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THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY**

**EMISSION SCENARIO DOCUMENT ON COATING APPLICATION
VIA SPRAY-PAINTING IN THE AUTOMOTIVE REFINISHING INDUSTRY**

**OECD Environment, Health and Safety Publications
Series on Emission Scenario Documents Number 11**

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INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

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

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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

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EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns, and potential release pathways of chemicals used in the automotive refinishing industry. The document presents standard approaches for estimating the environmental releases of and occupational exposures to the *nonvolatile* additives and components used in automotive refinishing paints and coatings. These approaches are intended to provide conservative, screening-level estimates resulting in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in the real-world setting.

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

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to *nonvolatile* chemical components contained in automotive refinishing coatings. Such estimates might result in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in real world practice.

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

Coverage and methodology

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

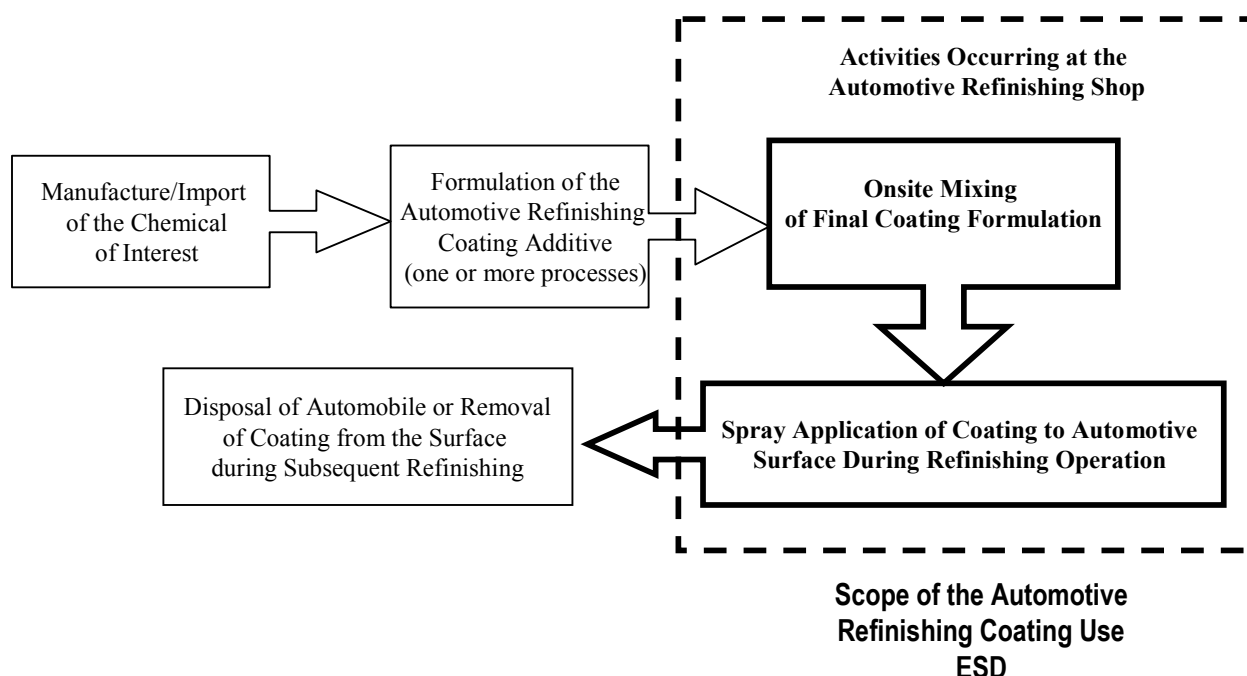
¹ Please refer to Section 8 for a list of the specific references used in developing this ESD.

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

The primary sources of information cited in this ESD include EPA's Design for the Environment (DfE) Auto Refinishing Project, the OAQPS Paint Stripping and Surface Coating NESHAP, the U.S. Census Bureau's County Business Patterns, and other government sources (e.g., NIOSH, CARB, OECD). Section 8 presents additional information on the sources investigated and the references cited in this document.

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

This ESD includes methods for estimating the environmental releases of and associated occupational exposures to the *nonvolatile* chemical components found in automotive refinishing paints and coatings, applied to surfaces via paint spray guns. The ESD covers the preparation/mixing and spraying of the coating components onto automobile surfaces, as well as associated cleaning activities. It does not cover the manufacture of chemical raw materials or component products, nor does it cover the formulation of the raw materials or component products into the automobile refinishing coating product. Below is an illustration of the scope of this ESD within the context of the life cycle of the chemical of interest.



This ESD presents methods for estimating the following releases and exposures to automotive refinishing coating products that are sprayed onto surfaces and associated facility operating parameters:

- Number of automotive refinishing shops in the United States that use coating products containing the chemical of interest to spray coat automobile surfaces, as well as the number of operating days for these activities;
- Release amount from transport container residue (via container cleaning or direct disposal of empty containers);
- Release amount from spray coating process equipment cleaning (i.e., disposal of mixing cup and spray gun coating residues);

- Release amount from oversprayed coating that is collected within the spray area and emission controls;
- Release amount from oversprayed coating that is emitted from the shop;
- Number of workers (painters) that may come into contact with the chemical-containing coating products;
- Dermal exposures during manual transfer of the coating product from the transport container to the mixing cup, as well as during the subsequent mixing of the product with other ingredients;
- Dermal exposures during container cleaning and/or disposal;
- Dermal exposures during transfer of the mixed coating from the mixing cup to the spray gun;
- Dermal exposures during spray coating process equipment cleaning; and
- Inhalation and dermal exposures during the spray coating process.

The estimation methods in this ESD apply to any nonvolatile automotive refinishing coating component, regardless of its function within the coating formulation.

How this document was developed

EPA with support from Eastern Research Group, Inc. (ERG) has developed this ESD on coating application via spray-painting in the automotive refinishing industry. The scope of the ESD is designed to serve the needs of both EPA and OECD programs. The Chemical Engineering Branch (CEB) of EPA's Office of Pollution Prevention and Toxics (OPPT) is responsible for preparing occupational exposure and environmental release assessments of chemicals for a variety of programs under the Toxic Substances Control Act (TSCA), including Premanufacture Notice (PMN) reviews. While OECD ESDs traditionally focus on the potential releases of chemicals from industrial processes, this document also describes approaches for estimating potential occupational exposures to automotive refinishing chemicals. The occupational exposure methods are included so that the ESD may be used to fully support EPA's chemical review programs.

2004 ESD

This ESD was originally developed by EPA and submitted to OECD in September 2002. Comments were received from Canada, the United Kingdom, and the Netherlands. EPA incorporated the comments received from these countries into the document, which was published by OECD in November 2004 [OECD, 2004].

2011 ESD Update

This ESD supersedes the OECD's November 2004 *Emission Scenario Document on Coating Application via Spray-Painting in the Automotive Refinishing Industry* [OECD, 2004]. The 2004 ESD was updated with additional data and information (see Summary of Changes Since the 2004 Publication below). An updated version of the 2004 ESD was submitted to the Task Force on Environmental Exposure Assessment (then TFEEA, to be re-organised to TFEA in 2009) in August 2008. Comments were received from Canada and the United Kingdom. EPA incorporated the comments received from these countries into the document and submitted a revised draft to the TFEA

in October 2009. EPA added additional information on the use of personal protective equipment to the Occupational Exposure Section and prepared a further revised draft in December 2009. Comments were received from the United Kingdom in February 2010 and incorporated by the EPA. The final draft ESD was then circulated to the TFEA in July 2010 and approved at the final commenting round by the end of January 2011.

Summary of Changes Since the 2004 Publication

Since publication of the 2004 ESD, significant changes have occurred in the automotive refinishing industry due to cost saving technologies (e.g., high-volume, low-pressure (HVLP) guns) and more stringent regulations on the emission of hazardous air pollutants (HAPs) and particulate matter (PM). In addition, most of the data included in the 2004 ESD were taken from a previous 1996 internal EPA version of the document. Therefore, EPA has revised and expanded the 2004 ESD to incorporate additional and updated information relevant to the automotive refinishing industry and its current practices. Specifically, the ESD includes the following key new data and information:

- Information and data collected by EPA's Office of Air Quality Planning and Standards (OAQPS) in support of the National Emission Standards for Hazardous Air Pollutants (NESHAP) for Paint Stripping and Miscellaneous Surface Coating Operations at Area Sources (hereinafter referred as the Paint Stripping and Surface Coating NESHAP) [73 FR 1738; January 9, 2008];
- 2004 U.S. Census Bureau data on refinishing paint production, number of refinishing shops and number of workers;
- 2001 refinishing coating product-specific sales data;
- Low-volatile organic compound (VOC) and waterborne coating information;
- 2004 study data on dermal exposures during various refinishing processes;
- Updated data analyses of available coating mist concentration and associated spray activity durations; and
- 2005 study on personal protective equipment (PPE) used in the automotive refinishing industry in the State of Washington.

