



Application of Spray Polyurethane Foam
Insulation –
Generic Scenario for Estimating Occupational
Exposures and Environmental Releases
-Draft-

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Purpose and Background

This methodology review draft is intended to provide information on the sources, use patterns, and potential release pathways of chemicals in two-component spray polyurethane foam (SPF) insulation during application at commercial or residential properties. The document presents standard approaches for estimating environmental releases and occupational exposures. This current document is neither complete nor transparent, and is only intended for internal Risk Assessment Division (RAD) review.

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to chemicals during application of SPF insulation by commercial applicators (i.e. contractors). This document covers both volatile and non-volatile chemicals. Some estimates might result in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in real world practice.

The users of this methodology review draft should consider how the information contained in the document applies to the specific scenario being assessed. Where specific information is available, it should be used in lieu of the defaults presented in this document, as appropriate. All input values (default or industry-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and methodology

EPA developed this methodology review draft using relevant data¹ and available information on the SPF insulation industry, including process descriptions, operating information, chemicals usage, waste generation, worker activities, and exposure information. EPA supplemented the data collected with standard models² to develop the environmental release and occupational exposure estimates presented in this draft.

This document is an update to EPA's draft Generic Scenario on the Application of Spray Polyurethane Foam Insulation, dated February 2011. The primary sources of information cited in this draft include industry-specific journal articles, various EPA and other government sources, and the U.S. Census Bureau's Economic Census. Additional information on the sources investigated and the references cited in this document are presented in Section 8.0.

For the purpose of this document, an SPF insulation chemical is defined as a component of the chemical formulation used in the spray application SPF insulation. The SPF insulation chemical formulation is composed of A-side and B-side chemicals. A-side is the primary reagent in forming polyurethane polymers, while B-side is largely composed of polyols with smaller amounts of additives such as surfactants, amine catalysts, blowing agents, flame

¹ Please refer to Section 10.0 for a list of the specific references used in developing this methodology review draft.

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 will be described in Appendix B of the final GS.

retardants, and colorants. Some of these chemicals, such as blowing agents, are frequently volatile, while others, such as surfactants are usually non-volatile. This GS covers environmental releases of and occupational exposures to both volatile and non-volatile chemicals used in SPF insulation.

The methodology review draft covers the application of SPF insulation by commercial applicators, who may apply SPF at commercial or residential properties. It should be noted that this GS does not cover the application of SPF in industrial settings (i.e., at industrial sites that spray apply SPF insulation into molds). The GS does not cover the manufacture and processing (formulation) of the chemicals into SPF insulation formulations prior to end use. An illustration of the scope of this document within the context of the life cycle of the chemical of interest is provided below.

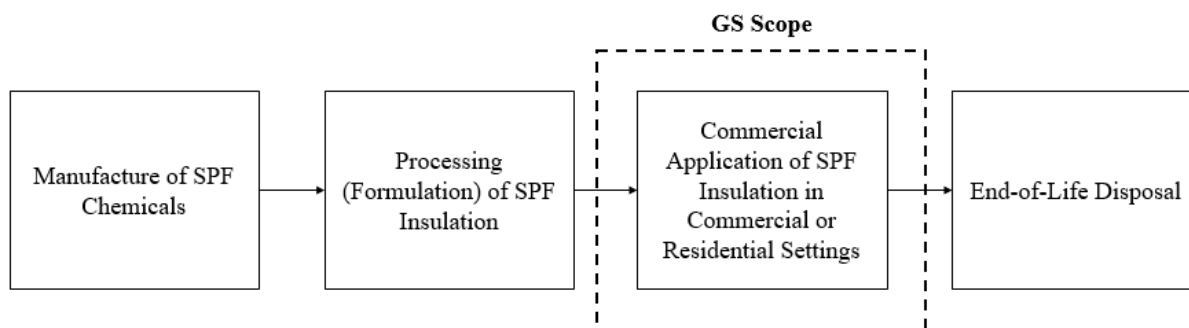


Figure 1-1. Scope of Generic Scenario for the Application of SPF Insulation

The estimation methods presented in this document apply to any volatile or nonvolatile chemical component, regardless of its function in the spray polyurethane foam formulation. If the chemicals are volatile, this document assumes there will be fugitive emissions to air and inhalation exposure to vapor while handling the chemical formulation. Operations involving nonvolatile chemicals are assumed to result in negligible air releases and associated inhalation exposures.

The methods for estimating SPF insulation end-use operating parameters, releases, and exposures include:

- Number of commercial applicators that conduct SPF applications; number of applications per day and per year; use rates for SPF chemicals;
- Volatile chemical releases during the transfer of SPF chemicals from storage containers to application equipment (i.e., spray guns or other applicators) and during equipment cleaning;
- Releases from transport container residues (via container cleaning or direct disposal of empty containers);
- Releases from equipment cleaning;
- Releases of any chemical aerosols or particulates during the application of SPF chemicals onto interior or exterior surfaces and during trimming of the applied SPF chemicals;
- Releases from disposal of trimming waste;

- Number of workers having contact with the SPF chemicals; including applicators and helpers;
- Inhalation and dermal exposures during container unloading and cleaning;
- Inhalation and dermal exposures during spray foam application;
- Inhalation and dermal exposures during foam cutting and trimming;

How this document was developed

The U.S. Environmental Protection Agency (EPA), with support from Eastern Research Group, Inc. (ERG), has developed this Generic Scenario on the application of SPF insulation.

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1.0 INDUSTRY SUMMARY AND BACKGROUND

Spray polyurethane foam (SPF) insulation is commonly used in renovation or new building construction and is made by mixing fast-reacting chemicals that expand on contact to create a continuous stream of foam. This foam is applied to walls, ceilings, roofs and other building structures to provide highly effective insulation from heat, air, and/or moisture.

1.1 Types of Polyurethane Foam

SPF insulation is a type of polyurethane foam. Polyurethane foams may be classified into two general categories (ACC, 2010a). The first category, flexible foams, is primarily used in cushioning. The second category consists of rigid foams, which are primarily used in markets where insulating properties are desired. SPF insulation is a type of foam under the rigid foam category.

SPF can be further classified by density. High-density SPF is a closed-cell foam that is used for exterior wall and roofing applications. Medium-density SPF is a closed-cell foam that is used for interior wall applications. Low-density SPF is an open-cell foam that is also used for interior wall applications; however, this foam has a smaller insulative value than medium-density SPF. All three of these types of SPF foam are included in the scope of this scenario. Figure 1-1 depicts the various categorization of polyurethane foam and the types of SPF in bold text.

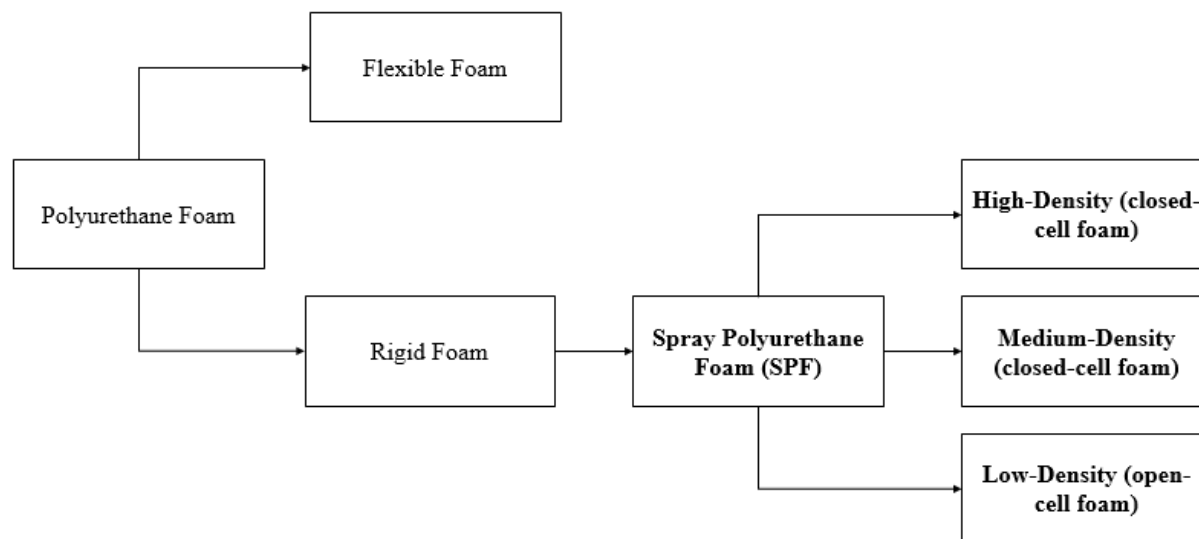


Figure 1-1. Types of Polyurethane Foam

1.2 SPF Chemical Lifecycle

SPF chemicals are manufactured as liquids. After manufacture, these chemicals are formulated into either A-side or B-side formulations, which combine during spray application to form SPF insulation. A-side is the primary reagent in forming polyurethane polymers, while B-

side is largely composed of polyols with smaller amounts of additives such as surfactants, amine catalysts, blowing agents, flame retardants, and colorants.

The properties of the foam produced are determined by the composition of B-side; therefore, catalysts and additives (e.g., flame retardants, surfactants) are typically mixed into the B-side component. Once the sides are formulated, they are packaged separately to prevent reaction. The manufacturing and formulation of SPF chemicals are not included in the scope of this scenario.

The use of SPF, as defined in the scope of this scenario, is the application of the SPF by commercial contractors onto building structures. During SPF application, the A-side and B-side components mix and react, causing the mixture to expand to form a foam that sticks to the surface onto which it is applied.

1.3 Spray Polyurethane Foam (SPF) Chemicals

The following subsections discuss in detail the chemical components of spray polyurethane foam insulation. Table 1-1 section lists out typical chemical compounds and generic weight fractions, organized by chemical function, for both A-side and B-side formulations. The specific weight fraction of compound in the formulation will depend on the type of foam (i.e., open-cell or closed-cell), density of foam, (i.e., low, medium, or high density), and the manufacturer of the SPF formulation.

Table 1-1. A-Side and B-Side Chemical Functions, Typical Compounds, and Weight Fractions

Side	Chemical	Function	Typical Compounds	Typical Composition (wt%) ^a
A	Monomeric diisocyanate	Reagent in forming polyurethane polymers	Methyl diphenyl diisocyanate (MDI)	50%
	Polymeric Diisocyanate	Reagent in forming polyurethane polymers	Polymeric methyl diphenyl diisocyanate (PMDI)	50%
B	Resins	Provides the foam network and strength.	Polyols (largely petroleum-based with some natural oil-based)	35 to 60%
	Flame Retardants	Prevents scorching of the foam due to high temperatures generated by the highly-exothermic polymerization reaction.	Tris(chloropropyl), Resorcinol bis(diphenyl phosphate), Ammonium polyphosphate, Phosphate esters, Melamine, Reactive phosphorus polyols, Tribromoneopentyl alcohol, Tetrabromobenzoate, and Pentabromodiphenyl ether	8 to 25%
	Blowing Agents	Create gases upon application to expand the foam, forming cells within the foam network.	Hydrofluoroolefins (HFOs): HFO-1234ze, HFO-1336mzz(Z) ((Z)-1,1,1,4,4,4-hexafluorobut-2-ene; HFC-245fa; Water	10 to 20%
	Catalysts	Initiates the chain-forming reaction in which the polyols form the polyurethane foam.	Tertiary amines, Diethyltoluenediamine, Isophorone diamine, and metal catalysts (uncommon)	3 to 10% (common) <0.15% (metal)

Table 1-1. A-Side and B-Side Chemical Functions, Typical Compounds, and Weight Fractions

Side	Chemical	Function	Typical Compounds	Typical Composition (wt%) ^a
	Surfactants	Acts as contact agent for the A-side and B-side chemicals to ensure reaction between the two; Modify foam properties such as cell structure, surface texture, and pinhole density.	Silicone	0.5 to 2%

a – (SPFA, 2013)

1.3.1 A-Side Chemicals

A-side is typically composed of a mixture of diisocyanates. Diisocyanates are a group of low-molecular weight aromatic and aliphatic compounds used as the primary reagent in forming polyurethane polymers. A-side is typically a 50/50 mixture of methyl diphenyl diisocyanate (MDI) and polymeric methyl diphenyl diisocyanate (PMDI), which are considered aromatic diisocyanates (Streicher et al, 1998). The PMDI component is typically comprised of 40-65% MDI monomer, with the remaining portion comprised of a substantial percentage of MDI dimer, a smaller percentage of MDI trimer, and small percentages of higher oligomers of MDI (Streicher et al, 1998; U.S. EPA, 1991).

1.3.2 B-Side Chemicals

The B-side of any SPF product consists of polyols, surfactants, amine catalysts, blowing agents, flame retardants, and colorants. These ingredients are blended to form a polyol resin blend. The composition of these blends varies, depending on the properties desired for the foam product, and is often proprietary.

1.3.2.1 Polyol

Polyols comprise approximately 40-65% by weight of the B-side formulation. The polyol may be derived from either petroleum- or bio-based feedstocks, such as soy. They are typically large alcohol-type molecules with multiple hydroxyl functional groups.³ The main use of polymeric polyols is as reactants to make other polymers. Various blends (or mixtures) of polyols are used to react with diisocyanates in the A-side in a chain reaction to form the polyurethane foam.

1.3.2.2 Flame Retardants

Flame retardants comprise approximately 10-20% by weight of the B-side formulation. The main manufacturing concern addressed by the inclusion of flame retardants is

³ A molecule with two hydroxyl groups is a diol, one with three is a triol, one with four is a tetrol and so on.

“scorching,” which occurs when high temperatures are generated by the highly-exothermic polymerization reaction. The selection of a particular flame retardant for use in a polyurethane foam product is related to the density of the foam, product specification, and manufacturing concerns. The use of TDI to manufacture foam generates more heat than the use of MDI; thus, scorching is more prevalent in low-density foam manufacturing. Therefore, the use of a higher thermally resistant flame retardant is required for manufacturing low-density foams.

Flame retardants can be incorporated into products as either an additive or reactive ingredient. Additive flame retardants are incorporated into SPF but are not chemically bound. Over time, these additives may migrate out of the foam and into the environment. By contrast, reactive flame retardants are chemically bound to the foam reactants. The bound chemicals do not migrate out of the foam.

1.3.2.3 *Blowing Agents*

Blowing agents comprise approximately 10-20% by weight of the B-side formulation. Blowing agents cause polyurethane foam to expand during reaction. Most blowing agents produce foam expansion through the boiling of the blowing agent within the foam. The gases produced from the boiling expand the foam, forming cells within the foam network. However, some blowing agents cause expansion through the formation of gases upon reaction. For example, water generates carbon dioxide upon reaction with diisocyanates that produces foam expansion through off-gassing.

Chlorofluorocarbons (CFCs) such as CFC-11 were widely used as blowing agents for SPF formulations during the 1980s and 90s. Subsequent regulations to address ozone depletion potential in those decades have banned CFC use and have led to the use of water or hydrochlorofluorocarbons (HCFCs) as the primary blowing agents instead. However, due to their relatively high ozone depletion potential, HCFCs were phased out of production in 2003 and replaced by hydrofluorocarbons (HFCs), which have similar energy performance with smaller ozone depletion potential (Huntsman, 2011). However, because HFCs still have a high global warming potential, they are now being phased out and replaced with hydrofluoroolefins (HFOs), which have a lower global warming potential and no ozone depletion potential.

1.3.2.4 *Catalysts*

Typical catalysts comprise approximately 3-10% by weight of the B-side formulation. Catalysts are usually mixed into the B-side chemical formulation as a blend of catalysts. Catalysts act as the chemical initiator for the chain-forming reaction. Catalysts also modify foam properties such as surface profile and pinhole density. Amine catalysts are most commonly used in SPF applications, with metal catalysts used far less commonly and at a much smaller concentration than the amine catalysts (usually less than 0.15%).

1.3.2.5 *Surfactants*

Surfactants comprise approximately 0-5% by weight of the B-side formulation. Surfactant chemicals are typically mixed with the B-side formulations and act as contact agents for the A-side and B-side chemicals to ensure reaction between the two. Surfactants also modify

foam properties such as cell structure, surface texture, and pinhole density. As a group, chemical hazards from surfactant chemicals vary, depending on the type of surfactant used.

1.4 **Market Profile**

The 2010 American Chemistry Council Center for the Polyurethanes Industry (ACC CPI, 2010) End-Use Market Survey on the Polyurethane Industry identifies a total annual polyurethane production of 4.1 billion pounds (lb), or roughly 1.86 billion kilograms (kg) (ACC CPI, 2010). The total U.S. production of polyurethanes specifically for the building and construction industry was approximately 1,432 million pounds, or 650 million kilograms (kg). Table 1-2 lists all end-use sectors for polyurethane materials, with the proportion of the total polyurethane production volume that is consumed by that sector.

Table 1-2. Polyurethane End-Use Sectors

Sector	Percent of Total Production ^a
Building and Construction	34.6%
Transportation and Marine	18.6%
Furniture and Bedding	17.6%
Machinery and Foundry	7.1%
Appliances	5.5%
Packaging	4.1%
Textiles, Fibers and Apparel	0.9%
Electronics	0.7%
Footwear	0.5%
Other End Use Markets for Polyurethanes	10.3%

a – (ACC CPI, 2010)

2.0 PROCESS DESCRIPTION

SPF application generally occurs at residential and commercial building sites by commercial applicators. Once these sites are prepared for SPF application, the SPF is applied, checked to ensure the appropriate thickness was achieved, allowed to cure, and trimmed to remove any excess SPF insulation that was errantly applied.

2.1 Disposal of Old Insulation

Prior to application, the applicators will remove any old insulation from the application area. For construction of new buildings, there is not any old insulation to be removed prior to application of the new insulation.

The expected service life of insulation is approximately 60 years (SPFA, 2012; UL Environment, 2011). Because of the long service life, it is not expected that the old insulation will contain newer chemical substances.

2.2 Pre-Spraying Activities

Industry information indicates pre-spraying activities include implementing work area restrictions, often including signs, to limit entry into the spray area until the level of airborne concentrations of chemical substances is below the applicable occupational exposure limits (ACC CPI, 2017).

The applicators will then remove any old insulation from the application area and check that the application site is clean, free of contaminants, and dry. The applicators will additionally check certain characteristics of the substrate to be applied, including temperature and moisture level. Finally, operators will check that the application equipment is clean and secured.

For spraying activities occurring in houses and other small buildings, the SPF chemicals are usually housed in a preassembled spray rig in a truck containing other materials and an air supply. This truck is parked near the building in which application will occur and operators run hoses from the spray rig to the application site. These hoses range in length to typically up to 300 feet long.

