/site-day)
$Q_{\text{transferred}}$	=	Quantity of chemical transferred per day (kg chemical/site-day)
$F_{\text{dust_generation}}$	=	Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$F_{\text{dust_control}}$	=	Control technology capture efficiency (kg captured/kg processed) (Default: If the control technology is unknown, assume capture efficiency = 0 kg captured/kg processed, see Table B-7).

The following equation estimates the portion of dust release captured by the control technology. The default media of release for this material should be selected based on the information presented in Table B-1.

$$E_{\text{local}_{\text{dust_captured}}} = Q_{\text{transferred}} \times F_{\text{dust_generation}} \times F_{\text{dust_control}} \quad (\text{B-2})$$

Where:

$E_{\text{local}_{\text{dust_captured}}}$	=	Daily amount captured by control technology from transfers or unloading (kg/site-day)
$Q_{\text{transferred}}$	=	Quantity of chemical transferred per day (kg chemical/site-day)
$F_{\text{dust_generation}}$	=	Loss fraction of chemical during transfer/unloading of solid powders (Default: 0.005 kg released/kg handled)
$F_{\text{dust_control}}$	=	Control technology capture efficiency (kg captured/kg processed) (Default: If the control

technology is unknown, assume capture efficiency = 0 kg captured/kg processed, see Table B-1).

References:

U.S. EPA. Chemical Engineering Branch. "Generic Model to Estimate Dust Releases from Transfer/Unloading Operations of Solid Powders". November 2006.

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

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

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

Model Description and Rationale:

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

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

Model Equation:

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

$$E_{\text{local}_{\text{container_residue_disp}}} = F_{\text{container_residue}} \times Q_{\text{total_daily_container}} \quad (\text{Eqn. B-3})$$

Where:

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

$F_{\text{container_residue}}$ = Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table B-2 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-3 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-2 and Table B-3. 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-3 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-2. 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-3. 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:

$$E_{\text{local}_{\text{equip_cleaning}}} = F_{\text{equip_residue}} \times Q_{\text{total_chem_capacity}} \quad (\text{Eqn. B-4})$$

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-4 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-5 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-4 and Table B-5. 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-5 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-4. 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>	Conservative: 0.01 (for <u>pumping</u> process materials from the vessel) *Alternative defaults: Central Tendency: 0.0007 High End to Bounding: 0.002 (alternative defaults for <u>gravity-draining</u> materials from the vessel)
<i>EPA/OPPT Multiple Process Vessel Residual Model</i>	Conservative: 0.02

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

Table B-5. Standard EPA Methodology for Calculating Default Q_{equip_chem_capacity} and TIME_{days equip_residue} Values for Use in the Process Equipment Residual Models

Process Type	Number of Batches per Day	Q _{equip_chem_capacity} (kg/site-day)	TIME _{days equip_residue} (days/year)
Batch	1 or more	(Mass quantity of chemical in each batch (kg/batch)) × (Number of batches run per day)	Total number of operating days for the facility/operation
	Less than 1	Mass quantity of chemical in each batch (kg/batch)	Total number of batches run per site-year
Continuous	Not applicable	Daily quantity of the chemical processed in the equipment (kg/site-day)	Total number of operating days for the facility/operation

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

B.5. 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.5.1 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*⁹ (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

⁹Worker 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).

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:

$$EXP_{\text{inhalation}} = (Q_{\text{shift_handled}} \times N_{\text{shifts}}) \times F_{\text{chem}} \times F_{\text{exposure}} \quad (\text{B-5})$$

Where:

- $EXP_{\text{inhalation}}$ = 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-6 for appropriate EPA default values; must be ≤ 54 kg/worker-shift for this model to be valid)
- N_{shifts}^{10} = 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))

¹⁰Note that this value is the number of shifts worked by *each worker* per day. This value would only be greater than one if a worker worked for over eight hours in a given day.