These new data and other updated information have necessitated revisions to some of the assessment methods and calculations performed for the general facility estimates, the amount of overspray captured by and released from the shop booth ventilation system, and exposures to the coating products during various refinishing steps. This updated ESD also describes in more detail the nature of the refinishing coatings used, as well as the practices and technologies currently used in automotive refinishing processes. In addition to enhancing the ESD with the most current information available, EPA made these and other revisions to meet its revised quality standards for generic scenarios [CEB, 2006].

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

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INDUSTRY SUMMARY AND BACKGROUND

This section provides an overview of the automotive refinishing industry and the refinishing process, as well as information about the coatings used and how they are applied in the process. This section also presents the number of facilities and workers in the U.S. automotive refinishing industry.

Automotive Refinishing Processes

Automotive refinishing shops apply coatings to motor vehicles subsequent to the original manufacturing process. The refinishing process typically involves the following steps:

- Structural repair;
- Surface preparation (cleaning and sanding);
- Primer coat mixing;
- Spray application of primer coat;
- Curing;
- Sanding;
- Solvent wipe-down;
- Topcoat (basecoat color and clearcoat) mixing;
- Spray application of topcoat; and
- Curing.

Surface preparation involves removing residual wax, grease, or other contaminants from the surface to be painted to ensure adhesion of the new coating. The new coating may be applied over an existing coating if it is free of chips or cracks after it has been roughened through sanding. Alternatively, the previous coating may be removed using a mechanical method (e.g., sanding) or a paint-removing solvent. After the coating is roughened or removed, the surface is typically wiped down with a solvent- or water-based surface preparation product.

Painting involves mixing and applying primers/sealers, dry or wet sanding of the primed surface, matching new coating color with the original color, mixing coating formulations, and applying the coatings to the target area using custom and conventional painting techniques.

This ESD describes methods to estimate the releases of and exposures to the *nonvolatile* coating components (e.g., pigment, binders) from automotive refinishing spray applications and the disposal of residual coating in waste containers, spray gun cleaning wastes, and other equipment. Section 2 of this ESD describes these potential releases and worker exposures in detail.

This ESD does not address releases of and exposures to other chemicals associated with other refinishing shop processes, such as surface preparation and solvent wipe-down; however, they are described in the following sections as additional background information on the automotive refinishing process.

Structural Repair and Surface Preparation

Often the first step in refinishing an automobile surface is repairing the surface to be refinished, if it is damaged. In some cases, dents and scratches can be “banged out” and smoothed over with body filler. In other cases, the damaged piece is removed and replaced with another new or salvaged piece.

Following the structural repair of the automobile, the surface is prepared for painting through a series of surface cleaning and sanding steps. First, the surface is cleaned with solvent to remove wax, grease, road tar, and other contaminants that may clog the sandpaper and reduce its

effectiveness during the subsequent sanding step. This step usually involves manually wiping the target surface with a solvent-laden rag.

Solvent chemicals commonly used during this step, as well as in the solvent wipe-down step described in Section 1.1.2, include methyl ethyl ketone (MEK), toluene, xylene, light aliphatic solvent naphtha, acetone, and various acetates such as n-butyl acetate and ethylene glycol monobutyl ether acetate [Heitbrink, 1993]. Many of these solvents are hazardous (e.g., both MEK and toluene are considered by EPA to be hazardous air pollutants (HAPs) under Title III of the Clean Air Act Amendments of 1990). There are low-volatile organic compound (VOC), waterborne products available for use in automotive refinishing as a substitute for traditional solvent-based products, especially for shops that must meet strict state or local VOC emissions limitations [USEPA, 2007a].

Facilities may utilize a spray booth or “prep station” (described in Section 2.2.2) for surface preparation. Prep stations are similar in design to spray booths except they use curtains instead of constructed walls to isolate and contain the work area. Surface preparation solvent vapors are emitted from the shop via the spray booth/prep station exhaust system. Occasionally, due to scheduling and availability of the prep station or spray booth, facilities may prepare automobile surfaces in the open area of the shop. The fugitive emissions from the evaporation of the solvent eventually exit the open area of the shop by way of a fan or other general or natural ventilation [USEPA, 2002].

In addition to the fugitive vapor release of the solvents, workers may inhale the vapors during this step, although performing the solvent cleaning within an enclosed spray booth/prep station and wearing appropriate respiratory protection will reduce this exposure. To prevent dermal exposure to the solvents, which may be irritating to the skin and harmful if absorbed into the body, workers may wear gloves and other skin protection.

The second step is sanding the automotive surface to remove abnormalities, to promote proper adhesion of the coatings, and to foster a high quality finish. Automotive shops commonly use two types of sanding techniques:

- Wet sanding - Workers manually remove surface irregularities using water and an abrasive material, typically sandpaper.
- Dry sanding - Workers manually remove surface irregularities using sand paper or a pneumatic disc sander. Pneumatic sanding stations occasionally contain vacuum attachments to remove dust that is created during sanding. Some painters may also use compressed air to remove dusts created during sanding.

After the initial surface cleaning and sanding, a primer coating is applied to the surface to provide corrosion resistance, help subsequent coatings adhere to the surface, and to enhance the uniform appearance of the topcoat (i.e., basecoat color and clearcoat) [USEPA, 2007a]. Section 2.2 describes primers and this spray coating step in more detail. After the primer coating cures and dries (see Section 2.3), the primed surface is again sanded.

Workers may be exposed to the components contained in the original coating and newly applied primer during sanding. The type of exposure depends upon the sanding method used. During wet sanding operations, workers' skin may be exposed to the abrasive compounds used to remove surface irregularities, as well as to the original and primer coating particles. During dry sanding operations, workers may inhale the dust generated during sanding (containing original coating particles). A vacuum sanding system (which is present in some pneumatic disc sanders) helps to control this particulate inhalation [ERG, 1998].

Solvent Wipe-Down

After the initial surface preparation and priming, the vehicle surface is again manually wiped down with a rag containing an organic solvent similar to that used in the surface preparation described in Section 1.1.1.

Often auto refinishers perform the solvent wipe-down in a spray booth or prep station (described in Section 2.2.2) to ensure that dust and other contaminants do not adhere to the surface prior to painting. Solvent vapors are expected to be released as they evaporate from the automobile surface, as similarly described for the surface preparation step in Section 1.1.1. Worker exposures are also expected to be similar to those of the surface preparation step.

Overview of Automotive Refinishing Coatings

Refinishing shops typically use three general types of coating products to paint an automobile:

- Undercoat or primer – Specifically designed to bind with the metal surface of the automobile and to protect it from oxidation; and
- Topcoat, which typically comprises:
 - Basecoat – Provides color for the automobile; and
 - Clearcoat – Provides protection for the basecoat and a high-gloss finish to the automobile surface;
- Reducers – A solvent used to thin (i.e., reduce the viscosity) the final mixed coating; and
- Other products and additives used to adjust the properties of the final mixed coating.

The chemical of interest is expected to be contained within a ***coating product*** formulation, which is sold to and used by automotive refinishing shops. Prior to their use, these coating products are often mixed by the painter with other coating products according to the manufacturers' specifications and "recipes" for particular colors and effects or for ease in application and curing (see Section 2.1). The ***final mixed and ready-to-spray coating*** is then sprayed onto the automotive surface to be refinished. There are also ready-to-use formulations that are used by some shops, which do not require premixing before use.

In 2001, the California Air Resources Board (CARB) conducted a survey of 17 refinishing coating manufacturers and distributors who sold coating products to California refinishing shops [CARB, 2005]. Table 1-1 summarizes the top 10 coating products sold to California shops in 2001. It should be noted that the reducers and other coating products included in the table are separate coating products that are sold to and used by the automotive refinishing shops, and should not be confused with the solvents/reducers and other additives that are already contained in the basecoat, clearcoat, and primer products sold to and used by the shops.

The formulation of ingredients and associated concentrations found in these coating products are highly varied, as are the final compositions of the coatings after they are mixed and sprayed onto the automobile surface. One manufacturer stated that traditional solvent-based automotive refinish coatings contain approximately 85 percent organic solvent and 15 percent

nonvolatile components, and waterborne basecoats are composed of 75 percent water and 10 percent organic solvent, and also contain approximately 15 percent nonvolatile components [DuPont, 2007]. Another source states that automotive refinishing coatings contain 25 percent nonvolatile components [Kirk-Othmer, 1993].

A typical automotive refinishing coating system (i.e., the final mixed coating types used to refinish the surface) comprises the following:

- Chromate-free etch primer (if coating a new or bare metal surface);
- Primer/filler putty for dents and minor defects (polyurethane or epoxy);
- Surfacer or sanding filler (often epoxy);
- Solid color or effect (e.g., metallic) basecoat; and
- Clearcoat (most often acrylic urethane) [Morrison, 2007].