2.3 SPF Application

During application, A-side and B-side formulations are mixed and aerosolized by spraying through a nozzle under pressure. A fraction of the resulting spray will bond to the desired surface while a portion of the reactants and synthesizing polyurethane will volatilize. The rate and amount of evaporation depends on the temperature of the chemical mixture.

2.3.1 Types of SPF Application Systems

There are generally three different types of SPF application systems: high-pressure two-component systems, low-pressure two-component systems and, one-component systems. High-pressure two-component systems and low-pressure two-component systems are typically

utilized by professionals. One-component foams are typically utilized by both professionals and consumers and consist of a pressurized foam-in-a-can system. This scenario includes high-pressure two-component and low-pressure two-component systems. The environmental release and occupational exposure potential for these systems are assumed to be similar, thus these systems are not differentiated in the methodology presented in this scenario. One-component systems are not included in the scope of this scenario, as the potential for environmental release and occupational exposure is expected to be significantly different than that for the two-component systems. Additionally, one-component systems are primarily utilized by consumers and this document does not assess the use of SPF by consumers. Figure 2-1 depicts SPF application systems and shows the scope of this scenario in a dashed box.

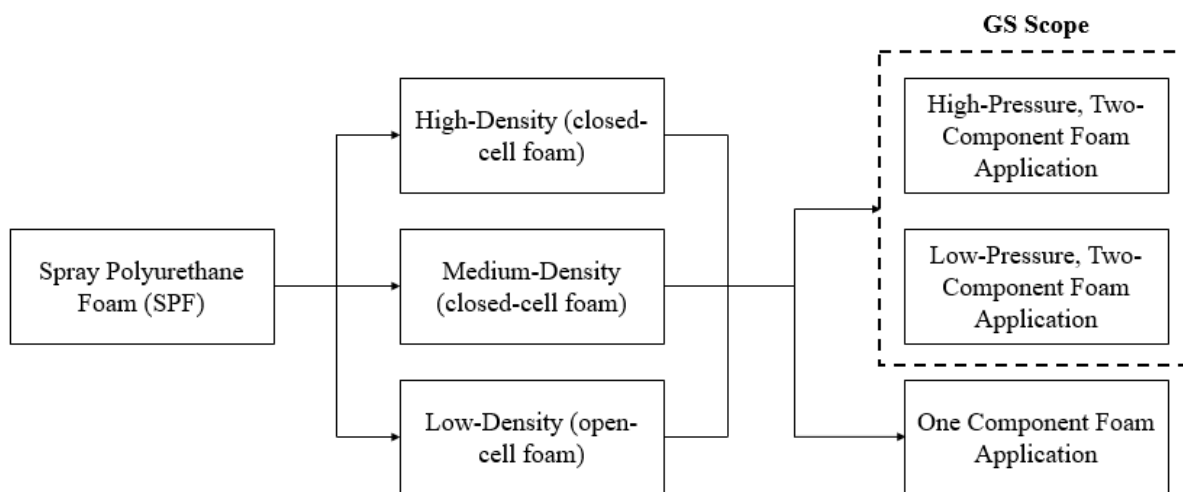


Figure 2-1. Types of SPF Application Systems

For both two-component application systems, the A-side and B-side components are pumped from separate containers through a proportioning and warming unit into a hand-held spray gun, where the components are mixed and react to form the foam. Automated spray systems employ a spray gun to meter out stoichiometric quantities of the A-side and B-side chemicals. Figure 2-2 is a diagram of a typical low-pressure two-component SPF application system. The apparatus used for low-pressure two-component SPF application has similar components as that used for high-pressure two-component SPF application.

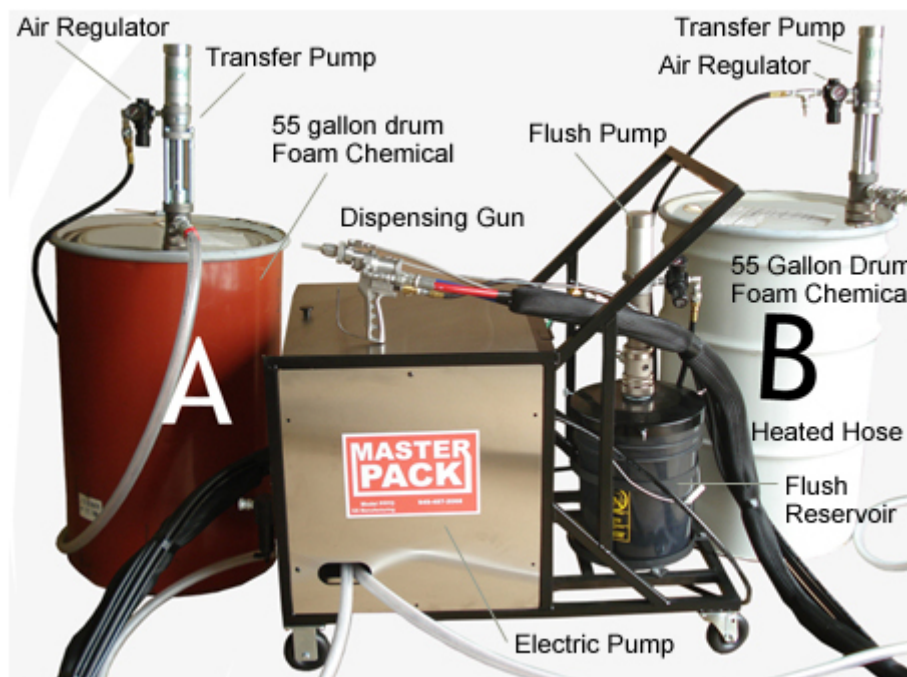


Figure 2-2. Diagram of Low-Pressure Two-Component SPF Application System
(Master Pack Spray Foam Insulation Solutions, 2017)

2.4 Thickness Verification

To check the thickness of the applied foam, applicators typically use nondestructive tools, such as a thin wire probe or depth gauge, to minimize repairs of holes in the foam (ACC SFC, 2012).

2.5 Curing

Upon application of the SPF insulation, the foam immediately begins to cure via chemical reaction at ambient conditions, forming a tack-free state within minutes (ACC CPI, 2016). However, while the surface of the foam may be tack-free, the curing process continues over the next 8 to 24 hours. Typically, SPF is 90% cured within an hour of application. Cure time may be affected by temperature, humidity, and wind conditions.

Curing allows the foam to achieve the optimal physical properties and is not directly related to chemical emissions. During curing, there are unreacted chemicals which present potential exposure routes during trimming or other handling of the applied foam. Even after curing is determined to be completed (i.e., the foam achieves optimal physical properties), certain chemicals may continue to emit from the foam (Bevington et al., 2017).

2.6 Trimming

During SPF application, sufficient foam is applied to allow it to expand to a thickness that sets it at an even plane with the wall studs. Trimming and cutting is conducted shortly thereafter to make the foam flush with the stud faces. Trimming typically occurs shortly after

application because the foam is softer and therefore easier to trim (ACC, 2010). Thus, at the time of trimming, the foam is not expected to be fully cured, leaving potential for occupational exposure.

Closed-cell SPF is rarely trimmed, but when it is, industry information indicates that less than 1% of the applied foam is expected to be trimmed (ACC CPI, 2017). Open-cell SPF is routinely trimmed, with trimmings expected to be less than 5% of total amount of foam applied.

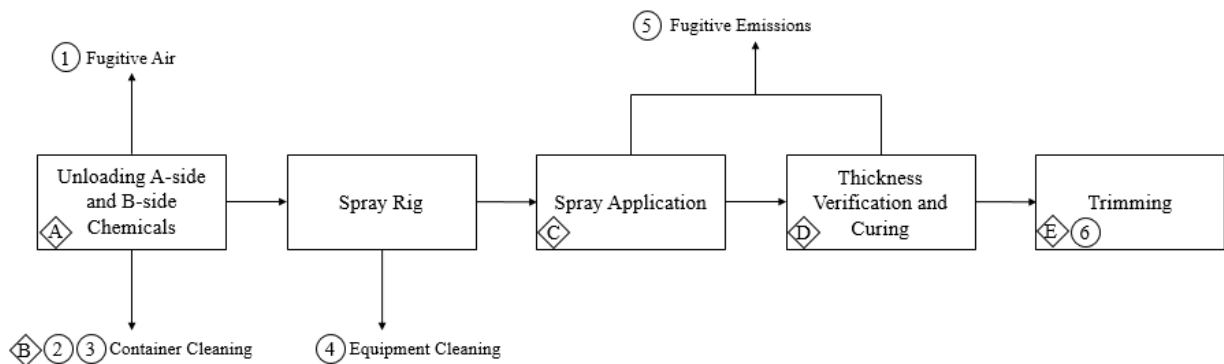
2.7 Cleaning and Maintenance Activities

Empty drums are treated as hazardous waste and are often sent to a professional drum re-conditioner, professional scrap metal recycler, or an approved landfill for disposal (ACC CPI, 2016). Spray gun parts are cleaned by charging them with a cleaning solvent (ACC CPI, 2017). This cleaning solvent may be comprised of solvents such as N-methyl-2-pyrrolidinone and 2(2-butoxyethoxy) ethanol (Spence, 2009). Spray gun parts are cleaned by the equipment operator. The equipment operator also maintains the respirators for the crew and occasionally assists with SPF application.

2.8 Release and Exposure Considerations

Figure 2-3 illustrates the typical release and exposure sources from SPF insulation application by a commercial applicator in a residential or commercial building. The first release comes from removal of old insulation on the application site, if any exists. A release of the chemical of interest will only occur from this activity if that old insulation contains that chemical. Additional releases can occur to air during unloading of the chemical, if the chemical is volatile, from container and equipment cleaning, as well as during the application of the SPF insulation, as the chemicals are aerosolized and sprayed onto the application site. The final expected release is after application, from the disposal of trimmed SPF insulation, if trimming is necessary.

Worker exposure can occur while unloading SPF chemicals into the spray rig equipment, cleaning the transport containers (i.e. disposing residual chemicals), during SPF application, and during trimming of the applied and hardened SPF insulation. Exposure during equipment cleaning is not expected, as the spray equipment is a closed system that is simply flushed with solvent; workers do not come into contact with the inside of the equipment.



Environmental Releases:

1. Release to air from unloading transport containers into spray rig equipment.
2. Release to uncertain media from cleaning of transport containers.
3. Release to air during cleaning of transport containers.
4. Release to uncertain media from cleaning of equipment.
5. Release to fugitive air from volatilization during spraying and curing.
6. Release to landfill from trimming the applied SPF.

Occupational Exposure:

- A. Dermal and inhalation exposure during unloading of transport containers.
- B. Dermal and inhalation exposure during cleaning of transport containers.
- C. Dermal and inhalation exposure during spray application.
- D. Inhalation exposure during foam thickness verification.
- E. Dermal and inhalation exposure during SPF trimming.

Figure 2-3. Typical Release and Exposure Points during the Application of SPF Chemicals

3.0 OVERALL APPROACH AND GENERAL FACILITY ESTIMATES

This document presents a standard approach for estimating environmental releases of and worker exposures to SPF chemicals that are commonly used during the commercial application of spray foam insulation and residential and commercial job sites.

The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible. Where information is not available, EPA's standard approach estimates default values to provide conservative, screening-level release and exposure estimates. It should be noted the default values cited throughout this document are intended to be used only when appropriate site-specific or chemical-specific information is not available.

This section of the methodology review draft presents general application site calculations; concentration of the chemical of interest in the spray polyurethane foam product; throughput of the SPF product containing the chemical of interest; and the number of containers used per site.

Section 4.0 of this document presents environmental release assessments for the application of SPF insulation. This section utilizes the general facility estimates to determine the quantity of chemical released from various points at the application sites and the most likely media of release for each source.

Sections 5.0 of this document presents the occupational exposure assessments. This section uses the general site estimates and release estimates to estimate the number of workers potentially exposed while performing various application activities and the corresponding potential level (quantity) of both inhalation and dermal exposure.

3.1 Introduction to the General Facility Estimates

For the purpose of this scenario, a commercial applicator, or contractor, is a company that professionally applies SPF insulation at commercial and residential job sites. The base location of the commercial applicator is therefore not the location at which environmental releases and occupational exposures are expected to occur. Releases and exposures are likely to occur at the commercial and residential job sites. Therefore, this section develops estimates for determining the number of commercial and residential job sites. For the purpose of this document, the term "facility" and "site" is used interchangeably and is defined as a commercial or residential job site at which a commercial applicator applies SPF insulation.

This section also describes the methods used and the assumptions made to estimate the typical amount of SPF insulation applied at a job site in a given day and the number of transport containers used annually to transfer a potential chemical of interest. The general assessment methodology is depicted in the flow diagram in Figure 3-1.

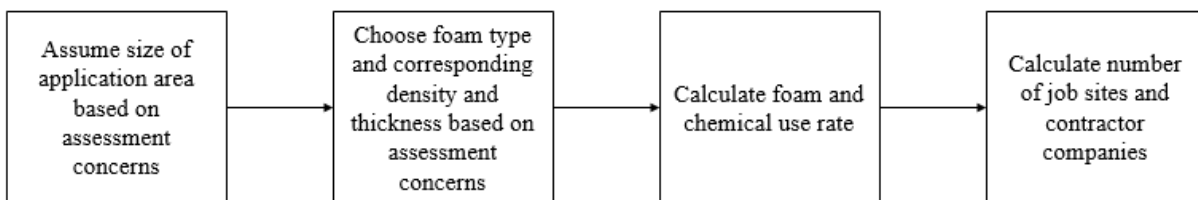


Figure 3-1. Assessment Methodology for General Facility Estimates

Table 3-1 summarizes the general facility estimates and the methodology review draft section in which they are discussed.

Table 3-1. General Facility Parameters

Parameter	Description	Methodology Review Draft Section
$TIME_{operating_days_contractor}$	Number of operating days per year for contractor companies (days/year)	3.2
$TIME_{operating_days_site}$	Number of operating days per year at job sites (days/year)	3.3
A_{app_site}	Surface area applied with foam per site (ft ²)	3.4
ρ_{SPF} and T_{SPF}	Density of SPF insulation (lb/ft ³) and thickness of SPF insulation (ft)	3.5
F_{chem_Side}	Mass fraction of the chemical of interest within the A or B-side formulation (kg chemical/kg formulation)	3.6
F_{Side_SPF}	Mass fraction of formulation within the SPF insulation (kg formulation/kg SPF)	3.7
F_{chem_SPF}	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)	3.8
Q_{SPF_site}	Throughput of SPF per job site (kg foam/site)	3.9
$Q_{chem_site_day}$	Daily throughput of chemical of interest per job site (kg chemical/site-day)	3.10
N_{sites}	Number of job sites at which SPF insulation is applied (sites)	3.11
$N_{contractor}$	Number of contracting companies that perform SPF insulation application (sites)	3.12
$N_{container_unload_site_yr}$	Number of transport containers unloaded annually at each job site (container/site-yr)	3.13

3.2 Days of Operation for Commercial Contractors ($TIME_{operating_days_contractor}$)

Note that this parameter represents the number of operating days for application contractors, who apply SPF at different commercial and residential job sites throughout the year. The number of operating days associated with the job sites is estimated in Section 3.3 below.

The number of operating days associated with commercial contractors can be estimated from employment data obtained through the U.S. Bureau of Labor Statistics Occupational Employment Statistics (OES) survey for residential and commercial construction (US BLS, 2016a and 2016b).

Table 3-2 lists the OES data used to estimate the number of operating days for commercial contractors performing residential and commercial construction. Dividing the average employee annual wage by the mean hourly wage yields an estimated average $TIME_{operating_days_company}$ of 260 days/year for both commercial and residential construction, assuming an eight-hour work day.

Table 3-2. Estimated Annual Operating Days for Commercial Contractors that Apply SPF

NAICS Code	NAICS Description	Average Employee Annual Wage (USD) ^a	Mean Hourly Wage (USD) ^b	Estimated Annual Operating Days ^c
236100	Residential Building Construction	\$50,920	\$24.48	260
236200	Nonresidential (Commercial) Building Construction	\$62,310	\$29.96	260

USD – U.S. Dollars

a – (US BLS, 2013)

b – (US BLS, 2014)

c - Estimated by dividing average employee annual wage by mean hourly wage and an assumed eight-hour work day.

3.3 Days of Operation at Job Sites ($TIME_{operating_days_site}$)

The parameter represents the number of operating days associated with each job site, which include both commercial and residential sites. Job sites are the locations at which SPF insulation is applied and, thus, are the locations at which environmental releases of and occupational exposures to chemical additives in the SPF insulation actually occur.

The amount of time spent at job sites depends on multiple factors, including the amount of foam applied, the length of time needed for the foam to cure, the need for SPF repairs and reapplication, and the length of time needed for the space to be adequately ventilated such that it is safe for re-occupancy. EPA did not find information on the amount of time applicators spend at job sites; however, re-occupancy time is generally at least 24 hours (refer to Section 6.2 for additional information). EPA therefore assumes an estimated default of three days of operation per job site, allowing for two days of application and associated activities (assembly of an enclosure around the application area, foam application, foam trimming, deconstruction of an application enclosure) and one additional day for foam curing and to ensure the site is safe for re-occupancy.

$$TIME_{operating_days_site} = \text{Number of operating days per year at job sites (Default: 3 day)}$$

3.4 Application Area per Job Site (A_{app_site})

This parameter (A_{app_site}) represents the total surface area onto which SPF insulation is applied at one site. EPA's *Exposure Factors Handbook* contains surface area approximations

for typical residential and commercial spaces, such as interior walls and attics (EPA, 2011a). These estimates are summarized in Table 3-3 below.

Table 3-3. Typical Application Surface Areas ^a

Application Location	Surface Area - A_{app_site} (ft²) ^b
Attic – residential or commercial	2,000 – 4,300
Crawl space – residential or commercial	1,300
Interior wall - residential	260 - 430
Interior wall - commercial	390 - 650
Interior walls of one room – residential	1,100
Interior walls of one room – commercial	1,600

a – (EPA, 2011a)

b – Converted from meters squared and rounded to two significant digits.

In lieu of chemical-specific information on the typical application surface area, EPA recommends assuming a default surface area based on the assessment concerns per Figure 3-2. Per Figure 3-2, if assessment concerns are primarily for environmental releases, a default A_{app_site} of the maximum surface area listed in Table 3-3 is recommended to maximize the site throughput of the chemical of interest. If assessment concerns are primarily for occupational exposures, a default A_{app_site} of the minimum surface area listed in Table 3-3 is recommended to minimize the site throughput of the chemical of interest and maximize the number of application sites and number of potentially exposed workers. If assessment concerns are for both environmental releases and occupational exposures, a median estimate for A_{app_site} of 1,560 ft² is recommended, which is an average of the maximum surface areas for the sources listed in Table 3-3.