Table B-6. Standard EPA Default Values for $Q_{\text{daily_handled}}$ in the EPA/OPPT Small Volume Solids Handling Inhalation Model

Activity Type	Default $Q_{\text{shift_handled}}$ ¹¹ (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: Batch process (<1 batch per day): Batch process (>1 batch per day):	Daily throughput of material / Number of shifts per day Quantity of material per batch 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 Division¹². *Textile Dye Weighing Monitoring Study*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington D.C., EPA 560/5-90-009. April 1990.

B.5.2 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

¹¹The 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 $Q_{\text{daily_handled}}$.

¹²Note: This reference is currently available for viewing in the ChemSTEER Help System.

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*¹³. As stated in Section B.5.1, 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-6 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:

$$C_{\text{chem_mass}} = C_{\text{total_mass}} \times F_{\text{chem}} \quad (\text{B-6})$$

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)

The *OSHA Total PNOR PEL-Limiting Model* then uses the mass airborne concentration of the chemical ($C_{\text{mass_chem}}$) in Equation B-6, to calculate the inhalation exposure to the particulate chemical using the following equation:

¹³Worker 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).

$$EXP_{\text{inhalation}} = C_{\text{chem_mass}} \times RATE_{\text{breathing}} \times TIME_{\text{exposure}} \quad (\text{B-7})$$

Where:

$EXP_{\text{inhalation}}$	=	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-7)
$RATE_{\text{breathing}}$	=	Typical worker breathing rate (EPA default = 1.25 m ³ /hr)
$TIME_{\text{exposure}}$	=	Duration of exposure for the activity (EPA default = 8 hours/worker-day ¹⁴)

References:

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

B.6. 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:

¹⁴Since 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.

$$EXP_{\text{dermal}} = AREA_{\text{surface}} \times Q_{\text{remain_skin}} \times F_{\text{chem}} \times N_{\text{event}} \quad (\text{Eqn. B-8})$$

Where:

EXP_{dermal}	=	Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)
$AREA_{\text{surface}}$	=	Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm ² ; see Table B-7 for appropriate EPA default values)
$Q_{\text{remain_skin}}$	=	Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm ² -event; see Table B-7 for appropriate EPA default values)
F_{chem}	=	Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
N_{event}^{15}	=	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-7. 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-8 summarizes these categories and the resulting qualitative dermal exposure assessments.

References:

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

¹⁵ Only one contact per day ($N_{\text{event}} = 1$ event/worker-day) is assumed because $Q_{\text{remain_skin}}$, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (i.e., wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

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-7. Standard EPA Default Values for Use in the Worker Dermal Exposure Models

Default Model	Example Activities	AREA _{surface} ^a (cm ²)	Q _{remain_skin} ^b (mg/cm ² - event)	Resulting Contact AREA _{surface} × Q _{remain_skin} (mg/event)
Physical Form: Liquids				
<i>EPA/OPPT 1-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> Liquid sampling activities Ladling liquid/bench-scale liquid transfer 	535 (1 hand mean)	Low: 0.7 High: 2.1	< 1,100
<i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> Maintenance Manual cleaning of equipment and containers Filling drum with liquid Connecting transfer line 	1070 (2 hand mean)	Low: 0.7 High: 2.1	< 2,200
<i>EPA/OPPT 2-Hand Dermal Immersion in Liquid Model</i>	<ul style="list-style-type: none"> Handling wet surfaces Spray painting 	1070 (2 hand mean)	Low: 1.3 High: 10.3	< 11,000
Physical Form: Solids				
<i>EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model</i>	<ul style="list-style-type: none"> Handling bags of solid materials (closed or empty) 	No defaults	No defaults	< 1,100 ^c
<i>EPA/OPPT 2-Hand Dermal Contact with Solids Model</i>	<ul style="list-style-type: none"> Solid sampling activities Filling/dumping containers of powders, flakes, granules Weighing powder/scooping/mixing (i.e., dye weighing) Cleaning solid residues from process equipment Handling wet or dried material in a filtration and drying process 	No defaults	No defaults	< 3,100 ²³

a - These default values were adopted in the 2013 EPA 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, 2011.

b - These default values were adopted in the 2013 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 2013 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-8. 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.