**Table 1-1. Top 10 Automotive Refinishing Coating Product Types
Sold in California, 2001**

Refinishing Coating Product Type: Definition	Total Volume Sold (gallons)	Percent, by Volume (F_{vol coattype}) (vol %)	Average Density (RHO_{coattype}) (lbs/gal)
Reducer			
Reducer: A solvent used to thin (reduce viscosity of) a coating.	1,097,457	29	--
<i>Reducer Total</i>	<i>1,097,457</i>	<i>29</i>	<i>--</i>
Basecoats			
Multistage color coat: The basecoat/midcoat portion of a multistage topcoat system.	429,980	11	9.0
Metallic/iridescent: A topcoat that contains iridescent particles composed of either metal as metallic particles or silicon as mica particles, in excess of 5 g/L (0.042 lb/gal) as applied, where such particles are visible in the dried film.	294,768	8	8.8
Single-stage color coat: A color coat that is ready for application as supplied to form an acceptable dry film (see also "Color coat" below).	263,335	7	9.1
Color coat: An intermediate for final pigmented coating applied over a primer or original finish.	135,048	4	8.2
<i>Basecoat Total</i>	<i>1,123,131</i>	<i>30</i>	<i>8.9</i>
Clearcoat			
Clearcoat: A coating that contains no pigments and is the final coating applied as part of a multistage topcoat system.	394,364	11	8.3
<i>Clearcoat Total</i>	<i>394,364</i>	<i>11</i>	<i>8.3</i>
Primers			
Primer surfacer: A high-solids coating applied for the purpose of corrosion resistance or adhesion, and which promotes a uniform surface by filling in surface imperfections.	184,820	5	10.2
Primer sealer: A coating applied prior to the application of a topcoat for the purpose of color uniformity, or to promote the ability of an underlying coating to resist penetration by the topcoat.	99,747	3	10.3
<i>Primer Total</i>	<i>284,567</i>	<i>8</i>	<i>10.2</i>

Refinishing Coating Product Type: Definition	Total Volume Sold (gallons)	Percent, by Volume (F _{vol coattype}) (vol %)	Average Density (RHO _{coattype}) (lbs/gal)
Other Coating Products			
Additive: A chemical substance added to a coating in relatively small amounts to impart or improve desirable properties (e.g., UV screeners, flow agents, defoamers, fish eye eliminators).	256,124	7	--
Hardener: A substance added to paint or varnish to harden the film.	213,758	6	--
Remaining 21 coating types: Accelerator, activator, camouflage, catalyst, extender, fish eye eliminator, flattener, flexible primer, ground coat, other, plasticizer, plastics primer, precoat, pretreatment wash primer, primer, specialty coating, temporary protective coating, truck bed coating, underbody coating, undercoat, and uniform finish coating.	316,098	<9	--
<i>Other Coating Product Total</i>	<i>785,980</i>	<i>21</i>	<i>--</i>
Total	3,685,499	100	--

Source: CARB, 2005.

Low-VOC Coating Legislation and Waterborne Coatings

Due in part to increasing limitations on solvent VOC emissions from automotive refinishing shops, waterborne and other low-VOC coatings are increasingly being manufactured and used in both the United States and Europe. Table 1-2 summarizes the automotive refinishing VOC limitations in the United States, European Union (EU), and California.

**Table 1-2. Low-VOC Regulations in the United States, California, and Europe
(grams per liter)**

Coating Category	U.S. Limit 1998	European Limit	California Limit 2009
Wash Primer	780	780	660
Primer Surfacer	550	540	250
Topcoats (i.e., Basecoats and Clearcoats) ^a	600-630	420	420 (basecoats) 250 (clearcoats)
Special Finishes	680	840	680

Source: Morrison, 2007.

a – In the United States, different limits apply to different systems; in Europe, the same limit applies to basecoats, clearcoats, and solid finishes (other than special finishes).

While the topcoat VOC-content limitations in the EU are stricter than in the United States, more than 5,000 European shops and their coating suppliers were able to comply by switching to waterborne coatings [Sramcik, 2007].

In 2005, with the success of the EU regulations in mind, the CARB published a Suggested Control Measure (SCM) for the automotive refinishing industry. The SCM has so far been adopted into the regulations of two California air districts (both targeted for implementation in 2009). The CARB SCM targets the sale, use, and possession of high-VOC automotive refinishing supplies (e.g., wash and reducing solvents, coatings). The maximum allowable VOC content is such that only waterborne coating products currently qualify [Sramcik, 2007]. Several other sources reviewed for this ESD stated that other states will likely adopt similar limitations in the future.

EPA's OAQPS has published National Emission Standards for Hazardous Air Pollutants (NESHAP) for Paint Stripping and Miscellaneous Surface Coating Operations at Area Sources (hereinafter referred as the Paint Stripping and Surface Coating NESHAP) [73 FR 1738; January 9, 2008]. The Paint Stripping and Surface Coating NESHAP does not include specific requirements on the VOC content of the coatings, but contains particular operating requirements for spray coating operations involving paints containing compounds of chromium, lead, manganese, nickel, or cadmium (e.g., these materials must be sprayed using a HVLP spray gun or equivalent high-efficiency equipment). These requirements are described in more detail in Section 2 of this ESD. Existing shops must comply with the requirements of the Paint Stripping and Surface Coating NESHAP no later than January 9, 2011. New shops must comply upon startup at any point after January 9, 2008.

Waterborne coatings use water as their primary solvent; however, they do contain some organic solvent, such as glycol ethers to improve their application. For the most part, the U.S. automotive refinishing industry's use of waterborne coatings has been limited to primers and basecoats, with most shops continuing to use solvent-based clearcoats. Waterborne coatings are less hazardous in that they do not contain VOCs or HAPs (e.g., xylene, toluene, methyl ethyl ketone, ethyl benzene) and are less flammable. While waterborne coatings tend to be more expensive than traditional solvent-based coatings, many shops have found that less waterborne coating is required to complete a given job [Sramcik, 2007]. For example, a job that required four to five coats of a traditional solvent-based coating needs only one or two coats of a waterborne coating [Albright, 2007].

Other than compliance with newer VOC limitations, waterborne coatings afford shops many other advantages over traditional solvent-based coatings. Waterborne coatings have a longer shelf life than solvent-based systems. Shops are able to save unused waterborne coatings for a longer period of time, provided they are maintained at optimal temperatures (i.e., are kept above their freezing point). Many shops have found that only minor adjustments to their existing HVLP spray guns were needed to achieve comparable results with waterborne coatings. When waterborne coatings are used, mixing and spray gun equipment may be rinsed and cleaned using water, as opposed to more hazardous and expensive organic solvents (e.g., acetone, methyl acetate) [Sramcik, 2007]. Note that, since waterborne coatings still contain some organic solvents and other potentially hazardous compounds, this rinse water may need to be collected and disposed to incineration or landfill with the other hazardous shop wastes.

Waterborne coatings require a longer drying/curing time than solvent-based coatings. Many shops have invested in improvements to the spray area or booth air circulation system or in portable heat or ultraviolet drying units to accommodate the longer drying times [Albright, 2007].

The 2001 CARB survey of coatings manufacturers revealed that less than one percent of all coating products sold in California were waterborne. Individual waterborne coating products sold ranged between one and eight percent of the total volume sold. The coating products highlighted in Table 1-1

that were also sold as a waterborne product to California shops and the associated percent volume sold are listed below:

- Primer surfacer – 5 percent;
- Primer sealer – 2 percent;
- Hardener – 2 percent;
- Multistage color coat – 1 percent; and
- Clearcoat – 1 percent [CARB, 2005].

While to date, EPA has not found more recent data on the relative volume of waterborne coating products sold to automotive refinishing shops, EPA expects that the amount of waterborne coating products being used within the automotive refinishing industry has increased since the 2001 CARB survey, especially in California and other locations that have passed strict VOC emissions limitations.

Physical Properties of Automotive Refinishing Chemicals

Table 1-3 lists the physical properties of example chemical compounds that may be used in each of the coating additives described in this ESD. EPA identified the specific chemicals within each component category through Material Safety Data Sheets (MSDS) of automobile refinishing coating product formulators.

EPA reviewed several sources of physical property data for each of the chemicals identified in the component categories. These sources are cited at the bottom of Table 1-3 and included in Section 8 of this ESD. EPA selected the example chemicals shown in the table based on the following data quality criteria:

- Available data are characterized as either experimental or extrapolated (i.e., estimated/modeled data are not included in Table 1-3);
- Physical property data were found to be relatively consistent among multiple sources; and,
- A complete “set” of Table 1-3 physical property data were found for the chemical.