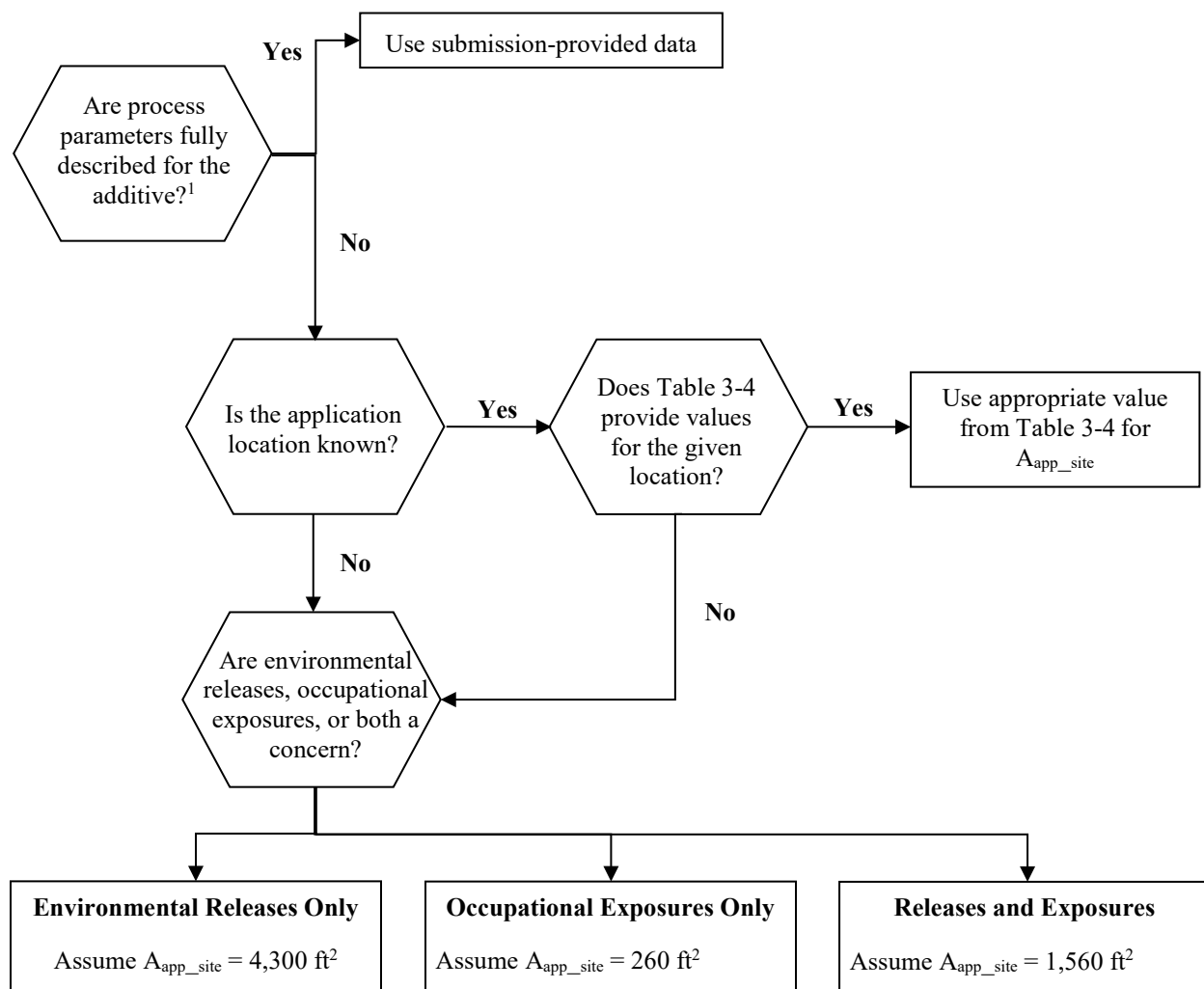


Figure 3-2. Logic Diagram for Selecting Appropriate A_{app_site}

3.5 Density and Thickness of SPF Insulation (ρ_{SPF} and T_{SPF})

The density and thickness of the SPF insulation are dependent on the type of foam being applied. The density of the SPF insulation is an implicit property of the SPF insulation. However, the thickness of the SPF insulation is dependent not only on the type of foam, but also the amount of foam needed to achieve the desired R-value, which represents the degree of insulation. SPF insulation manufacturers often specify a maximum recommended thickness of applied foam to avoid changing the bulk properties of the foam and to avoid thermal degradation during application (Insulation Institute, 2008).

Typical foam densities and application thicknesses are listed in Table 3-4. Note that there may be additional limitations on the thickness per pass of SPF insulation; however, Table 3-4 presents typical values for the maximum total amount of applied foam, from all passes. In lieu of chemical-specific information, EPA recommends assuming a type of foam, and therefore the foam density and thickness, based the assessment concerns. For example, if assessment concerns are only for environmental releases, EPA recommends assuming high-density closed-

cell foam because the density and thickness properties of this foam type will result in the largest daily use rate, and thereby the largest daily release estimates, for the chemical of interest.

Note that the type of foam assumed not only affects the calculation for general facility parameters but also affects the calculations for environmental release and occupational exposure estimates. The type of foam assumed should be consistent for all calculations.

Table 3-4. Typical SPF Insulation Density

Foam Type	Typical Density - ρ_{SPF} (lb/ft³)^a	Typical Maximum Thickness - T_{SPF} (ft)^{b,c}	Assessment Concern Default
High-density, Closed-cell	3	0.33	Default – concerns are for environmental releases
Medium-density, Closed-cell	2	0.33	Default – concerns are for both environmental releases and occupational exposures
Low-density, Open-cell	0.5	0.5	Default – concerns are for occupational exposures

a – (ACC CPI, 2006)

b – (Insulation Institute, 2008)

c – Converted from inches

3.6 Mass Fraction of Chemical of Interest within the A or B-Side Formulation ($F_{\text{chem_Side}}$)

Commercial contractors are expected to purchase A-side and B-side formulations that are ready to use. $F_{\text{chem_Side}}$ represents the mass fraction of the chemical of interest within the received A or B-side formulation. Because the A-side formulation contains two main components, monomeric and polymeric diisocyanates, any chemical substitutes in the A-side formulation is expected to be at a mass fraction of 0.5.

The B-side formulation contains more chemicals with variable compositions. If the mass fraction of the chemical in the B-side formulation is known, refer to Table 1-1 for suitable values default values for $F_{\text{chem_Side}}$. This will require knowledge of how the chemical of interest is used (i.e., its chemical function). If unknown, assume a suitable value for $F_{\text{chem_Side}}$ based on assessment concern(s) using Figure 3-3.

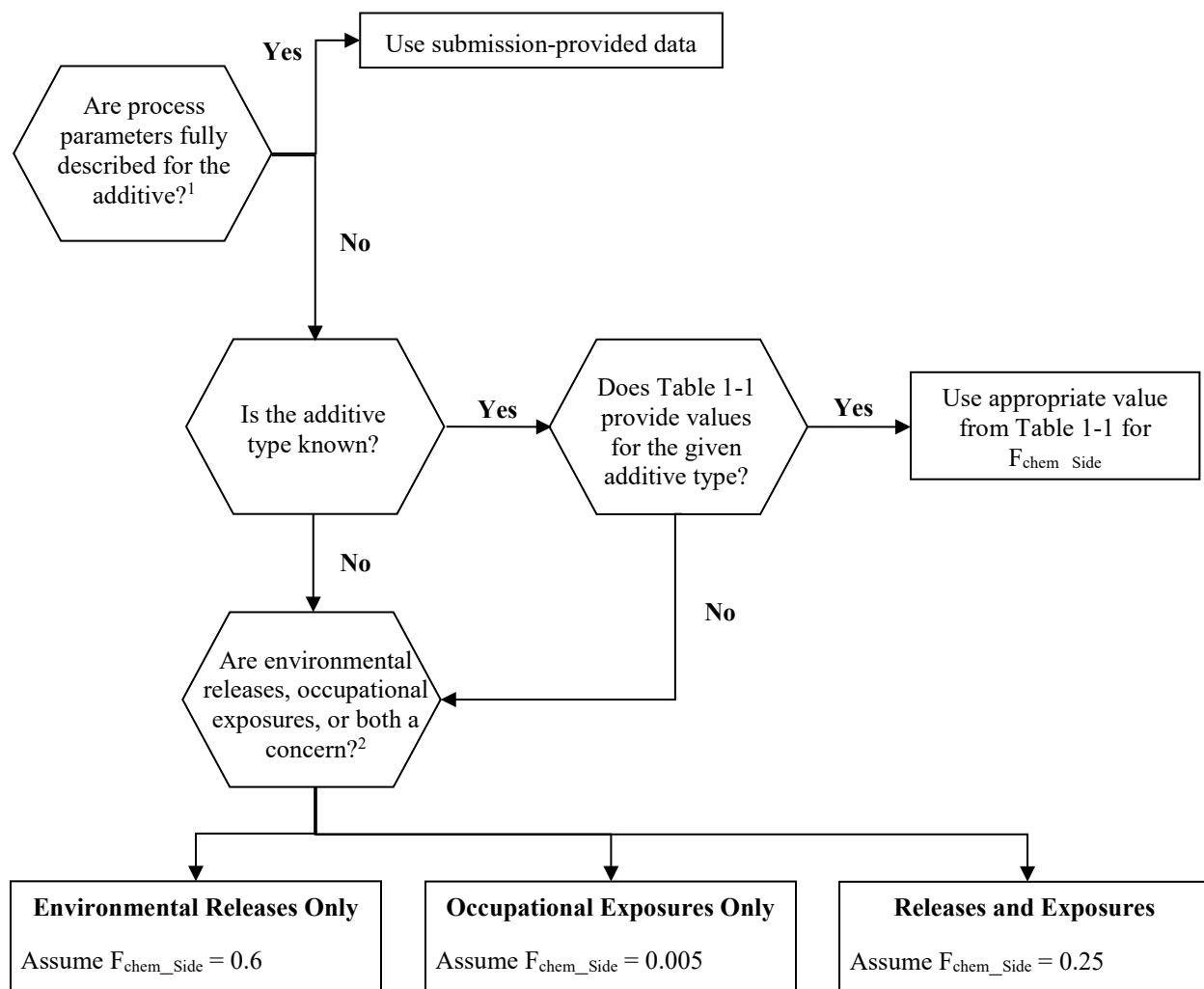


Figure 3-3. Logic Diagram for Selecting Appropriate F_{chem_Side}

Footnotes:

- 1) If the operation is fully described (e.g., additive concentration, number of sites, days of operation), then assessments should use the provided data.
- 2) If the additive type is unknown, assumptions must be made based on assessment concerns. EPA typically uses the following methodology to make conservative assessments:
 - a. Environmental release concerns: for a conservative release assessment, maximize the facility throughput for the chemical of interest by assuming the maximum value from Table 1-1 for F_{chem_Side} .
 - b. Occupational exposure concerns: for a conservative exposure assessment, minimize the facility throughput for the chemical of interest by assuming the minimum value Table 1-1 for F_{chem_Side} . This maximizes the number of use sites and thus maximizes the number of workers.
 - c. Release and exposure concerns: for both, use a median facility throughput for the chemical of interest by assuming a median value from Table 1-1 for F_{chem_Side} .

3.7 Mass Fraction of A or B-Side in SPF (F_{side_SPF})

This value represents the mass fraction of the A or B-side formulation in the SPF insulation. SPF is typically a mixture of equal parts A-side and B-side formulations (SPFA, 2013). Thus, if this fraction is not known, assessment calculations should assume 50 percent as a conservative-case assumption:

$$F_{side_SPF} = \text{Mass fraction of formulation within the SPF insulation (Default: 0.5 kg formulation/kg SPF)}$$

3.8 Mass Fraction of Chemical of Interest within the SPF (F_{chem_SPF})

This value represents the mass fraction of the chemical of interest in the finished SPF insulation, calculated using the following equation:

$$F_{chem_SPF} = F_{chem_side} \times F_{side_SPF} \quad (3-1)$$

Where:

$$\begin{aligned} F_{chem_SPF} &= \text{Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)} \\ F_{chem_Side} &= \text{Mass fraction of chemical of interest in the A or B-side formulation (kg chemical/kg formulation)} \\ F_{side_SPF} &= \text{Mass fraction of formulation within the SPF insulation (Default: 0.5 kg formulation/kg SPF)} \end{aligned}$$

3.9 Use Rate for SPF Insulation per Site (Q_{SPF_site})

The throughput for the SPF insulation per job site is estimated using the following equation:

$$Q_{SPF_site} = A_{app_site} \times \rho_{SPF} \times T_{SPF} \times \frac{1 \text{ kg}}{2.2046 \text{ lb}} \quad (3-2)$$

Where:

$$\begin{aligned} Q_{SPF_site_day} &= \text{Daily throughput of SPF insulation per job site (kg foam/site)} \\ A_{app_site_day} &= \text{Daily surface area applied with foam per site (Defaults: 4,300 ft}^2 \text{ (release concerns only), 260 ft}^2 \text{ (exposure concerns only), or 1,560 ft}^2 \text{ (both concerns))} \\ \rho_{SPF} &= \text{Density of SPF insulation (Defaults: 3 lb/ft}^3 \text{ (release concerns only), 0.5 lb/ft}^3 \text{ (exposure concerns only), or 2 lb/ft}^3 \text{ (both concerns))} \end{aligned}$$

T_{SPF} = Thickness of SPF insulation (Defaults: 0.33 ft (high- or medium- density) or 0.5 ft (low-density))

3.10 Daily Use Rate for the Chemical of Interest per Site ($Q_{chem_site_day}$)

The daily throughput for the chemical of interest per job site is estimated using the following equation:

$$Q_{chem_site_day} = \frac{Q_{SPF_site} \times F_{chem_SPF}}{TIME_{operating_days_site}} \quad (3-3)$$

Where:

$Q_{chem_site_day}$ = Daily throughput of chemical of interest per job site (kg chemical/site-day)
 Q_{SPF_site} = Daily throughput of SPF insulation per job site (kg foam/site)
 F_{chem_SPF} = Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)

$TIME_{operating_days_site}$ = Number of operating days per year at job sites (Default: 3 days)

3.11 Number of Job Sites (N_{sites})

The number of application sites at which SPF insulation is applied is estimated using the following equation:

$$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_site_day} \times TIME_{operating_days_site}} \quad (3-4)$$

Where:

N_{sites} = Number of job sites at which SPF insulation is applied (sites)⁴
 Q_{chem_yr} = Annual production volume of chemical of interest (kg chemical/yr)
 $Q_{chem_site_day}$ = Daily throughput of chemical of interest per job site (kg chemical/site-day)

⁴ The value for N_{sites} should be rounded to the nearest non-zero integer value. Then, to avoid errors due to rounding, $Q_{chem_site_day}$ should be adjusted to reflect the integer value for N_{sites} :

$$Q_{chem_site_day} = \frac{Q_{chem_yr}}{N_{sites}}$$

$TIME_{operating_days_site}$ = Number of operating days per year at job sites (Default: 3 day/year)

3.12 **Number of Contracting Companies ($N_{contractor}$)**

This parameter represents the number of contracting companies that send out workers to conduct SPF insulation application at job sites. The number of contractors is needed to determine the number of workers potentially exposed in Section 5.2. The number of contractors can be determined from the number of job sites by scaling the number of job sites by the days of operation as follows:

$$N_{contractor} = \frac{N_{sites} \times TIME_{operating_days_site}}{TIME_{operating_days_contractor}} \quad (3-5)$$

Where:

$N_{contractor}^5$ = Number of contractor companies that perform SPF insulation (sites)
 N_{sites} = Number of job sites at which SPF insulation is applied (sites)
 $TIME_{operating_days_site}$ = Number of operating days per year at job sites (Default: 3 day/year)
 $TIME_{operating_days_contractor}$ = Number of operating days for contractor companies (Default: 260 days/year)

3.13 **Number of Transport Containers Unloaded per Job Site ($N_{container_unload_site_day}$)**

The number of transport containers unloaded at each job site is estimated using the following equation:

$$N_{container_unload_site_day} = \frac{Q_{chem_site_day}}{F_{chem_side} \times V_{container} \times \rho_{formulation} \times 3.785 \frac{L}{gal}} \quad (3-6)$$

⁵ The value for $N_{contractor}$ should be rounded to the nearest non-zero integer value. Then, to avoid errors due to rounding, $TIME_{operating_days_contractor}$ should be adjusted with the following equation:

$$TIME_{operating_days_contractor} = \frac{N_{sites} \times TIME_{operating_days_site}}{N_{contractor}}$$

Where:

$N_{\text{container_unload_site_day}}$	=	Number of transport containers unloaded at each job site (container/site-day)
$Q_{\text{chem_site_day}}$	=	Daily throughput of chemical of interest per job site (kg chemical/site-day)
$F_{\text{chem_Side}}$	=	Mass fraction of chemical of interest in the A or B-side formulation (kg chemical/kg formulation)
$V_{\text{container}}$	=	Volume of transport container (Default: 208.1 L, equivalent to 55 gal)
$\rho_{\text{formulation}}$	=	Density of chemical formulation (kg/L formulation; Default: 1 kg/L)

4.0 ENVIRONMENTAL RELEASES

This section presents approaches for quantifying environmental releases of volatile and non-volatile SPF chemicals and identifying the most likely media of release (i.e., air, water, incineration, or landfill). The release sources are presented in the order that they occur in the process (see Figure 2-3). Key default values used in the release estimates are provided in Table A-1, Appendix A.

All release equations presented herein estimate daily rates for a given job site, as these are the sites at which release will occur. To estimate annual releases across all job sites from a given release source, the daily release rates must be multiplied by the number of release days ($\text{TIME}_{\text{operating_days_site}}$) and the total number of job sites using the chemical of interest (N_{sites}).

Note that EPA recognizes that some releases may not occur at job sites, and may occur at contractor company locations instead. For example, releases from unloading chemicals from transport containers, cleaning transport containers, and equipment cleaning may all occur at the contractor company location as opposed to the actual job sites. However, in lieu of industry-specific information regarding the location of releases, EPA assumes all releases occur at the actual job sites at which application occurs.