Table 1-3. Physical Properties of Example Automobile Refinishing Coating Product Chemicals

Component Category	Example Chemical (CAS, if available)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (mg/L)	Density, LogK _{ow}
Pigment	Titanium dioxide (13463-67-7)	Solid ^a	79.87 ^a	Metal oxide; vapor pressure assumed negligible	2900 ^b	1855 ^{a,b}	Insoluble ^a	ρ 4.23 (rutile) ρ 3.90 (anatase) ρ 4.13 (brookite) ^a
Binders	Ethylene-vinyl acetate copolymer (24937-78-8)	<p>The polymers used in automotive coating formulations may be solids or liquids and possess a wide range of molecular weights, vapor pressures, and other physical properties.</p> <p>These polymers are generally expected to be of high, variable molecular weight and have a negligible vapor pressure.</p> <p>If the physical state of the polymer is not known, EPA recommends that the polymer be assessed as a solid, which will result in more conservative worker inhalation exposure assessment.</p>						
	Acrylic polymer							
Reducer/Solvent	Water (7732-18-5)	Liquid ^a	18.02 ^a	23.8 ^c 760 (@ 100°C) ^d	100 ^a	0 ^a	1e6 ^c	ρ 0.997 ^a log K _{OW} -1.38 ^c
	Xylene (1330-20-7)	Liquid ^b	106.17 ^b	5.1 ^b	140 ^b	-50 ^b	Insoluble ^b	0.862 ^b Log Kow: 3.12-3.20 ^c
Hardener	1,6-hexamethylene diisocyanate (822-06-0)	Liquid ^d	168.2 ^d	0.05 ^d	255 ^b	-55 ^b	reacts ^b	1.04 ^b

Component Category	Example Chemical (CAS, if available)	Neat Physical State	Molecular Weight	Vapor Pressure (torr at 25°C)	Boiling Point (°C)	Melting Point (°C)	Water Solubility (mg/L)	Density, LogK _{ow}
Surfactant	2,5,8,11-Tetramethyl-6-dodecyn-5,8-diol ethoxylate (169117-72-0)	<p>The polymers used in automotive coating formulations may be solids or liquids and possess a wide range of molecular weights, vapor pressures, and other physical properties.</p> <p>These polymers are generally expected to be of high, variable molecular weight and have a negligible vapor pressure.</p> <p>If the physical state of the polymer is not known, EPA recommends that the polymer be assessed as a solid, which will result in more conservative worker inhalation exposure assessment.</p>						

a – Source: Merck, 1996.

b – Source: ChemFinder, 2007.

c – Source: SRC, 2006.

d – Source: NIOSH, 1994.

Limited information was available on the specific chemical components of automobile refinishing products. The physical properties of these chemicals are presented to provide the reader with a general understanding of potential characteristics of certain automobile refinishing product components. It should be noted, however, that these chemicals are simply examples of the wide array of chemicals that may be used in specific coating product formulations.

Isocyanates and VOCs, two components of concern that are commonly found in refinishing coatings, are described below.

Isocyanates Used in Coatings

Isocyanates are components of polyurethane coating hardeners and are commonly used in the primers and clearcoats applied in auto refinishing shops. Two types of isocyanates are used in polyurethane coatings: aliphatic and aromatic. Polyurethane coatings containing aromatic isocyanates are relatively fast-curing, but tend to lose their gloss upon weathering, while coatings containing aliphatic isocyanates have high mechanical and chemical resistance, are more light-stable, and retain their gloss longer. These advantages make aliphatic isocyanates more suitable for use in auto refinishing coatings than aromatic isocyanates. EPA studies have shown the aliphatic compound hexamethylene diisocyanate (HDI) to be the predominant isocyanate used in auto refinishing coatings. Other isocyanates used in polyurethane coating formulations include 2,4-toluene diisocyanate (TDI), 4,4'-diphenylmethane diisocyanate (MDI), and isophorone diisocyanate (IPDI) [OPPT, 1997]. EPA has listed MDI, TDI, and HDI as hazardous air pollutants (HAPs) under Title III of the Clean Air Act Amendments of 1990.

Isocyanates are released primarily during spray-coating activities from the emission of mist particles containing isocyanate polymers and isocyanate monomers, as well as from the volatilization of isocyanate monomers from the mist particles and applied coatings. In addition, isocyanate compounds may be contained in dust particles generated during sanding operations and in residual waste paint products and waste cleaning solvents. Typically, these wastes are expected to be collected in sealed drums until their transfer to a waste disposal site. Volatile isocyanate components may also be released when the paint and coating mixtures are prepared.

Appendix D to this ESD includes isocyanate exposure data and other related isocyanate concentrations, which may be used to estimate potential painter inhalation exposures to isocyanates contained in oversprayed coating mists (see Section 5.7.1).

Volatile Organic Compounds Used in Coatings

Although the volatile releases of and worker inhalation exposures to VOC vapors are outside the scope of this ESD, this subsection has been included to provide additional background information on common VOCs used in automotive refinishing coatings.

VOCs are used as the primary solvent (i.e., liquid carrier) in the coating products used by auto refinishers and at one point accounted for as much as 67 percent of the coating formulation [OPPT, 1997]. VOC-containing solvents, thinners, and reducers help provide optimal viscosity, flow, and drying characteristics to the coating products. Today, due to increasing restrictions on the VOC content of coatings, the industry is using newer low-VOC formulations.

VOCs are also contained in the solvents used by auto refinishing shops for surface preparation and equipment cleaning. VOC-containing cleaning solvents are used to dissolve grease, tar, wax, and other contaminants from the surface to be painted by manually spraying the surface and/or wiping the surface with a cloth laden with the solvent. Because of their volatility, the VOC-containing cleaning

solvents dry quickly, leaving the surface clean and ready to be painted. The solvents used to clean the painting equipment (i.e., spray guns and paint cups) are predominantly composed of VOCs and are effective at removing residual paint and coating products from the equipment [IWRC, 1994].

A wide array of VOCs can be found in auto refinishing shops depending on the types of coatings, thinners, and cleaners that are used. For example, one study identified up to 100 different organic compounds, 90 percent of which were acetone, xylenes, toluene, methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), and hexane, during indoor air sampling analyses at a single auto refinishing shop. Other VOCs that were found in the study included ethyl acrylates, ethylbenzene, benzene, perchloroethene, cumene, various acetates, glycols, and ethers [ATSDR, 1998]. EPA has listed several of these compounds among the 189 HAPs under Title III of the Clean Air Act Amendments of 1990. The following compounds are the most common HAPs found in paints, coatings, and cleaning solvents: MEK, MIBK, toluene, xylenes, 1,1,1-trichloroethane, and methylene chloride [ORD, 1996].

Virtually all of the VOCs contained in auto refinishing products are expected to volatilize and be released from the auto refinishing shop during their use. Most of the VOCs released from an auto refinishing shop are from the oversprayed coating mists as well as from the drying/curing of the coating applied to the automobile surface. VOCs may also be released when the paint and coating mixtures are prepared.

Residual paint products and waste cleaning solvents also contain VOCs; however, residual products and waste cleaning solvents are assumed to be contained in sealed drums until their transfer to a waste disposal site. Therefore, airborne releases of VOCs from within sealed drums at the auto refinishing shop are considered to be negligible.

Overview of the Automotive Refinishing Industry

Refinishing operations occur in auto body repair/paint shops, production auto body paint shops, new car dealer repair/repaint shops, fleet operator repair/paint shops, and custom-made car fabrication facilities.

Automotive refinishing shops fall under North American Industry Classification System (NAICS) code 811121 – Automotive body, paint, and interior repair and maintenance¹. According to the U.S. Census Bureau's 2004 *County Business Patterns* (CBP), there are 36,296 refinishing shops in the United States, employing a total of 227,489 people [USCB, 2004a]. Table 1-4 shows the distribution of facilities and employees, based on the employment-size class (i.e., the number of employees at each shop). Note that 80 percent of U.S. automotive refinishing shops have less than 10 total employees.

¹ The industry sector, defined by NAICS 811121, "...comprises establishments primarily engaged in repairing or customizing automotive vehicles, such as passenger cars, trucks, and vans, and all trailer bodies and interiors; and/or painting automotive vehicles and trailer bodies."

Table 1-4. Number of U.S. Facilities and Employees by Employment-Size Class for the Automotive Body, Paint, and Interior Repair and Maintenance Sector (NAICS Code 811121)

Employment -Size Class	1-4	5-9	10-19	20-49	50-99	100- 249	250- 499	500- 999	≥1,000	Total
Number of Facilities (% of total)	20,654 (57%)	8,243 (23%)	5,457 (15%)	1,792 (5%)	125 (<1%)	22 (<1%)	2 (<1%)	--	1 (<1%)	36,296 (100%)
Number of Employees (% of total)	38,718 (17%)	54,894 (24%)	72,239 (32%)	48,787 (21%)	5,000- 9,999 (2-4%)	3,083 (1%)	500- 999 (<1%)	--	1,000- 2,499 (<1%)	227,489 (100%)

Source: USCB, 2004a.