Some process releases are expected to occur 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 release estimation methods presented in this document are based on standard EPA release models. Table 4-1 presents the release sources, the likely media of release, and the models used to estimate the release. Note that the standard model defaults cited are current as of the date of this document; 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, the Chemical Screening Tool for Exposures and Environmental Release (ChemSTEER), containing the standard 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 Release Models Used in the GS

Release Number	Description	Model Name or Description^a	Standard EPA Model (✓)
1	Transfer operation losses to air during unloading	<i>EPA/OAQPS AP-42 Loading Model</i>	✓
2	Container residue losses to water, incineration, or landfill	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 Drum Residual Model</i> • <i>EPA/OPPT Small Container Residual Model</i> 	✓
3	Open surface losses to air during container cleaning	<i>EPA/OPPT Penetration Model</i>	✓
4	Equipment cleaning residue to incineration or landfill	<i>EPA/OPPT Multiple Process Vessel Residual Model</i>	✓
5	Fugitive emissions from applied foam over the first day of application	<i>Loss from this operation is estimated based on readily-available industry specific data</i>	
6	Trimming waste to landfill	<i>Loss from this operation is estimated based on readily-available industry specific data</i>	

EPA – U.S. Environmental Protection Agency

OAQPS – Office of Air Quality Planning and Standards

OPPT – Office of Pollution Prevention and Toxics

^a See Appendix B for additional detailed descriptions of each model.

4.1 Control Technologies

The main engineering controls used by SPF applicators are containment and ventilation. These technologies are described further below.

4.1.1 Work Zone Containment

Before application, a containment or enclosure system, often made up of plastic sheeting that is taped to walls to create a sealed area, is built to isolate the work zone (ACC SFC, 2016). The enclosure prevents airborne chemicals from entering building ventilation systems. The enclosure additionally minimizes the ventilation requirements for the work zone by minimizing the total volume of the work zone and maintaining negative pressure in the work area. To maximize the efficiency of the ventilation system, the enclosures should minimize the size of the enclosure to the smallest floor area and room volume compatible with the operation.

Materials used to construct enclosures generally consist of polyethylene or other plastic sheeting, cardboard, and fiberglass batts. These materials should be installed to maintain negative pressure and block the work zone from other parts of the building. In addition, all finished surfaces, including windows and other furnishings should be masked to prevent overspray. During installation of the enclosure, the heating, ventilation, and air conditioning (HVAC) system should be deactivated and all associated air intakes should be sealed to prevent the potential circulation of airborne chemicals from the work zone to other areas of the building.

4.1.2 Work Zone Ventilation

It is important that the work zone have adequate ventilation to prevent accumulation of chemical vapors and particulate emissions. Negative pressure within the enclosure exhausts the work zone air, which is released at a location outside of the building and away from occupied areas, to prevent potential exposures (ACC SFC, 2016). The exhaust air should also be positioned away from building air inlets. The exhaust outlet should be blocked off to prevent access to the area. The exhaust air system typically includes an exhaust fan and filter within the enclosure and ductwork to convey the exhaust air to the exhaust outlet. A supply air system is needed to make up the air that is exhausted. Make-up air can be provided from an active forced-air inlet system, consisting of a supply fan and ductwork to an inlet, or be provided passively through penetrations in the containment zone. It is important to maintain negative pressure, meaning that the volume of air drawn from the enclosure should exceed the volume pushed into it.

To maintain the efficiency of the ventilation system as the SPF is applied, ventilation systems typically consist of active exhaust and air supply systems (ACC SFC, 2016). This ensures that the enclosure is adequately supplied with make-up air as SPF is applied and seals passive air sources. Some additional considerations are to: maintain air flow across the enclosure, use a larger-capacity exhaust fan and smaller capacity supply fan to maintain negative pressure, use a filter on the exhaust inlet to capture mists and particulates.

4.2 Transfer Operation Losses to Air during Unloading (Release 1)

For non-volatile chemicals (i.e., those chemicals whose vapor pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapor pressures meet or exceed 0.001 torr, releases to air may occur from the displacement of saturated air if the chemical is transferred ($E_{\text{local_unload_air}}$). The standard EPA estimation model for transfer operations, the *EPA/OAQPS AP-42 Loading Model*, may be used to estimate the air release. The transfer operations model provides typical and worst-case estimates for releases and exposures during transfer operations (e.g., transferring liquids from transport containers into spray rigs). Note that some spray rigs pump chemicals directly from the drums in which they are received. In this case, transfer operations are not expected, and this release would be negligible.

Table 4-2 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

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

Input Parameter	Default Values
Saturation Factor	EPA defaults 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (U.S. EPA, 2002b) (See Appendix B for alternative default saturation factors)
Frequency of Release	Equal to the lesser of $TIME_{operating_days_site}$ or $N_{container_unload_site_day}$, See Sections 3.3 and 3.13
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.11
Operating Hours for the Activity	Number of containers per site, per day (see Section 4.3) divided by the unload rate (U.S. EPA, 2002b) (default unload rates are found in Appendix B)
Unloading Rate	EPA default 20 containers/hr for volumes between 20 and 1,000 gallons (U.S. EPA, 1991) (Alternative default unloading rates are found in Appendix B)
Container Volume	Default: 55-gallon drum (208 L) (consistent with Section 3.12)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

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

4.3 Container Residue Losses to Water, Incineration or Landfill (Release 2)

Chemicals used to formulate spray polyurethane foam are expected to be in liquid form. It is expected that a small amount of liquid will remain in the transport container after the container is emptied and the material is charged to the spray rig. The amount of liquid remaining in the container depends on the size of the container.

Industry information indicates that drums are predominately used when shipping A-side and B-side chemicals (ACC CPI, 2017). Transport containers can also include smaller cylinders and cans (ACC SFC, 2012). Therefore, in the absence of information, EPA recommends using the *EPA/OPPT Drum Residual Model* to assess container residue releases. The model applies to any containers having a minimum volume of 20 gallons and assumes liquids are pumped from drums and that up to 3% (a central tendency of 2.5%) of the liquid originally in the drums remains as residual after unloading. Alternative assumptions include 0.6% high-end and 0.3% central tendency when pouring liquids from drums.

It is generally expected that industry makes an effort to minimize container residuals prior to container cleaning or disposal, to reduce costs. Small amounts of unused A-side and B-side chemicals can be reacted to produce foam, which can be disposed of as non-hazardous waste in landfills (ACC SFC, 2012). According to industry information, releases from container cleaning and disposal are thus minimal (ACC CPI, 2017). Drums containing residual SPF chemicals are typically sent to a professional drum re-conditioner, scrap metal recycler, or approved landfill. Given this, EPA recommends conservatively assuming release to water, incineration, or landfill.

The following standard EPA models may be used to estimate residue releases from container cleaning or disposal:

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

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

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.

If the number of containers used per site per year ($N_{\text{container_unload_site_day}}$) is fewer than the days of operation ($\text{TIME}_{\text{operating_days}}$), the days of release equals the number of containers and the daily release is calculated based on the following equation:

$$E_{\text{local_container_residue}} = V_{\text{container}} \times \rho_{\text{formulation}} \times F_{\text{chem_Side}} \times F_{\text{container_disp}} \times N_{\text{container_unload_site_day}} \quad (4-1)$$

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

Where:

$E_{\text{local_container_residue}}$	=	Daily release of chemical from container residue (kg chemical/site-day)
$V_{\text{container}}$	=	Volume of transport container (Default: 208.1 L, equivalent to 55 gal)
$\rho_{\text{formulation}}$	=	Density of chemical formulation (kg/L formulation; Default: 1 kg/L)
$F_{\text{chem_Side}}$	=	Mass fraction of chemical of interest in the A or B-side formulation (kg chemical/kg formulation; See Section 3.6)
$F_{\text{container_disp}}$	=	Fraction of chemical remaining in the container as residue (Default: 0.03 kg container residue/kg formulation supplied in drums)
$N_{\text{container_unload_site_day}}$	=	Number of transport containers unloaded at each job site (container/site-day)

If the number of containers used per site ($N_{\text{container_unload_site_day}}$) is greater than the days of operation, the days of release equal the days of operation, and the average daily release is calculated based on Equation 4-3. Note this may also be used if a container size is not assumed in Equation 4-2 and the number of containers used per site-year is unknown.

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

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

Where:

$E_{\text{local_container_residue}}$	=	Daily release of chemical from container residue (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily throughput of chemical of interest per application establishment (kg chemical/site-day; See Section 3.10)
$F_{\text{container_disp}}$	=	Fraction of chemical remaining in the container as residue (Default: 0.03 kg container residue/kg formulation supplied in drums)

4.4 **Open Surface Losses to Air during Container Cleaning (Release 3)**

For non-volatile chemicals (i.e., those chemicals whose vapor pressures are <0.001 torr), releases to air are expected to be negligible.

For volatile chemicals, whose vapor pressures meet or exceed 0.001 torr, releases to air may occur while empty containers are being rinsed ($E_{\text{local_cont_clean_air}}$). This operation is likely to occur indoors; therefore, the *EPA/OPPT Penetration Model*, EPA's default model for indoor operations may be used to estimate air releases. The model only applies to chemicals whose adjusted vapor pressures do not exceed 35 torr. See Appendix B, Section B.2.1.1 and the articles cited therein for additional discussion of the model and its limitations.

Table 4-3 lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate open surface losses to air during container cleaning. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Table 4-3. *EPA/OPPT Penetration Model* Parameter Default Values During Container Cleaning

Input Parameter	Default Values
Diameter of Opening	EPA default 2 in. (5.08 cm) for all containers less than 5,000 gallons (U.S. EPA, 2002b) (See Appendix B for alternative default diameters)
Frequency of Release	Equal to the lesser of $N_{\text{container_unload_site_day}}$ or $TIME_{\text{operating_days_site}}$, consistent with Section 4.5
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section 3.6
Operating Hours for the Activity	Number of containers per site, per day ($N_{\text{container_unload_site_day}}$, consistent with Release 3) divided by the unload rate (U.S. EPA, 2002b) (Default: 20 containers/hr for volumes between 20 and 1,000 gallons (U.S. EPA, 1991); Alternative default unload rates are found in Appendix B)
Vapor Pressure	Chemical-specific parameter
Air Speed	EPA default 100 feet/min for indoor conditions (U.S. EPA, 1991)
Vapor Pressure Correction Factor	Standard EPA default = 1

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

4.5 Equipment Cleaning Residue to Incineration or Landfill (Release 4)

Spray polyurethane foam chemicals are in contact with multiple application equipment components (e.g., storage tanks, mixing heads, and dispensing equipment). As a default, the amount of residual remaining in process equipment may be estimated using the *EPA/OPPT Multiple Process Vessel Residual Model*, which assumes no more than two percent of the batch size or process capacity is released as a residue during equipment cleaning.

Industry information indicates that equipment cleaning is unlikely occur at the end of each application, and only occurs on an as-needed basis (ACC CPI, 2017). However, specific industry information on the frequency of cleaning is not available. Therefore, this release is conservatively assumed to occur at the end of each day of operation ($TIME_{\text{operating_days_site}}$).

To clean equipment, a chemical solvent is flushed through the equipment before being purged and disposed. Based on this process, there are no open surfaces during equipment cleaning from which chemical can become airborne. Solvent waste is typically disposed of via incineration or landfill. Therefore, this release should be assessed to incineration or landfill.

The following equation can be used to estimate the daily release of a chemical to water or incineration from equipment cleaning.

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

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

Where:

$E_{local_equipment_cleaning}$	=	Daily release of the chemical of interest from equipment cleaning (kg chemical/site-day)
$Q_{chem_site_day}$	=	Daily throughput of chemical of interest per application establishment (kg chemical/site-day; see Section 3.10)
$F_{equipment_cleaning}$	=	Fraction of formulation containing the chemical of interest released as residual in process equipment (Default: 0.02 kg product released/kg holding capacity (CEB, 1992))

4.6 Fugitive Emissions to Air During Application (Release 5)

For non-volatile chemicals (i.e., those chemicals whose vapor pressures are <0.001 torr), releases to air are expected to be negligible. This release estimate represents fugitive emissions of SPF chemicals during the installation of SPF, from the volatilization of chemicals during and after the exothermic reaction that takes place as the SPF is installed. Note that the estimates provided below are for blowing agents, as data is unavailable for other SPF chemical types. Because blowing agents are typically high volatility, these estimates likely over estimate releases of lower volatility chemicals. However, due to lack of additional information, EPA utilizes the data presented below as a conservative worst-case release scenario for all volatile SPF chemical additives.

The loss fractions utilized in this estimate are from the Life Cycle Assessment (LCA) of Spray Polyurethane Foam Insulation conducted by the Spray Polyurethane Foam Alliance (SPFA, 2012). This LCA estimates the loss in mass that happens upon installation of SPF, based on the loss of water that is used as a blowing agent. Specifically, the LCA calculates losses ranging from 2% to 5%, depending on the type of foam, based on the reaction of water with isocyanates that forms carbon dioxide, which is liberated from the foam and released into the air.

The LCA additionally references an additional study titled “A Life Cycle Look at Spray Foam Expansion Agents: A Cradle-to-Grave Analysis” (Johnas et al., 2011) that estimates a 10% release of chemical blowing agents, specifically for HFC-141b, HFC-245a, and FEA-1100. No readily available information was found on the loss of other SPF chemicals (e.g., catalysts and flame retardants) during installation of SPF and relative to foam type. Thus, in lieu of this information, EPA recommends assuming a loss fraction of 2-10% for all SPF components and all foam types. This loss fraction may not be representative of all chemical types and all foam types, but is provided as a conservative estimate.

The release can be calculated with the following equation:

$$E_{local_spray_release} = Q_{chem_site_day} \times F_{spray_release} \quad (4-4)$$

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

Where:

$E_{\text{local_spray_release}}$	=	Daily release of the chemical of interest during spray application (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily throughput of chemical of interest per application establishment (kg chemical/site-day; see Section 3.10)
$F_{\text{spray_release}}$	=	Fraction of formulation containing the chemical of interest released during spray application (Default: 0.02- 0.1 kg product released/kg sprayed)

4.7 **Trimming Waste to Landfill (Release 6)**

Upon installation and curing of the SPF insulation, trimming of the foam is conducted to remove any over sprayed insulation. The amount of waste from trimming depends on the type of foam being trimmed. Open-cell SPF requires more trimming than closed-cell foam. Industry input (ACC CPI, 2017) and the Life Cycle Assessment of Spray Polyurethane Foam Insulation conducted by the Spray Polyurethane Foam Alliance (SPFA, 2012) estimate that trimming of open-cell foam results in a loss fraction of 5 to 8% of the amount sprayed, while trimming of closed-cell foam results in a loss fraction of <1 to 4% of the amount sprayed.

Therefore, if the type of foam is known, EPA recommends conservatively assuming a loss fraction of 8% for open-cell foams and 4% for closed-cell foams for trimming waste. If the type of foam is unknown, EPA recommends assuming a conservative default loss fraction of 8% for trimming waste. Industry information indicates that trimmed foam is considered nonhazardous waste and is disposed of via sanitary landfill (ACC CPI, 2017).

Cutting and trimming operations will generate scraps that are likely to be disposed of as solid waste (Radian, 1984 and OECD, 2009). EPA recommends conservatively assuming that recycling does not occur, and assessing trimming operation releases to landfill or incineration.

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

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

Where:

$E_{\text{local_trimming}}$	=	Daily release of the chemical of interest from trimming operations (kg chemical/site-day)
$Q_{\text{chem_site_day}}$	=	Daily throughput of chemical of interest per application establishment (kg chemical/site-day; see Section 3.10)
F_{trimming}	=	Fraction of the chemical of interest lost during trimming operations (Default: 0.08 kg chemical released/kg trimmed for open-cell and unknown foam types; 0.04 kg chemical released/kg trimmed)

5.0 OCCUPATIONAL EXPOSURES

The following section presents estimation methods for worker exposures to volatile and non-volatile chemicals during the SPF insulation application process. Figure 2-3 illustrates the occupational activities performed within the process that have the greatest potential for worker exposure to chemicals. Table 5-1 summarizes the exposure estimation methods used in this methodology review draft.

Diisocyanates, which are the main component of the A-side formulation, are an occupational health concern because they are known to have caused occupational asthma from inhalation of aerosol mists or vapors and are skin sensitizers. MDI is a hazardous air pollutant (HAP) under the Clean Air Act (CAA) and is known to irritate lungs, skin, and eyes and may cause dermal sensitization or occupational asthma from prolonged exposures (Streicher et al, 1998). Some polyols may be slightly irritating to the eyes and skin; however, most are not (ACC CPI, 2009). Flame retardants are known to irritate lungs, skin, and eyes.

Some amine catalysts and various metal catalysts can be strongly basic. Catalysts may be respiratory irritants and/or irritants to the eyes and skin. Some amine catalysts are skin sensitizers, causing persistent dermatitis and skin problems, and/or are corrosive to the skin (Foster, 2014). If misted or handled at elevated temperatures, high concentration exposures to amine catalysts may occur and may cause respiratory tract irritation. Surfactants can cause slight irritation to eyes, skin, and the respiratory system (ACC CPI, 2016).

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 Exposure Models Used in the GS

Exposure Activity	Description	Route of Exposure and Physical Form	Model Name ^a	Standard EPA Model (✓)
A	Exposure during container unloading	Inhalation of volatile liquid chemical vapors	<i>EPA/OPPT Mass Balance Model</i>	✓
		Dermal exposure to liquid chemical	<i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model</i>	✓
B	Exposure during container cleaning	Inhalation of volatile liquid chemical vapors	<i>EPA/OPPT Mass Balance Model</i>	✓
		Dermal exposure to liquid chemical	<i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model</i>	✓

Exposure Activity	Description	Route of Exposure and Physical Form	Model Name ^a	Standard EPA Model (✓)
C	Exposure during spray application	Inhalation of mist (volatile) from spray coating	Industry data OR <i>OSHA Total PNOR PEL-Limiting Model</i>	✓
		Dermal exposure to liquid chemical	<i>EPA/OPPT 2-Hand Dermal Immersion in Liquid Model</i>	✓
D	Exposure during thickness verification	Inhalation of vapor during thickness verification	Exposure based on industry data	
E	Exposure during trimming	Inhalation of solids from trimming activities	Exposure based on industry data	
		Dermal exposure to solid chemical	<i>EPA/OPPT 2-Hand Dermal Contact with Solids Model</i>	✓

EPA – U.S. Environmental Protection Agency

OAQPS – Office of Air Quality Planning and Standards

OPPT – Office of Pollution Prevention and Toxics

^a See Appendix B for additional detailed descriptions of each model.

5.1 Personal Protective Equipment

Workers should use personal protective equipment (PPE), particularly when working directly with the spray foam. The Alliance for the Polyurethanes Industry (API) offers guidelines for selecting appropriate protective equipment when handling diisocyanates (API, 2001; API, 2002) or polyols. These guidelines include eye protection, respiratory protection, and proper selection of chemical resistant gloves and suits.