In a draft ESD prepared by the United Kingdom, a total of 60,330 automotive refinishing shops were projected to exist in Europe in 2007, and half of these were expected to employ five or fewer workers [OECD, 2006].

PROCESS DESCRIPTION

This ESD describes the sources of release and worker exposures to the *nonvolatile* components of coating formulations used in automotive refinishing operations. It does not cover the manufacture of the chemical raw materials used in coating additives or the formulation of those coating additives prior to their sale to automotive refinishing shops.

As described in Section 1.1, the automotive refinishing process involves the following steps (see Figure 2-1):

- Structural repair;
- Surface preparation (cleaning and sanding);
- Primer coat mixing;
- Spray application of primer coat;
- Curing;
- Sanding;
- Solvent wipe-down;
- Topcoat (basecoat color and clearcoat) mixing;
- Spray application of topcoat; and
- Curing.

This ESD describes the use of automotive refinishing coating additives in the mixing, spray painting, and curing steps. As illustrated in Figure 2-1, the process of mixing, spray painting, and curing is repeated for each coating applied to the automotive surface being refinished. Figure 2-2 presents a flow diagram for the use of coating products in the automotive refinishing operation, including potential release and exposure points of the chemical of interest.

The following subsections describe typical processes, chemicals used, and potential release and exposure points during these coating steps.

Paint Mixing

Automotive refinishing coating products arrive at most facilities in 1-quart to 5-gallon containers [BASF, 1996]. In most cases, the final automotive refinishing coatings are mixed into their final formulations just prior to being applied at the shop. Various coating products such as hardeners, reducers, activators, atomizing agents, or colorants are blended together according to the paint manufacturer's specifications to aid in the application or curing of the coatings or to properly match the basecoat colors [USEPA, 2002].

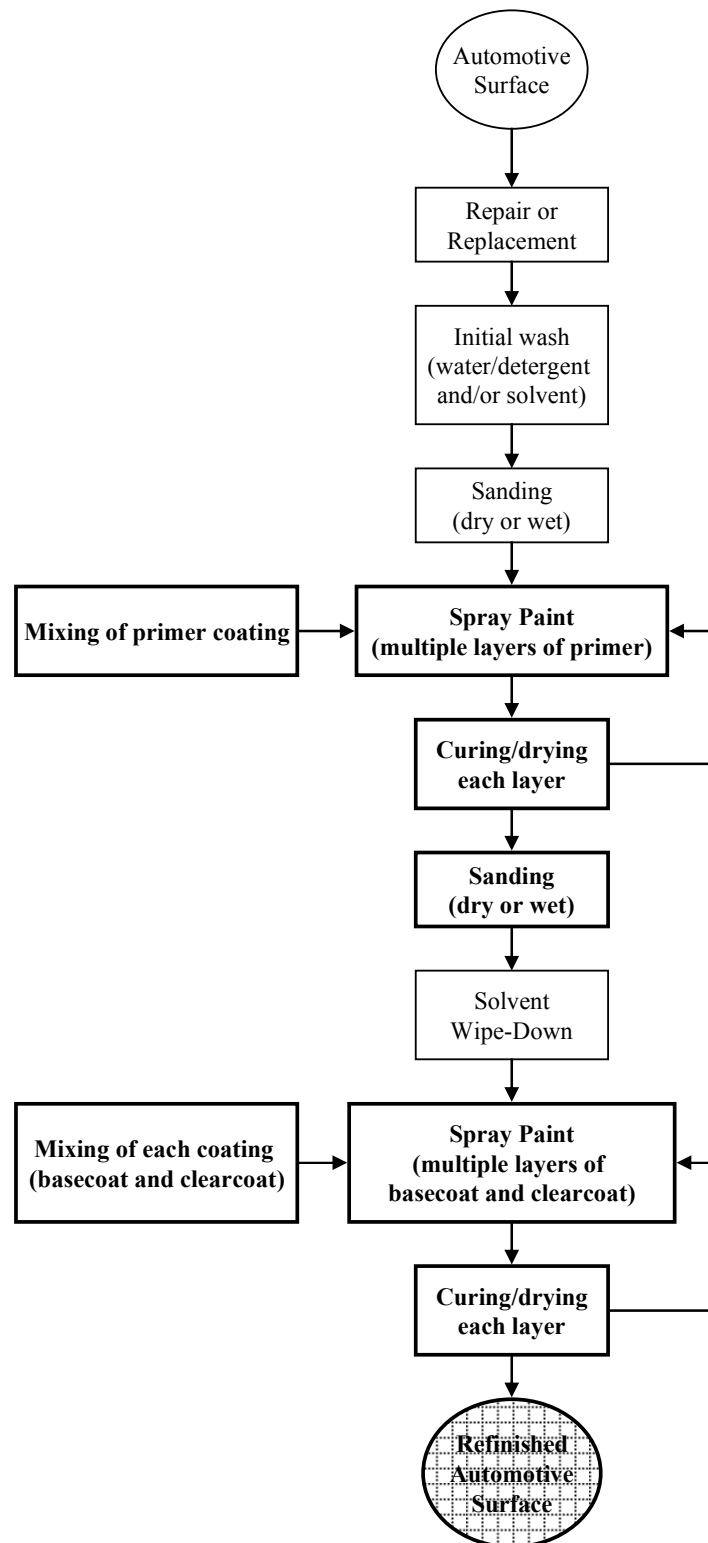
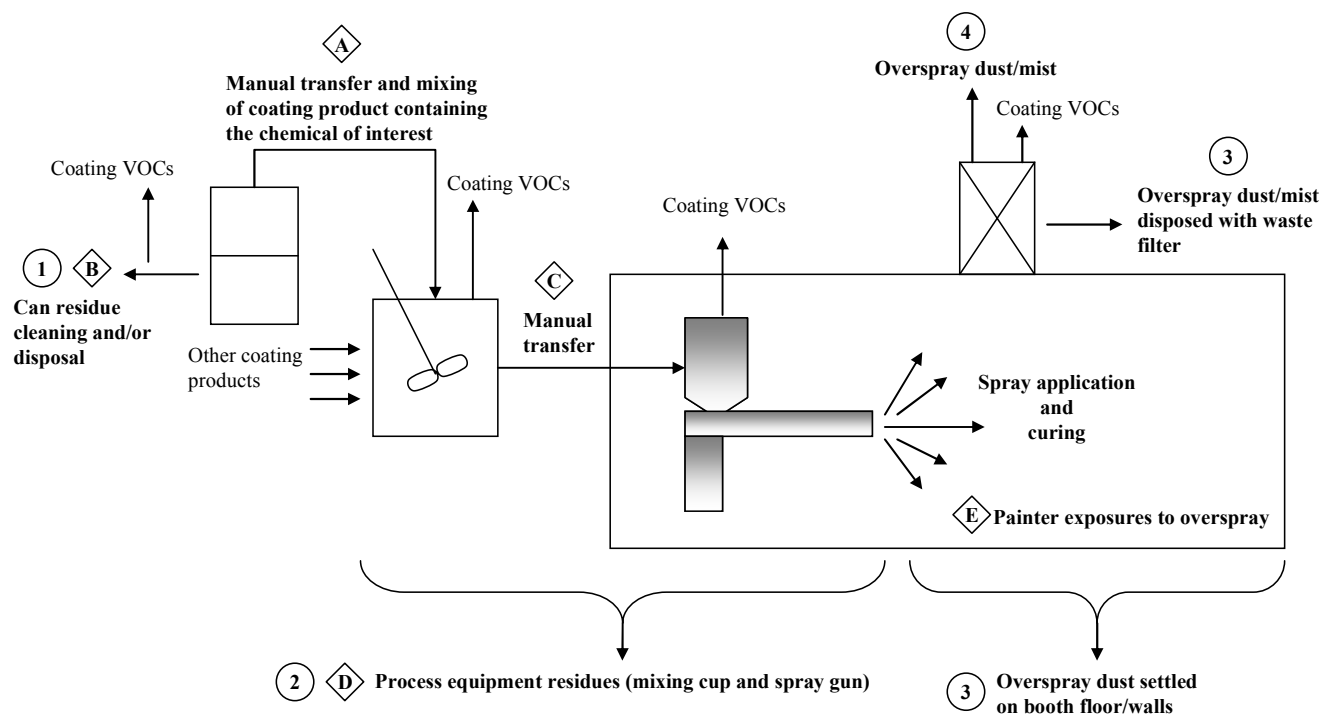


Figure 2-1. Overview of the Automobile Refinishing Process



○ = Environmental Releases:

1. Container residue from coating product transport container disposed to incineration or landfill.
2. Process equipment (mixing cup, spray gun, spray booth floors/walls) cleaning residues disposed to incineration or landfill.
3. Oversprayed coating mists/particles captured within spray area and other controls (e.g., dry filters) disposed to incineration or landfill.
4. Oversprayed coating mists/particles not captured by emission controls and vented to outside air.