In general, appropriate PPE includes chemical-resistant gloves, protective clothing (e.g., long sleeves, body suit, coveralls), eye and face protection (e.g., safety glasses, chemical goggles) and respiratory protection (ACC, 2017b). The level of recommended respiratory protection depends on the type of application and the application system. High pressure, two-component SPF application requires a full-face air purifying or supplied air respirator, while low pressure systems often require an air purifying respirator. The appropriate PPE should be chosen for the specific application, taking into consideration whether the application occurs indoors or outdoors, the level of ventilation, and the components of the SPF formulation.

EPA does not assess the effectiveness of PPE at mitigating occupational exposures. 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 (EPA, 1997). Therefore, the conservative, screening-level occupational exposure estimates presented in this document do not account for PPE. Actual occupational exposures may be significantly less than the estimates presented herein.

5.2 Number of Workers Potentially Exposed

The 2010 ACC CPI End-Use Market Survey on the Polyurethane Industry estimates the total number of building and construction establishments that are users of SPF insulation, as well as the total number of workers employed by these establishments. Unlike Census Bureau data, which identifies the total number of establishments and employees within a NACIS code, the estimates in the 2010 ACC CPI Survey are specific to those establishments that are downstream users of SPF insulation. Thus, the information in the 2010 ACC CPI survey is favorable over Census Bureau data.

The estimate for the number of workers employed by these establishments includes all job functions (e.g., administration, design, management, construction laborers). Not all workers are expected to perform active construction labor, such as SPF insulation application. The U.S. Bureau of Labor Statistics Occupational Employment Statistics (OES) surveys for residential and commercial construction (US BLS, 2016a and 2016b) identify the total number of employees for each NAICS code (236100 and 236200), as well as the number of employees within that total that perform construction labor. Based on this information, approximately 60 percent of all workers for both residential and nonresidential construction are laborers.

Thus, to determine the number of workers potentially performing construction labor, the total number of employees for each contractor company is scaled by 60 percent. This results in approximately eight workers per contractor company expected to perform construction activities.

The default number of employees is per contractor company that performs SPF insulation application and not per job site, as it is expected that employees may perform applications at more than one job site in one year. Thus, the number of workers are 8 workers for each $N_{\text{contractor}}$ calculated in Section 3.12. These workers will be exposed over the number of days that contractor companies are expected to perform work, not the number of days spent at one job site. Thus, exposures are assessed in this section over $\text{TIME}_{\text{operating_days_contractor}}$, per Section 3.2.

Table 5-2. Number of Workers per Company

Total Companies^a	Total Employees ^a	Employees per Company ^b	Construction Employees per Company (default) ^c
22,030	309,900	14	8

a – (ACC CPI, 2010)

b – Calculated by dividing the number of employees by the number of establishments.

c – Calculated by dividing the number of employees by the number of establishments and multiplying by 60%.

5.3 Exposure during Container Unloading (Exposure A)

Workers may connect transfer lines or manually unload chemical formulations from transport containers into spray rigs or storage containers. If the concentration of the chemical of interest in the formulated A or B-side ($F_{\text{chem_Side}}$) is not known, determine the most appropriate default value by referencing Section 3.6.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{\text{inhalation}}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapor pressures are below 0.001 torr). For volatile chemicals, use the vapor generation rate calculated for Release 2 (Section 4.2) and the EPA standard model for inhalation exposures due to volatile chemical evaporation (i.e., the *EPA/OPPT Mass Balance Model*) to estimate exposures. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

Table 5-3 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the unloading duration used in Section 4.2 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{\text{operating_days_contractor}}$ or $N_{\text{container_unload_site_yr}}$.

Table 5-3. EPA/OPPT Mass Balance Model Parameter Default Values for Container Unloading

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m ³ /hr (EPA, 1991)
Exposure Days	Equal to $TIME_{\text{operating_days_contractor}}$
Vapor Generation Rate	Calculated by the <i>EPA/OPPT AP-42 Loading Model</i> (Section 4.2)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.2, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (EPA, 1991)
Molecular Weight	Chemical-specific parameter
Number of Contractors	Calculated in Section 3.12
Ventilation Rate	EPA defaults to 237,600 ft ³ /min (typical) and 132,000 ft ³ /min (worst case) for outdoor conditions (EPA, 1991) (see Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

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

Dermal Exposure

Dermal exposure is expected for both automated and manual unloading activities. Automated systems may limit the extent of dermal exposure more than manual unloading; however, workers may still be exposed when connecting transfer lines or manually pouring out the additive. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to

estimate dermal exposures to the chemical of interest. Appendix B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during container unloading, use the following equation:

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

This exposure will occur over the lesser of $TIME_{operating_days_contractor}$ or $N_{container_unload_site_yr}$.

Where:

EXP_{dermal}	=	Potential exposure to the chemical of interest (mg chemical/day)
Q_{liquid_skin}	=	Quantity of formulation remaining on skin (Defaults: 2.1 mg/cm ² -incident (high end) and 0.7 mg/cm ² -incident (low end) for routine or incidental contact (EPA, 2000b))
$AREA_{surface}$	=	Surface area of dermal contact (Default: 1,070 cm ² for two hands (EPA, 2013))
$N_{exp_incident}$ ⁶	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem_Side}	=	Mass fraction of chemical of interest in the A or B-side formulation (kg chemical/kg formulation)

5.4 Exposure during Container Cleaning (Exposure B)

Workers may be exposed to the chemical of interest while rinsing transport containers. If the concentration of the chemical of interest in the formulated A or B-side (F_{chem_Side}) is not known, determine the most appropriate default value by referencing Section 3.6.

Inhalation Exposure

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility of the chemical of interest. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapor pressures are below 0.001 torr). For volatile chemicals, use the vapor generation rate calculated for Release 3 (Section 4.3) and the EPA standard model for inhalation exposures due to volatile chemical evaporation (i.e., the *EPA/OPPT Mass Balance Model*) to estimate exposures. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposures. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

⁶ After the initial exposure, the chemical layer that adheres to the skin (i.e., Q_{liquid_skin}) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

Table 5-4 lists the model inputs and default values. Note that the daily exposure duration (in hr/day) corresponds with the cleaning duration used in Section 4.3 release calculations for this activity. However, EPA exposure assessments typically assume a conservative daily exposure of eight hours per day. For annual exposure days, EPA assumes the lesser of $TIME_{operating_days_contractor}$ or $N_{container_unload_site_yr}$.

Table 5-4. EPA/OPPT Mass Balance Model Parameter Default Values for Container Cleaning

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m ³ /hr (EPA, 1991)
Exposure Days	Equal to $TIME_{operating_days_contractor}$
Vapor Generation Rate	Calculated by the <i>EPA/OPPT AP-42 Loading Model</i> (Section 4.3)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.3, up to 8 hr/day
Mixing Factor	EPA defaults to 0.5 (typical) and 0.1 (worst case) (EPA, 1991)
Molecular Weight	Chemical-specific parameter
Number of Contractors	Calculated in Section 3.12
Ventilation Rate	EPA defaults to 3,000 ft ³ /min (typical) and 500 ft ³ /min (worst case) for indoor conditions (EPA, 1991) (see Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

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

Dermal Exposure

Dermal exposure may occur during container cleaning. The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest. Appendix B provides discussion of the model's underlying rationale, defaults, and limitations.

To estimate exposures during container cleaning, use the following equation:

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

This exposure will occur over the lesser of $TIME_{operating_days_contractor}$ or $N_{container_unload_site_yr}$.

Where:

EXP_{dermal}	=	Potential exposure to the chemical of interest (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of formulation remaining on skin (Defaults: 2.1 mg/cm ² -incident (high end) and 0.7 mg/cm ² -incident (low end) for routine or incidental contact (EPA, 2000b))
$AREA_{\text{surface}}$	=	Surface area of dermal contact (Default: 1,070 cm ² for two hands (EPA, 2013))
$N_{\text{exp_incident}}^7$	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{\text{chem_Side}}$	=	Mass fraction of chemical of interest in the A or B-side formulation (kg chemical/kg formulation)

5.5 **Exposure to mist (non-volatile chemicals) or vapor (volatile chemicals) during Spray Foam Application (Exposure C)**

Workers may be exposed to the chemical of interest in aerosol or vapor form during the spray application of the foam insulation. During the application of SPF, aerosol is generated and available to exposure to workers. While this aerosol may encompass both non-volatile and volatile chemicals, it is expected that the volatile portion of the aerosol will eventually diffuse into the air as vapor from the aerosol. The non-volatile portion will likely remain in the airborne aerosol where it is available for exposure to workers. Due to lack of information on the complex diffusion of various SPF chemicals from airborne aerosols into the vapor phase, EPA assumes that, at the time of application and corresponding worker exposure, non-volatile SPF chemicals are available for exposure to workers in the form of aerosol and volatile chemicals are available for exposure to workers in the form of vapor.

It should be noted that the inhalation exposure estimates presented in this section do not account for the use of PPE, which is commonly used by applicators. Thus, these estimates likely overestimate actual worker exposures. EPA assesses exposures without considering the use of PPE, to represent a worst-case scenario.

Information on the amount of time per day that applicators spend actually spraying is limited. Based on the amount of time assumed for other activities and an eight-hour work day, EPA recommends assuming application occurs over 2 hours/day. This is based on the assumption that the workers will spend one hour each for set-up and tear-down of the application enclosure, one hour for equipment set-up, one hour for quality assurance such as thickness verification (see Section 5.6), and two hours for foam trimming (see Section 5.7).

⁷ After the initial exposure, the chemical layer that adheres to the skin (i.e., $Q_{\text{liquid_skin}}$) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

Inhalation Exposure for Non-Volatile Chemicals (Aerosol Exposure)

Limited data is available on concentrations of non-volatile chemicals in aerosols that are generated during the spraying of the SPF insulation. Where no industry-specific data is available, EPA recommends conservatively estimating exposures using the OSHA PNOR PEL of 15 mg/m³. This model is based on the amount of SPF containing the chemical of interest the worker is exposed to per day, not the amount of the chemical of interest the worker is exposed to ($Q_{chem_site_day}$).

$$EXP_{inhalation} = C_{particulate} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_SPF} \quad (5-3)$$

This exposure will occur over $TIME_{operating_days_contractor}$.

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)
$RATE_{breathing}$	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
$TIME_{exposure}$	=	Duration of exposure (Default: 2 hr/day)
F_{chem_SPF}	=	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)

Inhalation Exposure for Volatile Chemicals (Vapor Exposure)

EPA found a limited amount of data on the air concentration of SPF chemical additives during the application of SPF insulation. The information found is summarized in Table 5-5 below.

Table 5-5. Airborne Concentration of SPF Chemicals in During Application

Compound	Function	Vapor Pressure (torr) at 20°C	Molecular Weight (g/mol)	Number of Samples	Air Concentration (mg/m ³)		Source	Notes
					Typical (50%-tile)	Worst-Case (95th%-tile)		
MDI	Diisocyanate	5E-06	250.25	5	0.6	1.8	Ecoff et al., 2017	Where result was less than LOQ, the LOQ was used for calculations
HFC-245fa	Blowing Agent	922	134.03	5	2,750	85,628	Ecoff et al., 2017	None.
TDCE	Blowing Agent	250	96.94	5	1,290	146,852	Ecoff et al., 2017	None.

Table 5-5. Airborne Concentration of SPF Chemicals in During Application

Compound	Function	Vapor Pressure (torr) at 20°C	Molecular Weight (g/mol)	Number of Samples	Air Concentration (mg/m ³)		Source	Notes
					Typical (50%-tile)	Worst-Case (95th%-tile)		
TCPP	Flame Retardant	2	327.57	5	23	1,045	Ecoff et al., 2017	Where result was less than LOQ, the LOQ was used for calculations
Triethyl Phosphate	Catalyst	0.1	182.15	1	2,000		Light, 2017	None.
Unknown amines	Catalyst	unknown	unknown	1	2,500		Light, 2017	None.

MDI - Methylene diphenyl diisocyanate; HFC-245fa - 1,1,1,3,3-Pentafluoropropane; TDCE - Trans-1,2-Dichloroethylene; TCPP - Tris (chloroisopropyl) phosphate.

Air concentrations may be impacted by several factors, including the type of SPF applied, presence of engineering controls, and duration of spraying activities. EPA recommends the user compares the molecular weight and vapor pressure for the chemical of interest to the available surrogate data in Table 5-5 to determine the appropriate worker exposure level. Surrogate data may be converted for use with the chemical of interest with the following conversion (CEB, 1991):

$$C_{m_chem\ interest} = C_{m_surrogate} \times \frac{MW_{chem\ interest} \times VP_{chem\ interest} \times X_{chem\ interest}}{MW_{surrogate} \times VP_{surrogate} \times X_{surrogate}} \quad (5-4)$$

Where:

$C_{m_chem\ interest}$	=	Concentration of chemical of interest (mg/m ³)
$C_{m_surrogate}$	=	Concentration of surrogate chemical from Table 5-5 (mg/m ³)
$MW_{chem\ interest}$	=	Molecular weight of the chemical of interest (g/mol)
$MW_{chem\ interest}$	=	Molecular weight of surrogate chemical from Table 5-5 (g/mol)
$VP_{chem\ interest}$	=	Vapor pressure of the chemical of interest (torr)
$VP_{surrogate}$	=	Vapor pressure of the surrogate chemical from Table 5-5 (torr)
$X_{chem\ interest}$	=	Mole fraction of the chemical of interest (unitless) – assume this is equal to the mole fraction of the surrogate chemical, $X_{surrogate}$
$X_{surrogate}$	=	Mole fraction of the surrogate chemical (unitless) – assume this is equal to the mole fraction of the chemical of interest, $X_{chem\ interest}$

Note that EPA does not have sufficient information to determine the mole fraction of the surrogate chemical. Thus, EPA assumes that mole fractions in this equation approximate weight fractions. EPA further assumes that the weight fraction of the surrogate chemical and the

chemical of interest are equal, because the surrogate chemical data are for SPF formulations consistent with those the chemical of interest is used in. Thus, the mole fraction for the chemical of interest, $X_{\text{chem interest}}$, and for the surrogate chemical, $X_{\text{surrogate}}$, cancel in the equation above.

In lieu of chemical-specific data, EPA recommends assessing the highest typical and worst-case exposure concentration in Table 5-5 for appropriate chemical function of the chemical of interest.

Utilizing the appropriate typical and worst-case concentrations from Table 5-5 and assuming an activity length of 2 hours per day, the potential inhalation exposure to vapor form of the chemical of interest can be estimated with the following equation:

$$EXP_{\text{inhalation}} = C_{m_chem\ interest} \times RATE_{\text{breathing}} \times TIME_{\text{exposure}} \quad (5-5)$$

This exposure will occur over $TIME_{\text{operating_days_contractor}}$.

Where:

$EXP_{\text{inhalation}}$	=	Inhalation exposure to chemical per day (mg chemical/day)
$C_{m_chem\ interest}$	=	Concentration of chemical of interest (mg/m ³)
$RATE_{\text{breathing}}$	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
$TIME_{\text{exposure}}$	=	Duration of exposure (Default: 2 hr/day)

Dermal Exposure

Manual spray operations are conducted; therefore, dermal exposure may occur. For spray applications, the *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during application activities.

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

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

This exposure will occur over $TIME_{\text{operating_days_contractor}}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of formulation remaining on skin (Defaults: 10.3 mg component/cm ² -incident (high-end) and 1.3 mg component/cm ² -incident (low-end) for routine or incidental contact (U.S. EPA, 2000a))

$AREA_{\text{surface}}$	=	Surface area of dermal contact (Default: 1,070 cm ² for two hands (EPA, 2013))
$N_{\text{exp_incident}}$ ⁸	=	Number of exposure incidents per day (Default: 1 incident/day)
$F_{\text{chem_SPF}}$	=	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)

5.6 **Exposure during SPF Thickness Verification (Exposure D)**

For volatile chemicals, workers may be exposed to the chemical of interest in vapor form during verification of the thickness of the applied foam. Inhalation exposures are assumed to be negligible for non-volatile chemicals (chemicals whose vapor pressures are below 0.001 torr). Based on readily-available data, chemicals are expected to be present in vapor form after application of the foam (Duffy and Wood, 2017; Wood, 2017).

EPA did not find information regarding the length of time needed to perform thickness verification of the foam; however, verification is expected to be a short task, as the applicator need only insert a depth measurement probe into the foam (ACC SFC, 2012). EPA recommends assuming a default exposure time of one hour for this task, consistent with the time assumed in the EPA standard models for sampling tasks.

Inhalation Exposure

Field measurement data is readily available for the airborne concentration of certain SPF chemicals after SPF application. Concentration data is additionally available for different times after spraying. This data indicates that the concentration of the chemicals decreases over time from the point of application (Duffy and Wood, 2017; Wood, 2017). Data was obtained through field sampling during SPF applications in ventilated rooms, which are common practice during SPF application (ACC SFC, 2016).

Verification of thickness is expected to occur shortly after application. Of the readily available data, air concentration measurements at one hour after application are expected to be the most representative of the air concentration of chemicals during thickness verification. However, as noted above, the air concentration after SPF application is dynamic, thus this estimate is presented as the closest approximation and is not expected to be exactly representative of the actual airborne concentrations unless thickness verification occurs one hour after application.

Air concentration data at one hour after application is presented in Table 5-6 (Duffy and Wood, 2017; Wood, 2017). This table also presents default typical and worst-case concentrations for each chemical function and foam type, calculated as the 50th percentile and 95th percentile of the concentrations among available data, respectively.

⁸ After the initial exposure, the chemical layer that adheres to the skin (i.e., $Q_{\text{liquid_skin}}$) does not significantly increase upon repeated exposure, or decrease upon wiping off excess chemical. For this reason, EPA assumes one dermal exposure incident per day. Exceptions to this assumption may apply when assessing chemicals that are highly volatile, or that have significantly high skin absorption rates.

Table 5-6. Airborne Concentration of SPF Chemicals in Room of Application One Hour After Application

Compound	Function	Vapor Pressure (torr) at 20°C	Molecular Weight (g/mol)	Number of Samples	Air Concentration (mg/m ³) ^a		Source	Notes
					Typical (50%-tile)	Worst-Case (95%-tile)		
BDMAEE	Catalyst	0.28	160.26	4	0.28	0.42	Wood, 2017	None.
DAPA	Catalyst	No data available	201.35	2	0.156		Wood, 2017	Both measurements had the same result.
TMAEEA	Catalyst	0.97	146.23	4	0.093	1.34	Wood, 2017	None.
TMIBPA	Catalyst	No data available	187.33	2	0.11	1.13	Wood, 2017	The two measurements were 0.12 and 1.30 mg/m ³ .
1,2 DCE	Blowing Agent	61	98.96	2	0.044	0.077	Duffy and Wood, 2017	The two measurements were 0.08 and 0.008 mg/m ³ .
HFC-245fa	Blowing Agent	922	134.05	2	6.31	7.05	Wood, 2017	The two measurements were 7.13 and 5.48 mg/m ³ .
TCPP	Flame Retardant	2	327.57	6	0.032	0.09	Duffy and Wood, 2017; Wood, 2017	Typical and worst-case were calculated using data from both sources.
MDI	Diisocyanate	5E-06	250.25	8	0.0015	0.0016	Wood, 2017	None.

a - Air concentrations were converted from ppm to mg/m³ by $C_m = C_{ppm} \times (\text{molecular weight}) / \text{molecular volume}$ (CEB, 1991).

TMAEEA – Trimethylaminoethylethanolamine; BDMAEE - Bis (2-dimethylaminoethyl) Ether; DAPA – bis(dimethylaminopropyl) methylamine; TCPP - Tris (chloroisopropyl) phosphate; HFC-245fa - 1,1,1,3,3-Pentafluoropropane; 1,2-DCE - 1,2-Dichloroethane; MDI - Methylene diphenyl diisocyanate

Air concentrations may be impacted by several factors, including the type of SPF applied, ventilation rates, and presence of engineering controls. EPA recommends the user compares the molecular weight and vapor pressure for the chemical of interest to the available surrogate data in Table 5-6 to determine the appropriate worker exposure level. Surrogate data may be converted for use with the chemical of interest with the following conversion (CEB, 1991):

$$C_{m_chem\ interest} = C_{m_surrogate} \times \frac{MW_{chem\ interest} \times VP_{chem\ interest} \times X_{chem\ interest}}{MW_{surrogate} \times VP_{surrogate} \times X_{surrogate}} \quad (5-7)$$

Where:

$C_{m_chem\ interest}$	=	Concentration of chemical of interest (mg/m ³)
$C_{m_surrogate}$	=	Concentration of surrogate chemical from Table 5-6 (mg/m ³)
$MW_{chem\ interest}$	=	Molecular weight of the chemical of interest (g/mol)
$MW_{chem\ interest}$	=	Molecular weight of surrogate chemical from Table 5-6 (g/mol)
$VP_{chem\ interest}$	=	Vapor pressure of the chemical of interest (torr)
$VP_{surrogate}$	=	Vapor pressure of the surrogate chemical from Table 5-6 (torr)
$X_{chem\ interest}$	=	Mole fraction of the chemical of interest (unitless) – assume this is equal to the mole fraction of the surrogate chemical, $X_{surrogate}$
$X_{surrogate}$	=	Mole fraction of the surrogate chemical (unitless) – assume this is equal to the mole fraction of the chemical of interest, $X_{chem\ interest}$

Note that EPA does not have sufficient information to determine the mole fraction of the surrogate chemical. Thus, EPA assumes that mole fractions in this equation approximate weight fractions. EPA further assumes that the weight fraction of the surrogate chemical and the chemical of interest are equal, because the surrogate chemical data are for SPF formulations consistent with those the chemical of interest is used in. Thus, the mole fraction for the chemical of interest, $X_{chem\ interest}$, and for the surrogate chemical, $X_{surrogate}$, cancel in the equation above.

In lieu of chemical-specific data, EPA recommends assessing the highest typical and worst-case exposure concentration in Table 5-6 for the chemical function of the chemical of interest.

Utilizing the appropriate typical and worst-case concentrations from Table 5-6 and assuming an activity length of 1 hour per day, the potential inhalation exposure to vapor form of the chemical of interest can be estimated with the following equation:

$$EXP_{inhalation} = C_{m_chem\ interest} \times RATE_{breathing} \times TIME_{exposure} \quad (5-8)$$

This exposure will occur over $TIME_{operating_days_contractor}$.

Where:

$EXP_{inhalation}$	=	Inhalation exposure to chemical per day (mg chemical/day)
$C_{m_chem\ interest}$	=	Concentration of chemical of interest (mg/m ³)
$RATE_{breathing}$	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
$TIME_{exposure}$	=	Duration of exposure (Default: 1 hr/day)

Dermal Exposure

Dermal exposure may occur during thickness verification. The *The EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* may be used to estimate dermal exposure to chemicals in the solid SPF insulation. 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):

$$EXP_{dermal} = up\ to\ 3,100\ \frac{mg\ SPF}{incident} \times N_{exp_incident} \times F_{chem_SPF} \quad (5-9)$$

This exposure will occur over $TIME_{operating_days_contractor}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to chemical of interest per day (mg chemical/day)
$N_{exp_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem_SPF}	=	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)

5.7 Exposure during SPF Trimming (Exposure E)

This work might be performed by helpers or applicators and may occur as shortly as 15 minutes after application, because the foam is easier to trim while it is still soft. The curing process for SPF insulation begins immediately upon application and that it is typically 90% complete within an hour of application (ACC CPI, 2016). Because of how soon trimming occurs after application, there is a potential for exposure to A-side and B-side chemicals.

Indirect exposure to unreacted isocyanates bound to dust or other particles is also possible and may vary, depending on the type of tool used to trim the foam. Tools used for cutting and trimming vary from hand tools, such as planers, saws, and scrapers, to automated tools, such as sanders and saws. Use of automated tools generate a greater potential for exposure to airborne particles.

Inhalation Exposure

Where no industry-specific data is available, EPA recommends conservatively estimating exposures using the OSHA PNOR PEL of 15 mg/m³. This model is based on the amount of SPF containing the chemical of interest the worker is exposed to per day, not the amount of the chemical of interest the worker is exposed to ($Q_{chem_site_day}$).

$$EXP_{inhalation} = C_{particulate} \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_SPF} \quad (5-10)$$

This exposure will occur over $TIME_{operating_days_contractor}$.

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)
$RATE_{breathing}$	=	Typical worker breathing rate (Default: 1.25 m ³ /hr (CEB, 1991))
$TIME_{exposure}$	=	Duration of exposure (Default: 2 hr/day)
F_{chem_SPF}	=	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)

Dermal Exposure

Dermal exposure to solid, uncured chemicals in the SPF may occur during trimming activities. The *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model* may be used to estimate dermal exposure to additives in the solid SPF insulation. 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):

$$EXP_{dermal} = up\ to\ 3,100\ \frac{mg\ SPF}{incident} \times N_{exp_incident} \times F_{chem_SPF} \quad (5-11)$$

This exposure will occur over $TIME_{operating_days_contractor}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to chemical of interest per day (mg chemical/day)
$N_{exp_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem_SPF}	=	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)

6.0 NON-OCCUPATIONAL EXPOSURES

The following section describes some considerations affecting potential non-occupational exposures to spray polyurethane foam insulation. While the majority of SPF application systems are not marketed to individuals for at-home use, smaller application systems such as SPF sealant are available to Do-It-Yourself (DIY) individuals. These products generally take the form of aerosol cans. DIY individuals can be exposed during the use of these products; however, proper use and personal protection measures can reduce this potential for exposure.

In addition to individuals conducting SPF applications, building residents have the potential to be exposed upon reentry of buildings after a SPF application has been conducted. This section presents general guidelines on re-occupancy to reduce the likelihood of exposure. Finally, residents can also be exposed to SPF chemicals should thermal degradation or fire occur. However, this exposure is contingent on the occurrence of such an event.

6.1 DIY Considerations

DIY individuals can conduct SPF sealant application with low-pressure, one-component cans. These cans allow homeowners to seal small cracks and gaps in existing insulation. It is also possible that DIY individuals conduct application with low-pressure, two-component kits, though many manufacturers limit the use of these products to trained weatherization contractors and professionals (ACC, 2017c). High-pressure, two-component application systems are not available to DIY individuals. Thus, DIY individuals are generally limited to SPF sealant application, not insulation application.

6.1.1 Precautions

DIY individuals are recommended to follow all product instructions, which will specify the type of protective gear that the user should wear. Typically, this will include full-coverage clothing, safety glasses, and gloves (ACC, 2017c). Additional recommendations can include providing good ventilation, avoiding spray activities in high heat areas or near ignition sources, and ensuring that children and pets are away from spraying areas. Generally, occupants can reenter the area once the foam has achieved a tack-free state, which is typically achieved in 5 to 60 minutes. Full cure is expected within 8 to 24 hours of application and users are recommended to wear protective gear when checking the cure level of the foam.

6.1.2 Potential Exposure Routes

While DIY individuals are recommended to wear the appropriate protective gear during SPF sealant application, potential dermal and inhalation exposure still exists during application and if any trimming is necessary.

A University of South Florida study on airborne particulates generated from DIY SPF insulation application provides monitoring data for total particulates not otherwise regulated (PNOR) (Foster, 2015). For this study, samples were taken during application of SPF from low-pressure, two-component spray kits in a residential setting. Sampling occurred during the duration of the application event (15-24 minutes). The results are summarized in Table 6-1. The results indicate that, with proper ventilation and application, this type of consumer application is

not expected to exceed occupational exposure limits (OSHA permissible exposure limit = 15 mg/m³).

Table 6-1. Consumer Application PNOR Survey Results (Foster, 2015)

Foam Type	Sample Duration (min)	PNOR Concentration (mg/m ³)
Closed-cell	16.10	11.35
	16.10	11.38
	15.17	8.74
	15.17	6.52
	24.40	11.86
	24.40	12.53

6.2 Re-occupancy

Once applied, SPF insulation begins to cure immediately, forming a tack-free state within minutes (ACC CPI, 2016). However, while the surface of the foam may be tack-free, the curing process continues over the next 8 to 24 hours. Curing is related to when the optimal physical properties of the foam are achieved and is not directly related to chemical emissions. However, while the foam is curing, there are unreacted chemicals which present potential exposure routes during trimming or other handling of the applied foam. Cure time may be affected by temperature, humidity, and wind conditions. Typically, SPF is 90% cured within an hour of application.

Re-occupancy guidelines prepared by Bayer for its open- and closed-cell SPF products states that 24 hours, as a rule of thumb, are sufficient to reduce exposures to building occupants (Karlovich, 2010). This rule of thumb is based on experimental data; however, the waiting period may vary depending on the size of the project, site characteristics, and venting conditions during and after SPF installation. The experimental results showed that after 24 hours, airborne concentrations were below California Office of Environmental Health Hazard Assessment (OEHHA) chronic reference exposure levels (CRELs) or 1/100 of the occupational exposure levels for SPF chemicals.

During the first 24 hours after SPF installation, the guidelines recommend ventilation of SPF curing areas at a minimum of one air change per hour (ach). After the initial 24 hours, the guidelines assume there to be at least 0.3 ach, though in most houses, air exchange rates between 0.5 and 1.0 ach are common when heating, ventilation, and air conditioning (HVAC) systems are operating. When HVAC systems are not operating, exchange rates of 0.1 to 0.2 ach are common. Building ventilation, particularly after SPF installation, should encourage flushing of the entire curing area. This should permit SPF aerosols and vapors to be purged from the building (Lstiburek, 2006).

6.2.1 Studies on Inhalation Exposure Potential Upon Re-occupancy

Experimental data published in Bayer's reoccupancy guidelines for the Bayseal OC foam (an open-cell foam) show that two of the three amine catalysts present in the formulation were below detectable limits after the recommended time reoccupancy. The third catalyst, "Amine A," was detected at levels slightly exceeding 1/100 of the occupational exposure level of a surrogate amine (73 ug/m³; there is no OEL for Amine A) for the first five days of the study. The presence of the catalyst persisted for 20 days before it was no longer detectable. Neither MDI nor pMDI were detected. Acetaldehyde and formaldehyde byproducts were also detected, though they were below their respective occupational exposure levels (Karlovich, 2010).

Experimental data published for Bayseal CC foam (a closed-cell foam) show the emission of low levels of the blowing agent 1,1,1,3,3,-Pentafluoropropane can occur after SPF installation. The levels observed throughout the study were below 1/100 of the agent's occupational exposure level (16,400 ug/m³) and declined consistently over time. MDI, pMDI, nor amine catalysts present in the SPF formulation were detected. Acetaldehyde and formaldehyde were also detected, similar to that described above for the open-cell foam (Karlovich, 2010).

Other experimental studies show similar results in which MDI levels drop below detectable limits within one to two hours after spray application (Karlovich, 2009; Spence, 2009; Lesage et al, 2007; Roberge et al, 2009; NIOSH, 2005).

6.3 Thermal Degradation/Fires

It is estimated that non-flaming thermal degradation of polyurethane products may begin as low as about 150°C (300°F). However, it is important to note that the temperature at which thermal degradation starts can vary due to the many different heating processes and varying types of polyurethanes used. When exposed to open flame, SPF will burn briefly and form a charred surface layer that is less flammable than the foam. This layer protects the foam from further degradation. Combustible gases and black smoke will be generated during this initial stage. If the combustible gases accumulate in confined spaces, they may ignite, resulting in flashover. During flashover, additional foam or combustibles can also degrade and act as a fuel source for the flame. At temperatures exceeding 379°C (700°F), the protective surface char layer will no longer protect the foam and complete thermal degradation will occur (SPFA, 2005).

When polyurethanes undergo thermal degradation, toxic chemicals may be emitted. This may or may not be seen as smoke or vapors. The importance of being aware of this type of degradation is because of the lack of visible warning signs of the chemicals that may be released during these processes (API, 2005). Airborne thermal degradation chemicals potentially emitted during combustion of polyurethane products may include carbon dioxide, carbon monoxide, nitrogen oxides, hydrogen cyanide, isocyanates and amines. The composition of these chemicals, when emitted in the form of smoke or vapors, may vary (White House Task Force, 2006).

Exposure to thermal degradation byproducts may cause irritation or sensitization of the respiratory tract with symptoms such as running nose, watering eyes, coughing, headaches, dizziness, nausea and breathlessness. People exposed to polyurethane thermal degradation

products may experience these effects as the exposure occurs or days after the exposure has occurred (White House Task Force, 2006).

7.0 REGULATORY HISTORY & REQUIREMENTS

The following section briefly describes the regulatory history of and protective requirements for the use of spray polyurethane foam. These include a consideration of regulatory requirements and recommendations in the United States, such as those under the U.S. Occupational Safety and Health Administration (OSHA), the U.S. Department of Health and Human Services (DHHS) National Institute of Occupational Safety and Health (NIOSH), and the U.S. Consumer Product Safety Commission (CPSC); as well as select international regulatory requirements from the European Union (EU) and Canada.

Occupational exposure standards for MDI⁹ are based on respiratory irritation and sensitization. The available human evidence is insufficient to describe the carcinogenic potential of MDI according to a current intelligence bulletin (CIB No. 53) published by NIOSH in 1989 on the evidence for carcinogenicity of toluene diisocyanate (TDI) and toluenediamine (TDA) (NIOSH, 2006).¹⁰

Mandatory and recommended limits have been established for MDI monomer, as discussed below. However, no recommended or regulatory limit exists for higher molecular weight species at this time. Therefore, regardless of the relative amount of MDI monomer present, employers and workers are encouraged to adhere to recommended control methods whenever MDI aerosols may be generated (NIOSH, 2006).

In addition to federal standards and recommendations, there are consensus-based recommendations for occupational exposure limits (OELs) for MDI proposed by the American Conference of Governmental Industrial Hygienists (ACGIH) who recommend a threshold limit value of 5 ppb as a time-weighted average over an 8-hour period.

7.1 EPA

7.1.1 EPA Regulation

In the 1990s, EPA used its authority to request information from industry under TSCA sections 8(a) and 8(d). The requested information was related to the manufacture and use of SPF and to unpublished health and safety studies, respectively. EPA also received, under TSCA section 8(c), copies of allegations of significant adverse reactions occurring to diisocyanate manufacturers. Diisocyanates are a TSCA New Chemicals Program (NCP) chemical category and are further regulated as a result. NCP recommended actions for diisocyanates can include tests for dermal sensitization and pulmonary toxicity and the development and implementation of appropriate hazard communication. Additional details are provided in the TSCA NCP Chemical Categories document (EPA, 2002).

⁹ Methylenebis(phenyl isocyanate) or MDI refers to all MDI-based isocyanates (NIOSH, 2006)

¹⁰ The historical evolution of the occupational exposure standards for isocyanates is discussed in greater detail in the literature review *Polyisocyanates in Occupational MDI Exposure During Spray-on Truck Bed Liner and Related Applications Environments: A Critical Review of Exposure Limits and Metrics* published by Dhimiter Bello and colleagues in 2004.

MDI and TDI are also regulated under the Clean Air Act as hazardous air pollutants (HAPs) and volatile organic chemicals (VOCs). Under the Clean Air Act, EPA has the authority to develop technology-based national emissions standards for hazardous air pollutants (NESHAPs) to limit the release of specified HAPs from specific industrial sectors.

Diisocyanates, as a category, are subject to Toxics Release Inventory reporting. If quantities of TDI are generated or used in quantities above the minimum reporting thresholds, then any subsequent chemical releases and waste management activities must be reported to EPA on an annual basis.

Under the Resource Conservation and Recovery Act (RCRA), TDI is listed as a hazardous waste under the U-list, which corresponds to the hazardous waste category for discarded commercial chemical products. Therefore, use of TDI must adhere to RCRA Subtitle C regulations concerning TDI generation; transportation; and treatment, storage or disposal.

7.1.2 MDI Action Plan Development

EPA identified a list of widely recognized chemicals, including both MDI and TDI, to develop action plans for based on their persistent, bioaccumulative, and toxic characteristics, as well as their use in consumer products (EPA, 2011b). EPA developed an action plan for MDI in 2011, containing information in its uses, hazards, environmental fate, and human exposures. As a result of this initial review of MDI proposed the following potential actions:

1. Issue a data call-in for uncured MDI under TSCA section 8(c) to determine if there are allegations of significant adverse effects and initiate a TSCA section 8(d) rulemaking for onetime reporting of relevant unpublished health and safety studies for uncured MDI.
2. Consider initiating a TSCA section 4 test rule to require exposure monitoring studies on uncured MDI and its related polyisocyanates in consumer products and exposure monitoring studies in representative locations where commercial products with uncured MDI and its related polyisocyanates would be used.
3. Consider initiating rulemaking under TSCA section 6 for
 - a. Consumer products containing uncured MDI, and
 - b. Commercial uses of uncured MDI products in locations where the general population could be exposed.
4. Consider identifying additional diisocyanates and their related polyisocyanates that may be present in an uncured form in consumer products that should be evaluated for regulatory and/or voluntary action.