◇ = Occupational Exposures:

- A. Dermal exposure from unloading/mixing liquid coating product into final coating, as sprayed.
- B. Dermal exposure to cured/solid or liquid coating product components during container cleaning.
- C. Dermal exposure to final mixed liquid coating during manual transfer from mixing cup to spray gun.
- D. Dermal exposure to final mixed liquid coating during equipment cleaning of mixing cup, spray gun, and spray booth floors/walls.
- E. Inhalation and dermal exposure to solid/liquid coating particulates (i.e., overspray mist) during spray application.

Figure 2-2. Automotive Refinishing Spray Coating Processes

Most automotive refinishing shops have designated paint mixing rooms where the majority of coating mixing occurs. Primers, clearcoats, and basecoats are usually mixed separately by hand in small containers to match the amount of coating needed for the job. Basecoat colors are often also mixed with mechanical agitators to ensure thorough mixing for color matching purposes [USEPA, 2002].

Some shops will order a limited range of basecoat colors premixed from their supplier; however, most automotive refinishing shops mix their own colors. Basecoat colors are typically mixed according to specific color menus provided through hard-copy materials, microfiche, or a computerized database system. These menus can provide specific instructions for several thousand colors. Shops that mix their own colors typically stock 30 to 60 colored tones [USEPA, 2007].

While hard-copy and microfiche menu systems require painters to mix predetermined amounts (e.g., 1 quart, 1 pint, ½ pint), computerized systems allow painters to mix varying (typically smaller) amounts based on an estimate of the amount of paint needed for the job. Thus, computerized systems can help painters reduce paint wastes [USEPA, 2002]. Workers may also rely on their own experience and information provided by the coating distributor to determine the relative amounts of the individual ingredients needed to achieve the desired basecoat properties [ERG, 1998].

The quantity of coating required varies based on the size of the job. One automotive refinishing coating product manufacturer estimated that about one gallon of coating is mixed at a time for a full body job; one quart for fenders or panel repairs; and one pint for small touch-ups [DuPont, 2006].

The coatings are metered or poured by hand into a mixing cup or other apparatus (Exposure A). The empty transport containers are either crushed for disposal or solvent-washed for future use (Release 1, Exposure B), and their residue is disposed to landfill or incineration (Release 1) [ERG, 1999]. If the chemical is contained in a waterborne coating product, the shop could potentially rinse the containers with water and discharge this rinse water; however, some states and localities require that this water be disposed of with the shop's hazardous waste.

The mixed coating is then transferred from the mixing cup to the spray gun cup (Exposure C). In situations where all of the coating in the mixing container is not needed for a particular job, the container is resealed with the remaining coating. Often these "left-over" coatings can be used in primers, for which a perfect color match is not important. Once these mixing/storage containers are emptied, the residues are rinsed from the mixing cup and disposed with the other process equipment wastes to landfill or incineration (Release 2, Exposure D). Again, if the chemical is contained in a waterborne coating product, the mixing container could be rinsed with water and this rinse water discharged from the shop; however, some states and localities require that this water be disposed of with the shop's hazardous waste.

Many engineering control practices exist to mitigate worker exposure to the volatile solvents contained in the paint products. In most shops, the paint mixing rooms have some form of general mechanical ventilation (e.g., an exhaust fan installed on an external wall). Some shops may have a local exhaust system installed over the mixing bench [USEPA, 2002].

Coating Application via Spray Painting

The primer coating is the first coating applied to the car. If the car part to be coated is new, *primer sealer* is applied to provide corrosion resistance, promote adhesion of subsequent coatings, and enhance the uniform appearance of the topcoat (i.e., basecoat color and clearcoat) [USEPA, 2007a]. As described in Section 1.1.1, if the surface is an existing or salvaged part to be refinished, the part is first structurally repaired, then the area to be sprayed is masked and a high-solids surfacer (which performs the same functions as the primer sealer and also fills in surface imperfections) is sprayed on the part. Some

primer surfacers can be rolled or brushed onto small areas (generally less than one-half of a square foot), which greatly reduces the waste generated via spray application techniques [USEPA, 2007a]. The primer sealer is lightly sanded to smooth out dirt or other imperfections, but most of the sanding is performed on the primer surfacer [USEPA, 2002]. Since the goal in sanding the primer is to remove minor imperfections, EPA expects that releases of and exposure to the primer coating during this activity are negligible compared to the other spray coating processes; therefore, this release and exposure are not quantified in this ESD.

After the primer coating is applied, sanded, and wiped down (see Section 1.1.2), the basecoat color and clearcoat are sprayed on and cured (see Section 2.3). Often, more than one coat of each type of coating (i.e., primer, basecoat, and clearcoat) is applied.

Spraying a liquid coating onto a surface generates a certain amount of “bounce-back” of the atomized coating mist from the surface it impinges. This bounce-back is the source of coating mist generated during the spray coating process, termed *overspray*. The *transfer efficiency* of a spray gun is the measure of how much coating is transferred to the automobile surface vs. how much is oversprayed (i.e., a spray gun having 65 percent transfer efficiency can transfer 65 percent of the coating in the cup to the automobile surface and loses 35 percent in overspray).

Nearly all automotive refinishing spray coating processes are conducted in an enclosed or curtained area of the shop, equipped with ventilation systems and supply air filters to prevent contamination of the newly applied finish (e.g., a spray booth, as described in Section 2.2.2) [USEPA, 2007a]. Often, these areas also incorporate a dry filter or other device to trap the oversprayed paint mists prior to their emission from the shop. Some of that oversprayed mist settles on the floor and walls of the area/booth and is subsequently swept or cleaned and disposed with other oversprayed coating wastes (Release 3) to landfill or incineration. For the purposes of estimating inorganic HAP and particulate matter (PM) emission reductions for the Paint Stripping and Surface Coating NESHAP, EPA assumed that 50 percent of the overspray settles on the spray area walls, floor, and the masking paper [USEPA, 2007a].

The remaining mist is removed from the workspace via the ventilation system. This ventilated mist typically passes through a dry filter that is installed in the exhaust system. These filters are periodically changed out and disposed to landfill or incineration (Release 3). The coating mists/particulates that are not captured by the filter are emitted from the shop stacks into the surrounding environment (Release 4).

Painters may be exposed to chemicals in the coating mists through dermal contact and inhalation of the oversprayed coating mists during spray painting (Exposure E). Companies can likely reduce releases and exposures by conducting all spraying activities in a well-maintained and ventilated prep station or spray booth using a high transfer efficiency spray gun (e.g., HVLP) with proper spray techniques. The subsections below discuss these two primary technologies, which impact the releases of and exposures to chemicals contained in the refinishing coatings.

Using proper personal protection equipment such as respiratory protection and skin protection also reduces occupational exposures.

Spray Guns

The two most common coating application tools are the conventional spray gun and the high-volume, low-pressure (HVLP) spray gun. Both spray guns have a mounted cup to hold the coating formulation and are connected to a pressurized air supply by a hose. The pressurized air atomizes the

coating materials into a spray that is transferred to the automobile surface. These spray gun types are described below.

Conventional Spray Guns

Pressurized air, provided by an air compressor, is forced through the gun nozzle at 30 to 90 psig [USEPA, 1994]; the coating is atomized in the air at the nozzle throat. Due to the high pressures at the gun nozzle, conventional spray guns are characterized by excessive spray mist and overspray fog. High overspray amounts result in lower transfer efficiencies of approximately 20 to 40 percent [Heitbrink, 1996]. As transfer efficiency decreases, material use, air emissions, and solid wastes increase.

A transfer efficiency of 20 percent is recommended for use as the *worst-case* default value for the environmental release estimates from the use of conventional spray guns.

HVLP Spray Guns

HVLP spray guns use large quantities of low-pressure air (typically less than 10 psig at the tip of the spray gun) to atomize the coating. Two types of HVLP guns are primarily used: gravity-fed and siphon cup. Gravity-fed spray guns are designed with the paint cup above the atomization nozzle. The coating is released into the spray gun's air stream to be sprayed on to the automobile. Siphon cup spray guns, also known as suction guns, have paint cups below the gun nozzle. Controlled air pressure meters the flow of coating into the atomization nozzle. Because these spray guns use lower pressures to atomize the coatings than conventional spray guns, more of the coating is transferred to the surface with less overspray, with higher transfer efficiencies averaging 65 percent [Heitbrink, 1996].

A transfer efficiency of 65 percent is recommended for use as the *typical* default value for the environmental release estimates from the use of HVLP spray guns.

Conventional vs. HVLP Spray Guns

In 1995, 64 percent of automotive refinishing shops reported owning HVLP spray guns [BSB, 1995]; however, many painters reported using a HVLP spray gun to apply primer and basecoat, but a conventional spray gun to apply clearcoats. At the time, shops resisted the switch to HVLP spray guns because of the capital investment and the training costs for painters to learn proper techniques for applying coatings using lower pressures.