Since development of the action plan, EPA has opened a docket to gather public comment on the action plan and its proposed actions listed above. The public comment period was extended multiple times, lasting until April 2017.

7.1.3 SPF Federal Partnership Promoting Stewardship & Research

In 2009, EPA became alarmed that information about the hazards and safe use of SPF was not sufficiently disseminated to workers, occupants of buildings using SPF or consumers (especially when considering the growing market of DIY applicators). EPA convened a multi-agency partnership, which included OSHA, NIOSH, and CPSC, to evaluate and address potential

exposures to diisocyanates during installation of SPF insulation and air sealants by both commercial and DIY applicators. EPA is continuing to work with its partners to facilitate comprehensive hazard communication to workers and consumers; to promote better training, labeling and other practices to prevent exposure; and to address research needs and exposure assessment data gaps. The recognition of the increased exposure to consumers of uncured polyurethane products beyond SPF was an outgrowth of this work.

7.2 OSHA

OSHA's mission is to assure safe and healthful working conditions for working men and women. OSHA responsibilities include the development of safety and health standards; the enforcement of standards; assistance to States; and providing research, training, education, and information. OSHA oversees that employers meet their responsibilities for hazard communications; worker training; and the use of appropriate exposure control systems, personal protective equipment, when necessary, and ventilation. Material Safety Data Sheets (MSDS) are a critical aspect of hazard communications. OSHA recognizes that there may be current deficiencies and inconsistencies in MSDS preparation and use. In September 30, 2009 OSHA proposed to align OSHA's Hazard Communication Standard (HCS) with provisions of the United Nations Globally Harmonized System (GHS) of Classification and Labeling of Chemicals. The current OSHA permissible exposure limit (PEL) for methylenebis(phenyl isocyanate) or MDI monomer is 0.2 mg/m^3 as a ceiling limit (0.02 ppm).¹¹ The current OSHA PEL for toluene diisocyanate is 0.14 mg/m^3 (0.02 ppm). Diisocyanate hazards are addressed by OSHA in specific standards for the general industry; shipyard employment; and the construction industry, including PELs for workplace exposure. OSHA also requires the use of personal protective equipment to reduce worker exposure to hazards when engineering and administrative controls are not feasible or effective in reducing exposure below permissible exposure limits. OSHA is also concerned for worker safety aspects, including fire and explosivity standards and practices.

7.3 NIOSH

NIOSH's mission is to ensure safety and health at work for all people through research and prevention. NIOSH is responsible for providing leadership in conducting occupational safety and health research to prevent work-related illness, injury, disability, and death. NIOSH is also responsible for developing and providing worker education and training. NIOSH has led the development of methods for determining airborne isocyanate exposures and the issuance of several alerts on the prevention of asthma and death from diisocyanate exposure.

NIOSH recommends that MDI monomer exposure be limited to 0.05 milligram per cubic meter of air (mg/m^3) or 0.005 part per million parts of air (0.005 ppm) as a time-weighted average (TWA) for up to a 10-hour workday during a 40-hour workweek, with a ceiling limit of 0.2 mg/m^3 (0.02 ppm) for any 10-minute period. This NIOSH recommended exposure limit (REL), published in 1978, is intended to prevent acute and chronic irritation and sensitization of workers but not to prevent health effects in workers who are already sensitized. Available data do not indicate a concentration at which MDI fails to produce adverse reactions in sensitized

¹¹ OSHA PELs for MDI may be found under 29 CFR 1910.1000 (a)(1).

persons. Unless otherwise stated, use of the term NIOSH REL means the NIOSH REL of 0.2 mg/m³ as a 10-minute ceiling concentration when referring to spray-on truck bed liner processes (NIOSH, 2006).

In 1996, NIOSH issued an Alert, “Preventing Asthma and Death from Diisocyanate Exposure,” which provides RELs intended to prevent acute and chronic irritation and sensitization of workers (1). In 2006, NIOSH issued an Alert, “Preventing Asthma and Death from MDI Exposure During Spray-on Truck Bed Liner and Related Applications” (NIOSH, 2006). NIOSH considers SPF insulation application to present hazards similar to other spray polyurethane applications and recommends use of the same safety procedures and personal protective equipment as detailed in the 2006 Alert. NIOSH recommends supplied air respirators as well as personal protective equipment, including chemical resistant gloves, coveralls, and goggles to prevent dermal and eye exposure.

7.4 CPSC

CPSC’s mission is to protect the public from unreasonable risk of injury and death associated with consumer products. CPSC’s jurisdiction includes thousands of different types of products sold to consumers for personal use in or around the household or school and in recreation. CPSC authorities include the Consumer Product Safety Act (CPSA), Federal Hazardous Substances Act (FHSA), the Consumer Product Safety Improvement Act of 2008 (CPSIA), and amendments to FHSA, including the Labeling of Hazardous Art Materials Act (LHAMA). FHSA places the burden on product manufacturers to ensure that their products are not hazardous and are properly labeled. CPSC is also interested in the health hazards and the synergistic and/or cumulative exposures to chemical ingredients used in SPF products (e.g., flame retardants, catalysts). These interests include:

- The range of substances, often described as proprietary, that might be used as functional alternatives in SPF products;
- The potential for cumulative or successive exposures to other products containing isocyanates, particularly for hypersensitized individuals; and
- Product degradation over time, so that exposure sources and strength may be better understood.

Polyurethane products used by consumers are subject to the FHSA. CPSC administers FHSA, which requires that certain hazardous household products bear cautionary labeling to alert consumers to the potential hazards posed by those products and to inform them of proper hazard protection measures. The FHSA was amended by the LHAMA, which requires that appropriate warning labels be put on those art materials found to pose a chronic hazard.

7.5 FTC

The Federal Trade Commission (FTC) has the authority under Section 5 of the FTC Act to bring actions against false or misleading marketing claims, including environmental or “green” marketing claims. The FTC has issued its “Guides for the Use of Environmental Marketing Claims,” (FTC, 1998) commonly known as the “Green Guides,” to help marketers avoid making environmental claims that are unfair or deceptive. The FTC has also issued guidance to help consumers sort through environmental claims (FTC, 1999).

7.6 ACGIH Requirements

Although occupational exposure to diisocyanates has been regulated for years, most attention has been given to the issue of respiratory sensitivity. More recently, dermal sensitivity has been recognized as an important issue. It has been suggested that there is now sufficient information to recommend the addition of a “skin notation” to the TLVs for MDI and TDI to bring attention to the potential for absorption of diisocyanates through the skin and to the need for appropriate personal protection for workers (Bello et al, 2004).

7.7 EU Requirements

The European Union published a risk assessment (European Chemicals Bureau, 2005) on MDI which identified risks to human health for consumers and the need for risk reduction measures that would ensure consumer protection from eye, skin, and respiratory tract irritation; respiratory and skin sensitization; and lung effects induced by short-term repeated exposure. Subsequently, the EU amended its Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation to include restrictions on certain consumer uses of MDI. Effective December 27, 2010, all consumer products manufactured and imported into the EU containing concentrations of 0.1 percent or more of MDI must include protective gloves, which must comply with certain EU safety requirements, and specific warnings and use instructions. In a separate activity, the EU has also revised its classification and labeling requirements for MDI to include a “limited evidence of carcinogenicity” designation based on animal studies only.

Under EU’s REACH regulation, manufacturers of MDI and TDI are required to submit registration dossiers by November 30, 2010 that contain, in addition to basic chemical information, risk assessments considering risk management actions to control any risks discovered during exposure scenario development for typical product uses throughout the supply chain.

7.8 International Agency for Research on Cancer (IARC)

The International Agency for Research on Cancer (IARC) has examined the risk of several types of cancer from occupational exposure to isocyanates. In its evaluation of various case studies, IARC found there to be inadequate evidence to support the carcinogenicity of MDI, pMDI, or TDI in humans (IARC, 1999a; IARC, 1999b).

7.9 Canadian Requirements

On May 12, 2010, Canada published an Order adding TDI to its List of Toxic Substances, following an assessment which determined that TDI is carcinogenic and affects the respiratory system. Subsequent to the development of a Risk Management Approach to control TDI exposure, Canada decided that a sector-based Pollution Prevention (P2) Planning Notice would be the most appropriate risk management instrument for TDIs. In late 2009, Environment Canada conducted an email consultation with industry regarding its Working Document. The document, “Working Document for the P2 Planning Notice for the Urethane and Miscellaneous Foam Sector (excluding Polystyrene),” was published for a 60-day public comment period on

July 3, 2010 (Environment Canada, 2010). The need for risk management of non-foam consumer products containing TDI will be investigated separately (Environment Canada, 2008).

8.0 SAMPLE CALCULATIONS

This section presents an example of how the equations described in Sections 3 through 5 may be used to estimate releases of and occupational exposures to a chemical used in professional application of SPF insulation. The default values used in these calculations are presented in Sections 3, 4, and 5 and should be used only in the absence of site-specific information. Sample calculations are based on the following assumptions:

1. The production volume of the chemical of interest ($Q_{\text{chem_yr}}$) is *10,000 kg chemical/yr*.
2. The chemical of interest is an unknown type of B-side additive.
3. The chemical of interest is received at end-use sites in the B-side formulation at unknown concentration.
4. The chemical of interest is a volatile liquid with a molecular weight (MW_{chem}) of 100 g/mol and a vapor pressure (VP_{chem}) of 0.1 torr (at 20°C).
5. Assessment concerns are for both releases and exposures.

8.1 General Facility Estimates

8.1.1 Days of Operation for Commercial Contractors ($TIME_{\text{operating_days_contractor}}$)

Since specific information is not available to estimate the days of operation for contractor companies ($TIME_{\text{operating_days_contractor}}$), a default value of 260 days/year should be assumed.

8.1.2 Days of Operation at Job Sites ($TIME_{\text{operating_days_site}}$)

Since specific information is not available to estimate the days of operation at job sites ($TIME_{\text{operating_days_site}}$), a default value of 3 days/year should be assumed.

8.1.3 Application Area per Job Site ($A_{\text{app_site}}$)

Since specific information on the amount of area that is applied with spray foam in a day is unknown, a default estimate of 1,560 ft² should be assumed as the application area. This estimate was determined using Figure 3-2 and considering that concerns are for both environmental releases and occupational exposures.

8.1.4 Density and Thickness of SPF Insulation (ρ_{SPF} and T_{SPF})

Since specific information on the type of SPF insulation being applied is unknown, based on Table 3-4 and given that assessment concerns are for both environmental releases and occupational exposures, medium-density closed-cell foam is assumed. The density (ρ_{SPF}) of medium-density closed-cell foam is 2 lb/ft³. The thickness (T_{SPF}) of medium-density closed-cell foam is 0.33 ft.

8.1.5 Mass Fraction of Chemical of Interest within the A or B-Side Formulation (F_{chem_Side})

Since specific information on the received formulation composition is not known, a default value of 0.2 kg chemical/kg formulation should be assumed because the assessment concerns are for both releases and exposures. Figure 3-3 was used to determine this default value.

8.1.6 Mass Fraction of A or B-Side in SPF (F_{Side_SPF})

Since no information on the SPF formulation is known, assessment calculations should assume F_{Side_SPF} is the default value of 0.5 kg formulation/kg SPF.

8.1.7 Mass Fraction of Chemical of Interest within the SPF (F_{chem_SPF})

The mass fraction of the chemical of interest in the finished SPF insulation can be calculated using Equation 3-1 as follows:

$$F_{chem_SPF} = F_{chem_side} \times F_{side_SPF}$$

$$F_{chem_SPF} = 0.2 \frac{kg \text{ chemical}}{kg \text{ formulation}} \times 0.5 \frac{kg \text{ formulation}}{kg \text{ SPF}}$$

$$F_{chem_SPF} = 0.1 \frac{kg \text{ chemical}}{kg \text{ SPF}}$$

Where:

F_{chem_SPF}	=	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)
F_{chem_Side}	=	Mass fraction of chemical of interest in the A or B-side formulation (kg chemical/kg formulation)
F_{Side_SPF}	=	Mass fraction of formulation within the SPF insulation (Default: 0.5 kg formulation/kg SPF)

8.1.8 Use Rate for SPF Insulation per Site (Q_{SPF_site})

The throughput for the SPF insulation per job site is estimated using the following equation:

$$Q_{SPF_site} = A_{app_site_day} \times \rho_{SPF} \times T_{SPF} \times \frac{1 \text{ kg}}{2.2046 \text{ lb}}$$

$$Q_{SPF_site} = 1,560 \text{ ft}^2 \times 2 \frac{\text{lb}}{\text{ft}^3} \times 0.33 \text{ ft} \times \frac{1 \text{ kg}}{2.2046 \text{ lb}}$$

$$Q_{chem_job_day} = 467 \frac{kg\ SPF}{site}$$

Where:

Q_{SPF_site}	=	Throughput of SPF insulation per job site (kg foam/site)
A_{app_site}	=	Surface area applied with foam per site (Defaults: 4,300 ft ² (release concerns only), 260 ft ² (exposure concerns only), or 2,000 ft ² (both concerns))
ρ_{SPF}	=	Density of SPF insulation (Defaults: 3 lb/ft ³ (release concerns only), 0.5 lb/ft ³ (exposure concerns only), or 2 lb/ft ³ (both concerns))
T_{SPF}	=	Thickness of SPF insulation (Defaults: 0.33 ft (high- or medium- density) or 0.5 ft (low-density))

8.1.9 Daily Use Rate for the Chemical of Interest per Site ($Q_{chem_site_day}$)

The daily throughput for the chemical of interest per job site is estimated using the following equation:

$$Q_{chem_site_day} = \frac{Q_{SPF_site_day} \times F_{chem_SPF}}{TIME_{operating_days_site}}$$

$$Q_{chem_site_day} = \frac{467 \frac{kg\ SPF}{site} \times 0.1 \frac{kg\ chemical}{kg\ SPF}}{3\ days}$$

$$Q_{chem_site_day} = 15.56 \frac{kg\ chemical}{site - day}$$

Where:

$Q_{chem_site_day}$	=	Daily throughput of chemical of interest per job site (kg chemical/site-day)
Q_{SPF_site}	=	Daily throughput of SPF insulation per job site (kg foam/site)
F_{chem_SPF}	=	Mass fraction of chemical of interest in the SPF insulation (kg chemical/kg SPF)
$TIME_{operating_days_site}$	=	Number of operating days per year at application sites (Default: 3 days)

8.1.10 Number of Job Sites (N_{sites})

The number of application sites at which SPF insulation is applied is estimated using the following equation:

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

$$N_{sites} = \frac{10,000 \frac{kg \text{ chemical}}{year}}{15.56 \frac{kg \text{ chemical}}{site-day} \times 3 \frac{day}{year}}$$

$$N_{sites} = 214 \text{ construction sites}$$

Where:

N_{sites}	=	Number of application sites at which SPF insulation is applied (sites)
Q_{chem_yr}	=	Annual production volume of chemical of interest (kg chemical/yr)
$Q_{chem_site_day}$	=	Daily throughput of chemical of interest per application site (kg chemical/site-day)
$TIME_{operating_days_site}$	=	Number of operating days per year at application sites (Default: 3 day/year)

8.1.11 Number of Contracting Companies ($N_{contractor}$)

The number of contractors can be determined from the number of job sites by scaling the number of job sites by the days of operation as follows:

$$N_{contractor} = \frac{N_{sites} \times TIME_{operating_days_site}}{TIME_{operating_days_contractor}}$$

$$N_{contractor} = \frac{214 \text{ sites} \times 3 \frac{day}{year}}{260 \frac{day}{year}}$$

$$N_{contractor} = 2.5 \text{ contractor sites}$$

$$N_{contractor} = 3 \text{ contractor sites}$$

Since the number of contractor companies calculated was rounded to three, the number of operating days for contractor companies needs to be recalculated with the following equation:

$$TIME_{operating_days_contractor} = \frac{N_{sites} \times TIME_{operating_days_site}}{N_{contractor}}$$

$$TIME_{operating_days_contractor} = \frac{214 \text{ sites/year} \times 3 \frac{\text{day}}{\text{year}}}{3 \text{ sites}}$$

$$TIME_{operating_days_contractor} = 214 \text{ days/year}$$

8.1.12 Number of Transport Containers Unloaded per Job Site ($N_{container_unload_site_day}$)

The number of transport containers unloaded at each job site is estimated using the following equation:

$$N_{container_unload_site_day} = \frac{Q_{chem_site_day}}{F_{chem_side} \times V_{container} \times \rho_{formulation} \times 3.785 \frac{L}{gal}}$$

$$N_{container_unload_site_day} = \frac{15.56 \frac{kg \text{ chemical}}{site - day} \times}{0.2 \frac{kg \text{ chemical}}{kg \text{ formulation}} \times 55 \frac{gal \text{ formulation}}{container} \times 1 \frac{kg}{L} \times 3.785 \frac{L}{gal}}$$

$$N_{container_unload_site_day} = 0.37 \frac{containers}{site - day}$$

Where:

$N_{container_unload_site_day}$	=	Number of transport containers unloaded at each job site (container/site-day)
$Q_{chem_site_day}$	=	Daily throughput of chemical of interest per job site (kg chemical/site-day)
F_{chem_Side}	=	Mass fraction of chemical of interest in the A or B-side formulation (kg chemical/kg formulation)

$V_{\text{container}}$	=	Volume of transport container (Default: 208.1 L, equivalent to 55 gal)
$\rho_{\text{formulation}}$	=	Density of chemical formulation (kg/L formulation; Default: 1 kg/L)

8.2 Environmental Releases

8.2.1 Transfer Operation Losses to Air during Unloading (Release 1)

Since the chemical of interest is volatile, it will be emitted during transfer due to the displacement of saturated air. The *EPA/OAQPS AP-42 Loading Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 8-1 summarizes the model's inputs.

$$Q_{\text{vapor_generation}} =$$

$$\frac{F_{\text{saturation_factor}} \times MW_{\text{chem}} \times \left(V_{\text{cont_empty}} \times \frac{3,758.4 \text{ cm}^3}{\text{gal}} \right) \times \left(\frac{\text{RATE}_{\text{fill}}}{3,600 \text{ sec/hr}} \right) \times F_{\text{correction_factor}} \times \left(\frac{VP_{\text{chem}}}{760 \text{ torr/atm}} \right)}{R \times TEMP_{\text{ambient}}}$$

Table 8-1. Summary of ChemSTEER Inputs for Release 1

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	MW_{chem}	g/mol	100
Saturation Factor	$F_{\text{saturation_factor}}$	Dimensionless	0.5 (typical) 1 (worst case)
Vapor Pressure	VP_{chem}	torr	0.1
Container Volume	$V_{\text{cont_empty}}$	gal	55
Fill Rate	$\text{RATE}_{\text{fill}}$	containers/hour	20
Temperature	$TEMP_{\text{ambient}}$	K	298
Vapor Correction Factor	$F_{\text{correction_factor}}$	Dimensionless	$F_{\text{chem_side}}$
Gas Constant	R	atm·cm ³ /K·mol	82.05

Therefore:

$$Q_{\text{vapor_generation}} = 6.22 \times 10^{-5} \text{ g/sec (typical case)}$$

$$Q_{\text{vapor_generation}} = 1.24 \times 10^{-4} \text{ g/sec (worse case)}$$

Using the $Q_{\text{vapor_generation}}$ calculated above, the model then estimates daily air releases using the following equation. The number of release days should equal $\text{TIME}_{\text{operating_days_site}}$.

$$Elocal_{unload_air} = Q_{vapor_generation} \times TIME_{activity_hours} \times \frac{3,600 \text{ sec/hr}}{1,000 \text{ g/kg}}$$

$$Elocal_{unload_air} = \left(6.22 \times 10^{-5} \text{ to } 1.24 \times 10^{-4} \frac{\text{g}}{\text{sec}} \right) \left(\frac{1.12 \frac{\text{containers}}{\text{site} - \text{yr}}}{1 \frac{\text{day}}{\text{yr}} \times 20 \frac{\text{containers}}{\text{hr}}} \right) \left(\frac{3,600 \text{ sec/hr}}{1,000 \text{ g/kg}} \right)$$

$$Elocal_{use_unload_air} = 1.25 \times 10^{-5} \text{ to } 2.51 \times 10^{-4} \text{ kg chemical/site} - \text{day}$$

...over 3 days/year from 214 sites.