Today, while conventional spray guns are still commercially available, they are becoming obsolete in the automotive refinishing industry. Industry sources have estimated that HVLP is now used for more than 90 percent of automobile refinishing. This is in part due to the increasing limitations placed on automotive refinishing shop emissions (e.g., several states and ozone nonattainment areas require the use of HVLP spray guns or their equivalent), but shops can also achieve a significant material savings by switching from conventional spray guns to HVLP. [USEPA, 2007a]

The Paint Stripping and Surface Coating NESHAP requires that all spray coating processes involving certain HAPs are performed by certified, trained painters using HVLP spray guns. HVLP spray guns used by trained painters are considered to be *generally available control technology* (GACT) for the automotive refinishing industry [73 FR 1738; January 9, 2008].

Prep Stations and Spray Booths

Automotive refinishing shops conduct several of their process steps in a prep station or spray booth to control dispersion of coating overspray, provide a closed compartment for forced air drying, and separate volatile components and coating solids from the workplace. Air entering spray booths is filtered to remove dust, which is necessary to ensure the quality of coating jobs. Spray application facilities vary in design from designated spray areas to well designed and operated booths.

Between 50 and 80 percent of automobile refinishing shops use minimum engineering controls to protect workers [BSB, 1995]. The majority of automotive refinishing shops use spray booths, the generally accepted practice for ensuring a good quality finish; however, it is difficult to determine the exact fraction of U.S. shops that have and use spray booths [USEPA, 2007a]. As expected, the larger shops are more likely to have spray booths [BSB, 1995]. As this industry continues to move toward slower-drying, high-solids coatings, more shops are likely to install them.

Spray booths are designed with the following configurations:

- Crossdraft booths move overspray along the length of the car using forced air. Make-up air is drawn through filters in the front of the booth, over the automobile, and through filters located in the back of the booth. Approximately 50 percent of automobile refinishing shops use cross-draft booths [BSB, 1995].
- Downdraft booths blow air to move overspray from the ceiling to the floor, out of the breathing zone. Clean make-up air enters through filters in the ceiling of the booth, and the contaminated air is drawn from the booth through metal grates in the floor. Figure 2-3 illustrates the ventilation scheme of a downdraft spray booth. Approximately 30 percent of automobile refinishing shops use downdraft booths [BSB, 1995]. Downdraft booths are preferred over cross-draft booths because they lower mist and particle concentrations in the workspace. An increasing number of shops are buying downdraft booths instead of cross-draft booths [BSB, 1995]. Although they are the most expensive of the spray booth types.
- Semi-downdraft booths provide make-up air through filters in the ceiling like downdraft booths; however, exhaust air is drawn through filters in the back of the booth like crossdraft booths.

Prep stations are similar in design to spray booths except they are often smaller and use curtains instead of constructed walls to isolate and contain the work area.

The Paint Stripping and Surface Coating NESHAP requires that all spray coating processes involving certain HAPs are performed in a prep station or spray booth having a full roof and at least three complete walls or side curtains, and ventilated such that clean air is drawn into the booth and exhaust is directed through a filter and outside of the shop workspace. This equipment is considered to be GACT for the automotive refinishing industry [73 FR 1738; January 9, 2008].

These control technologies lower the potential for painter exposure by removing oversprayed coating particles and volatile components from the workspace, and often incorporate either dry filtration or wet filtration (also termed *water-washed* or *water-backed* filtration) of the exhaust prior to emission from the shop. Shops in the U.S. automotive refinishing industry typically use dry filters over wet systems because they are inexpensive and relatively simple to maintain. If wet filtration systems are

found in this industry, they are usually limited to the high-production shops [USEPA, 2007a]. Hygiene surveys in literature and information from a spray booth manufacturer indicate that water controls in refinishing spray booths are seldom, if ever, used [DeVilbiss, 1996].

Industry and vendor information collected by EPA indicates that fiberglass and polyester fiber filters are the most common type used by the automotive refinishing industry. In general, the mist/dust capture efficiency of dry filters typically ranges from 87 to 99.8 percent, with an average of 90 percent [USEPA, 1987]. Fiber-type filters are at least 99 percent efficient, while cardboard and styrofoam baffle filters have significantly lower efficiencies [USEPA, 2006].

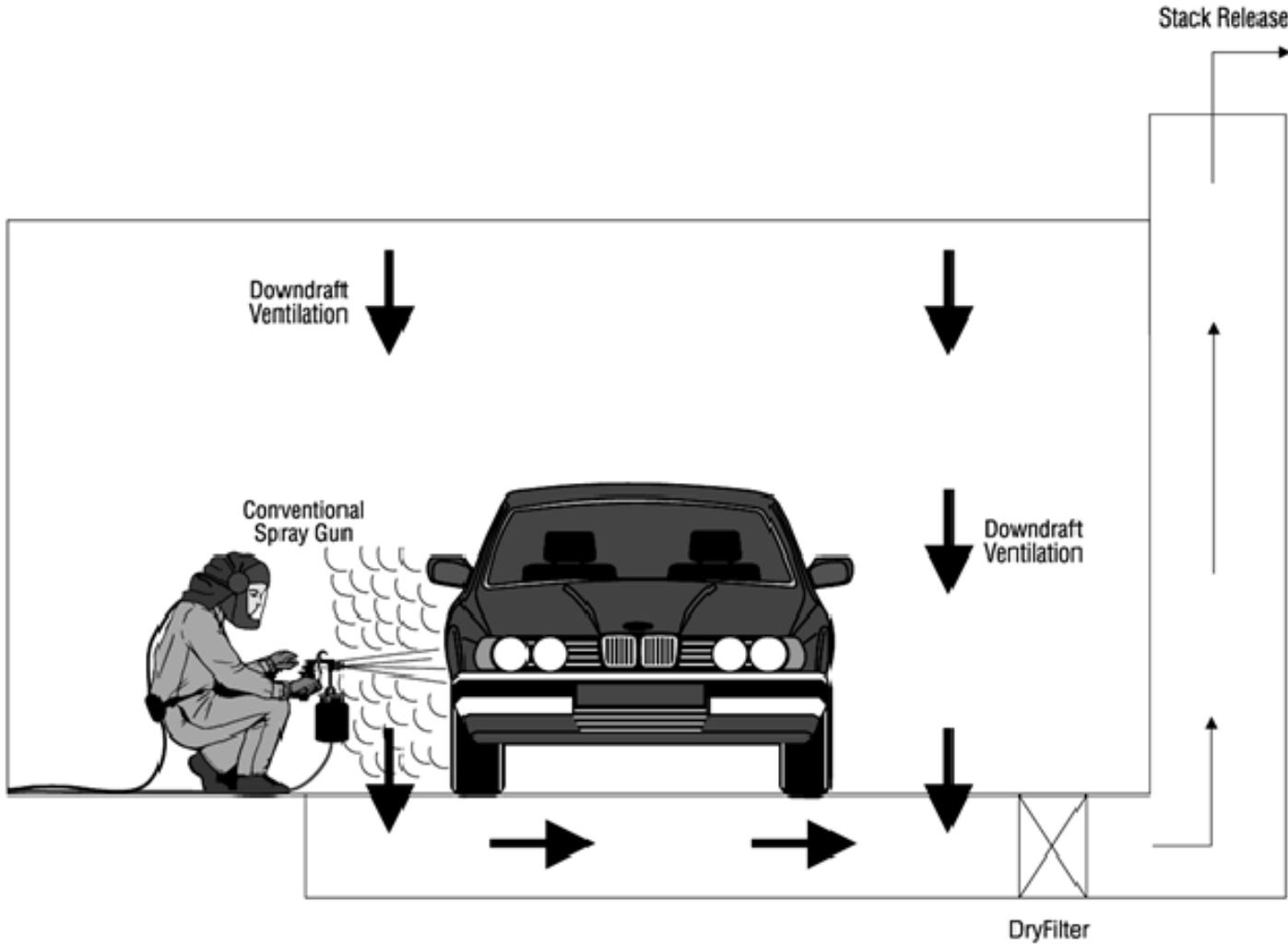


Figure 2-3. Air Flow in Downdraft Spray Booth

For the purposes of estimating inorganic HAP and PM emission reductions for the Paint Stripping and Surface Coating NESHAP, EPA assumes that the filters have a 96 percent capture efficiency (median of all filter performance data collected in support of the Paint Stripping and Surface Coating NESHAP) [USEPA, 2007a]. The Paint Stripping and Surface Coating NESHAP requires that all spray coating processes involving certain HAPs are performed in a prep station or spray booth equipped with fiberglass or polyester fiber filters or other technology having at least a 98-percent capture efficiency. This equipment is considered to be GACT for the automotive refinishing industry [73 FR 1738; January 9, 2008].