8.2.2 Container Residue Losses to Water, Incineration or Landfill (Release 2)

The default container size is a 55-gallon drum (208 kg/container at an assumed density of 1 kg formulation/L formulation). Therefore, the *EPA/OPPT Drum Residual Model* should be used to estimate container residue releases. Since $N_{\text{container_unload_site_day}}$ is less than $TIME_{\text{operating_days_site}}$, the number of release days should equal $N_{\text{container_unload_site_day}}$ and this release can be estimated with the following equation:

$$Elocal_{\text{container_resiude}} = Q_{\text{chem_site_day}} \times F_{\text{container_disp}}$$

$$Elocal_{\text{container_resiude}} = 15.56 \frac{\text{kg chemical}}{\text{site} - \text{day}} \times 0.03 \frac{\text{kg residue}}{\text{kg chemical}}$$

$$Elocal_{\text{containaer_residue}} = 0.47 \text{ kg} \frac{\text{chemical}}{\text{site} - \text{day}}$$

...over 0.37 days/year from 214 sites.

8.2.3 Open Surface Losses to Air during Container Cleaning (Release 3)

Since the chemical of interest is volatile, it will be emitted while empty containers are cleaned. The *EPA/OPPT Penetration Model* may be used to estimate the rate at which the chemical of interest is emitted during this activity. Table 8-2 summarizes the model's inputs, which assumes the default container size, a 55-gallon drum (208 kg/container at an assumed density of 1 kg formulation/L formulation).

$$Q_{vapor_generation} =$$

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

(Eqn. B-3)

Table 8-2. Summary of ChemSTEER Inputs for Release 3

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	MW _{chem.}	g/mol	100
Vapor Correction Factor	F _{correction_factor}	Dimensionless	F _{chem_side}
Vapor Pressure	VP _{chem.}	torr	0.1
Air Speed	RATE _{air_speed}	ft/min	100
Surface Area of Pool Opening	AREA _{opening}	cm ²	20.3
Temperature	TEMP _{ambient}	K	298
Diameter of Opening	D _{opening}	cm	5.08
Pressure	P _{ambient}	atm	1

Therefore:

$$Q_{vapor_generation} = 2.4 \times 10^{-6} \text{ g/sec}$$

Using the $Q_{vapor_generation}$ calculated above and the default values in Table 4-3 for container cleaning, the model then estimates daily air releases using the following equation. Since $N_{container_unload_site_day}$ is greater than $TIME_{operating_days_site}$, the number of release days should equal $TIME_{operating_days_site}$.

$$Elocal_{cont_clean_air} = Q_{vapor_generation} \times TIME_{activity_hours} \times \frac{3,600 \text{ sec/hr}}{1,000 \text{ g/kg}} \quad (\text{Eqn. B-4})$$

$$Elocal_{use_cont_clean_air} = \left(2.4 \times 10^{-6} \frac{\text{g}}{\text{sec}} \right) \left(\frac{1.12 \frac{\text{containers}}{\text{site} - \text{yr}}}{1 \frac{\text{day}}{\text{yr}} \times 20 \frac{\text{containers}}{\text{hr}}} \right) \left(\frac{3,600 \text{ sec/hr}}{1,000 \text{ g/kg}} \right)$$

$$Elocal_{use_cont_clean_air} = 4.84 \times 10^{-7} \text{ kg chemical/site} - \text{day}$$

...over 3 days/year from 214 sites.

8.2.4 Equipment Cleaning Residue to Incineration or Landfill (Release 4)

To estimate daily releases from equipment cleaning, use the following equation:

$$Elocal_{equipment_cleaning} = Q_{chem_site_day} \times F_{equipment_cleaning}$$

$$Elocal_{equipment_cleaning} = 15.56 \frac{kg\ chemical}{site - day} \times 0.02 \frac{kg\ residual}{kg\ capacity}$$

$$Elocal_{equipment_cleaning} = 0.31 \frac{kg\ chemical}{site - day}$$

...over 3 days/year from 214 sites.

8.2.5 Fugitive Emissions During Application (Release 5)

To estimate fugitive emissions from spray application, use the following equation:

$$Elocal_{spray_release} = Q_{chem_site_day} \times F_{spray_release}$$

$$Elocal_{spray_release} = 15.56 \frac{kg\ chemical}{site - day} \times 0.02\ to\ 0.10 \frac{kg\ released}{kg\ sprayed}$$

$$Elocal_{spray_release} = 0.31\ to\ 1.56 \frac{kg\ chemical}{site - day}$$

...over 3 days/year from 214 sites.

8.2.6 Trimming Waste to Landfill (Release 6)

To estimate daily releases from trimming, use the following equation, assuming the default loss fraction for unknown foam types of 0.08 kg released/kg trimmed:

$$Elocal_{trimming} = Q_{chem_site_day} \times F_{trimming}$$

$$Elocal_{trimming} = 15.56 \frac{kg\ chemical}{site - day} \times 0.08 \frac{kg\ released}{kg\ trimmed}$$

$$Elocal_{trimming} = 1.24 \frac{kg\ chemical}{site - day}$$

...over 3 days/year from 214 sites.

8.3 Occupational Exposures

8.3.1 Number of Workers Potentially Exposed

Per Section 5.2, assume eight workers per contractor company. N_{contractors} was calculated to be three contractor companies operating over 214 days/year. Therefore, the total

number of potentially exposed workers is equal to 24 workers. These values are used for the exposure estimates as workers from contractor companies are expected to perform multiple applications in a given year.

8.3.2 Exposure during Container Unloading (Exposure A)

Inhalation Exposure:

Together with the vapor generation rate calculated in Release 2, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 8-3 summarizes the model's inputs.

$$C_{chem_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing_factor}}$$

Table 8-3. Summary of ChemSTEER Inputs for Exposure A

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F _{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	TEMP _{ambient}	K	298
Molecular Weight	MW _{chem}	g/mol	100
Ventilation Rate	RATE _{ventilation}	ft ³ /min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	Q _{vapor_generation}	g/s	6.22 × 10 ⁻⁵ (typical) 1.24 × 10 ⁻⁴ (worst case)
Breathing Rate	RATE _{breathing}	m ³ /hr	1.25
Molar Volume	V _{molar}	L/mol	24.45
Fill Rate	RATE _{fill}	containers/hr	20
Duration of Exposure	TIME _{exposure}	hour/day	0.04

Therefore:

$$C_{chem_volumetric} = 2.1 \times 10^{-2} \text{ ppm (typical case)}$$

$$C_{chem_volumetric} = 1.26 \text{ ppm (worse case)}$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem_mass} = \frac{C_{chem_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem_mass} = 8.6 \times 10^{-2} \text{ mg/m}^3 \text{ (typical case)}$$

$$C_{chem_mass} = 5.15 \text{ mg/m}^3 \text{ (worse case)}$$

Finally, using the mass concentration and default values in Table 5-3 for container unloading, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(8.6 \times 10^{-2} \text{ to } 5.15 \frac{\text{mg}}{\text{m}^3} \right) \left(1.25 \frac{\text{m}^3}{\text{hr}} \right) \left(\frac{1.12 \frac{\text{containers}}{\text{site} - \text{yr}}}{1 \frac{\text{day}}{\text{yr}} \times 20 \frac{\text{containers}}{\text{hr}}} \right)$$

$$EXP_{inhalation} = 6.03 \times 10^{-3} \text{ to } 3.6 \times 10^{-1} \text{ mg/day}$$

...for 24 workers over 214 days/year.

Dermal Exposure:

Use the following equation to estimate dermal exposures during container unloading:

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

$$EXP_{dermal} = \left(0.7 \text{ to } 2.1 \frac{\text{mg formulation}}{\text{cm}^2 - \text{incident}} \right) (1,070 \text{ cm}^2) \left(1 \frac{\text{incident}}{\text{day}} \right) \left(0.2 \frac{\text{mg chemical}}{\text{mg formulation}} \right)$$

$$EXP_{dermal} = 1.5 \times 10^2 \text{ to } 4.5 \times 10^2 \text{ mg chemical/day}$$

...for 24 workers over 214 days/year.

8.3.3 Exposure during Container Cleaning (Exposure B)

Inhalation Exposure:

Together with the vapor generation rate calculated in Release 4, use the *EPA/OPPT Mass Balance Model* to estimate inhalation exposures. Table 8-4 summarizes the model's inputs.

$$C_{chem_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor_generation}}{MW_{chem} \times RATE_{ventilation} \times F_{mixing_factor}}$$

Table 8-4. Summary of ChemSTEER Inputs for Exposure C

Input Parameter	Variable	Units	ChemSTEER Input
Mixing factor	F _{mixing_factor}	Dimensionless	0.5 (typical) 0.1 (worst case)
Temperature	TEMP _{ambient}	K	298
Molecular Weight	MW _{chem}	g/mol	100
Ventilation Rate	RATE _{ventilation}	ft ³ /min	3,000 (typical) 500 (worse case)
Vapor Generation Rate	Q _{vapor_generation}	g/s	2.4×10^{-6}
Breathing Rate	RATE _{breathing}	m ³ /hr	1.25
Molar Volume	V _{molar}	L/mol	24.45
Fill Rate	RATE _{fill}	containers/hr	20
Duration of Exposure	TIME _{exposure}	hour/day	0.02

Therefore:

$$C_{chem_volumetric} = 8.0 \times 10^{-4} \text{ ppm (typical case)}$$

$$C_{chem_volumetric} = 2.4 \times 10^{-2} \text{ ppm (worse case)}$$

Next, convert the volumetric concentration to a mass concentration using the following equation:

$$C_{chem_mass} = \frac{C_{chem_volumetric} \times MW_{chem}}{V_{molar}}$$

Therefore:

$$C_{chem_mass} = 3.3 \times 10^{-3} \text{ mg/m}^3 \text{ (typical case)}$$

$$C_{chem_mass} = 9.9 \times 10^{-2} \text{ mg/m}^3 \text{ (worse case)}$$

Finally, using the mass concentration and default values in Table 5-4 for container cleaning, estimate the inhalation exposure:

$$EXP_{inhalation} = C_{chem_mass} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = \left(3.3 \times 10^{-3} \text{ to } 9.9 \times 10^{-2} \frac{\text{mg}}{\text{m}^3} \right) \left(1.25 \frac{\text{m}^3}{\text{hr}} \right) \left(\frac{1.12 \frac{\text{containers}}{\text{site} - \text{yr}}}{1 \frac{\text{day}}{\text{yr}} \times 20 \frac{\text{containers}}{\text{hr}}} \right)$$

$$EXP_{inhalation} = 2.32 \times 10^{-4} \text{ to } 7.0 \times 10^{-3} \text{ mg/day}$$

...for 24 workers over 214 days/year.

Dermal Exposure:

Use the following equation to estimate dermal exposures during container cleaning:

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

$$EXP_{dermal} = \left(0.7 \text{ to } 2.1 \frac{\text{mg formulation}}{\text{cm}^2 - \text{incident}} \right) (1,070 \text{ cm}^2) \left(1 \frac{\text{incident}}{\text{day}} \right) \left(0.2 \frac{\text{mg chemical}}{\text{mg formulation}} \right)$$

$$EXP_{dermal} = 1.5 \times 10^2 \text{ to } 4.5 \times 10^2 \text{ mg chemical/day}$$

...for 24 workers over 214 days/year.

8.3.4 Exposure during Spray Foam Application (Exposure C)

Inhalation Exposure

Because the chemical of interest is a volatile chemical, worker inhalation exposure is to vapor. The molecular weight of the chemical of interest is 100 g/mol. The vapor pressure of

the chemical of interest is 0.1 torr, which is equal to that for triethyl phosphate in Table 5-5. Using the air concentration for triethyl phosphate of 2,000 mg/m³ and the properties of this chemical from Table 5-5, an approximate air concentration of the chemical of interest can be calculated as follows:

$$C_{m_chem\ interest} = 2,000 \frac{mg}{m^3} \times \frac{100 \frac{g}{mol} \times 0.1\ torr \times X_{chem\ interest}}{182.15 \frac{g}{mol} \times 0.1\ torr \times X_{surrogate}}$$

$X_{chem\ interest}$ and $X_{surrogate}$ cancel out

$$C_{m_chem\ interest} = 1,098 \frac{mg}{m^3}$$

The dose of the chemical of interest can then be calculated as follows:

$$EXP_{inhalation} = C_{m_chem\ interest} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = 1,098 \frac{mg}{m^3} \times 1.25 \frac{m^3}{hr} \times 2 \frac{hrs}{day}$$

$$EXP_{inhalation} = 2,745 \frac{mg\ chemical}{day}$$

...for 24 workers over 214 days/year

Dermal Exposure:

Use the following equation to estimate dermal exposures during spray application:

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

$$EXP_{dermal} = \left(1.3\ to\ 10.3 \frac{mg\ SPF}{cm^2 - incident}\right) (1,070\ cm^2) \left(1 \frac{incident}{day}\right) \left(0.1 \frac{kg\ chemical}{kg\ SPF}\right)$$

$$EXP_{dermal} = 1.4 \times 10^2\ to\ 1.1 \times 10^3\ mg\ chemical/day$$

...for 24 workers over 214 days/year.

8.3.5 Exposure during SPF Thickness Verification (Exposure D)

Inhalation Exposure

Inhalation exposure during thickness verification can be estimated using monitoring data in Table 5-6. The vapor pressure of the chemical of interest is 0.1 torr, which is closest for that of BDMAEE in Table 5-6. Using the air concentration for BDMAEE (typical = 0.28 mg/m³, worst-case = 0.42 mg/m³) and the properties of this chemical from Table 5-6, an approximate air concentration of the chemical of interest can be calculated as follows:

$$C_{m_chem\ interest} = 0.28\ to\ 0.42\ \frac{mg}{m^3} \times \frac{100\ \frac{g}{mol} \times 0.1\ torr \times X_{chem\ interest}}{160.26\ \frac{g}{mol} \times 0.28\ torr \times X_{surrogate}}$$

$X_{chem\ interest}$ and $X_{surrogate}$ cancel out

$$C_{m_chem\ interest} = 0.062\ to\ 0.094\ \frac{mg}{m^3}$$

The dose of the chemical of interest can then be calculated as follows:

$$EXP_{inhalation} = C_{m_chem\ interest} \times RATE_{breathing} \times TIME_{exposure}$$

$$EXP_{inhalation} = 0.062\ to\ 0.094\ \frac{mg}{m^3} \times 1.25\ \frac{m^3}{hr} \times 1\ \frac{hrs}{day}$$

$$EXP_{inhalation} = 0.078\ to\ 0.12\ \frac{mg\ chemical}{day}$$

...for 24 workers over 214 days/year.

Dermal Exposure

Dermal exposure to solid, uncured chemicals in the SPF can be calculated with the EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model:

$$EXP_{dermal} = up\ to\ 3,100\ \frac{mg\ SPF}{incident} \times N_{exp_incident} \times F_{chem_SPF}$$

$$EXP_{dermal} = \left(3,100\ \frac{mg\ SPF}{incident}\right) \left(1\ \frac{incident}{day}\right) \left(0.1\ \frac{mg\ chemical}{mg\ SPF}\right)$$

$$EXP_{inhalation} = 3.1 \times 10^2\ mg\ chemical/day$$

...for 24 workers over 214 days/year.

8.3.6 Exposure during SPF Trimming (Exposure D)

Inhalation Exposure

Inhalation exposure during trimming can be estimated as follows:

$$EXP_{inhalation} = C_m \times RATE_{breathing} \times TIME_{exposure} \times F_{chem_side}$$

$$EXP_{inhalation} = \left(15 \frac{mg\ SPF}{m^3}\right) \left(1.25 \frac{m^3}{hr}\right) \left(2 \frac{hr}{day}\right) \left(0.1 \frac{mg\ chemical}{mg\ SPF}\right)$$

$$EXP_{inhalation} = 3.5\ mg\ chemical/day$$

...over 24 workers 214 days/year.

Dermal Exposure

Dermal exposure to solid, uncured chemicals in the SPF can be calculated with the *EPA/OPPT Direct 2-Hand Dermal Contact with Solids Model*:

$$EXP_{dermal} = up\ to\ 3,100 \frac{mg\ SPF}{incident} \times N_{exp_incident} \times F_{chem_SPF}$$

$$EXP_{dermal} = \left(3,100 \frac{mg\ SPF}{incident}\right) \left(1 \frac{incident}{day}\right) \left(0.1 \frac{mg\ chemical}{mg\ SPF}\right)$$

$$EXP_{inhalation} = 3.1 \times 10^2\ mg\ chemical/day$$

...over 167 days/year.

9.0 DATA GAPS/UNCERTAINTIES AND FUTURE WORK

This section will be completed in a subsequent draft, in accordance with the SOP.

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APPENDIX A: ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES

This appendix will be completed in a subsequent draft.