Very few automotive refinishing shops utilize VOC controls, due to their relatively high costs; therefore, virtually all of the VOCs in the applied coatings are expected to be vented from the spray booth during application and curing (see Section 2.3).

A particulate/mist removal efficiency of 96 percent is recommended for use as the default value for the environmental release estimates.

Curing

Following application, each layer of coating is cured or dried. The coating may be allowed to dry at atmospheric conditions, or curing may be accelerated by using heated paint booth air or portable heat sources [USEPA, 1994]. Spray booths are typically equipped with fans that provide a flow of heated air to freshly painted vehicle parts. Air from outside of the shop is routed through a heat exchanger and a filter prior to entering the booth. Typical curing temperatures range from 49°C to 60°C (120°F to 140°F) [USEPA, 1997]. Spray booths with a heated air supply reduce the typical curing time from 12 hours to approximately 20 to 30 minutes. After leaving the heated paint booth, the coating will be dry, although the coating film may not be completely cured for days. During curing, coating solvents continue to evaporate.

Spray Gun Cleaning

The spray guns used to apply the coatings may be cleaned manually or with a spray gun cleaning system. When cleaning spray guns manually, painters typically rinse the outside of the spray gun and cup with a solvent. To clean the internal parts of the spray gun, the cup is filled with solvent, which is then transferred through the spray gun by spraying the solvent into the air or into a waste solvent collection drum [USEPA, 1994].

EPA estimates that at least 60 percent of auto refinishing shops use some type of spray gun cleaning system [USEPA, 1994]. In this system, the spray gun is placed within a container (which may be open or enclosed) having connections that pump solvent through the spray gun. Cups and other accessories may also be placed within the container where solvent is flushed over the exposed surfaces. Most cleaning systems collect and reuse the solvent until it becomes too contaminated with waste to clean effectively. When this occurs, the solvent is removed from the system and fresh solvent is added. Often, refinishing shops arrange to have the spent cleaning solvent incinerated by an off-site disposal service. Some shops may reclaim the solvent through distillation performed either on site or through an off-site contracted service [USEPA, 1994].

To reduce the amount of solvent used to clean the spray guns, some shops may utilize disposable Teflon-lined paint cups inside the spray gun cup. After use, the liners are removed from the spray gun cup and disposed of [USEPA, 2007a]. The residual paint may be allowed to dry and the waste liners disposed to a landfill, along with the shop's other solid wastes (e.g., empty coating product

containers described in Release 1). Similarly, it is possible that these liners could be collected with the shop's hazardous wastes and disposed to incineration.

The Paint Stripping and Surface Coating NESHAP requires that, where a HAP solvent is sprayed through the spray gun to clean residues, the process is to be performed within an enclosed spray gun cleaner. Alternatively, the spray gun may be cleaned by hand. Spraying HAP-containing cleaning solvent through the spray gun outside of an enclosed cleaning system is prohibited [73 FR 1738; January 9, 2008].

For the purposes of this ESD, the residual coating cleaned from the spray guns is estimated as part of the overall process equipment residual disposed to landfill or incineration (Release 2, Exposure D). If the chemical is contained in a waterborne coating product, there is a potential that the spray guns are cleaned with water and this rinse water is discharged from the shop; however, some states and localities require that the cleaning water be disposed of with the shop's hazardous waste.

OVERALL APPROACH AND GENERAL FACILITY ESTIMATES

This ESD presents EPA's standard approach for estimating environmental releases of and worker exposures to components used in automotive refinishing coating products. The ESD covers the final onsite formulation of refinishing coatings and their spray application onto automotive surfaces.

The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible; however, EPA acknowledges several areas in which additional automotive refinishing industry data are needed (see Section 7 of this ESD). It should be noted that the default values cited throughout this ESD are intended to be used only when appropriate site-specific or industry-specific information is not available.

Because this ESD presents several alternative default assumptions or values for some estimation parameters, one must consider carefully how the selection of these defaults will affect the final assessment results. For example, conservative or high-end daily use rates will result in more conservative release estimates¹. Alternatively, average or median use rates will result in release estimates that are more "typical" of the industry. This ESD presents available data that support alternative input values.

This section of the ESD presents general facility calculations, which estimate daily use rates of refinishing coating products containing the chemical of interest (as received at the shop), the number of automotive refinishing sites using the chemical of interest, and the number of days the chemical is expected to be mixed and applied in the automotive refinishing operation.

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

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

Introduction to the General Facility Estimates

This section describes a method utilizing available automotive refinishing industry data to estimate the number of refinishing sites that may use a particular type of coating product containing the chemical of interest. These default assumptions and calculations are then used to estimate the number of U.S. automotive refinishing shops that may use the chemical of interest, as well as the number of containers that are emptied and disposed of annually.

The 2004 ESD estimated the facility use rate of the coating product containing the chemical of interest based on the monthly amount of money spent per shop on coating products, an estimated cost per liter of coating obtained from one coating supplier, and an estimated breakdown of the different coating

¹ When evaluating environmental releases, EPA typically assumes the highest daily release is the most conservative, because it will result in the highest aquatic stream concentrations. Therefore, EPA typically uses high-end daily use rates to generate conservative environmental release estimates. Conversely, for conservative occupational exposure assessments, EPA typically uses lower daily use rates, which will result in a greater number of use sites, longer use duration, and a greater number of workers exposed.

products obtained from a 1987 internal EPA memorandum. The resulting default use rate of chemical-containing coating product in the previous 2004 ESD was 160 gallons per shop, per year¹.

This ESD instead uses national 2004 Census Bureau data on the total quantity of automobile refinishing coatings produced in the United States and the total number of automobile refinishing shops in the United States, paired with 2001 California data on the breakdown of the different types of coating products purchased by automobile refinishing shops. The default use rate presented in this ESD ranges from 45 to 452 gallons per shop, per year (median: 105) gallons per shop, per year². While the revised methodology presented in this ESD results in a lower median default use rate than the previous 2004 ESD, EPA will use it because it is based on recent national data rather than older data from individual companies.

Table 3-1 summarizes the general facility estimates described in this section with their corresponding ESD section number. In addition, Table A-2 in Appendix A summarizes the default values used as inputs to each of the general facility estimates, accompanied by their references.

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

Table 3-1. Summary of General Facility Parameters

Parameter	Description	ESD Section
TIME _{working_days}	Annual number of days the coating product is used at each shop (days/yr)	3.2
V _{allcoat_site_yr}	Annual facility total automotive refinishing coating product use rate (gal/site-yr)	3.3
V _{allcoat_site_day}	Daily facility total automotive refinishing coating product use rate (gal/site-day)	3.4
F _{vol_coattype_prod}	Volumetric fraction of all automotive refinishing coating products that contain the chemical of interest (gal chemical-containing product/gal all coating products)	3.5
Q _{coattype_day}	Daily facility automotive refinishing coating product use rate (kg/site-day)	3.6
Q _{chem_day}	Daily use rate of the chemical of interest (kg/site-day)	3.7
N _{sites}	Number of shops using the chemical-containing coating product	3.8
N _{cont_site_yr}	Annual number of chemical-containing coating product containers emptied per facility (container/site-yr).	3.9

¹ This default use rate was determined using Equation 3-1 and the associated default values presented in the 2004 ESD (605 L/shop-yr), and then converted to gallons (160 gal/shop-yr) to compare with the current ESD median default use rate.

² The default use rate range is determined using Equation 3-1 and the 2004 U.S. Census data presented in this ESD (1,505 gal/shop-yr), along with the range in volumetric fractions of coating products that are expected to contain a single chemical of interest, as described in Figure 3-1 for an unknown coating product as a default (i.e., 3 to 30% (median: 7%) of all coating products contain a common chemical): 1,505 gal/shop-yr \times 7% = 105 gal/shop-yr.

Operating Days (TIME_{working_days})

If specific information is not available to estimate the number of days that refinishing coatings are spray applied per year (TIME_{working_days}), EPA recommends assuming a default of 250 days per year at each shop:

$$\text{TIME}_{\text{working_days}} = \text{Days of automotive refinishing coating product use per year (Default: 250 days/yr)}$$

For the purposes of this assessment, the shops may be assumed to operate over five days per week, 50 weeks per year, based on best engineering judgment. EPA did not find alternative, industry-specific data in the references reviewed for this ESD (refer to the Section 8 for a description of the sources reviewed and full citations for those specifically used in these calculations).

Average Annual Facility Volume Use Rate, All Coating Products (V_{allcoat_site_yr})

The average annual facility use rate for all automotive refinishing coating products (in this case, the amount of coating *received* at each shop) is estimated using data available through the U.S. Census Bureau. The *Current Industrial Report for Paint and Allied Products* reported that 54,473,000 gallons of “automotive, other transportation and machinery refinish paints and enamels, including primers” were produced in 2004 [USCB, 2004b]¹, and accounted for approximately three percent of all paint products manufactured in the United States. EPA assumes an additional 160,000 gallons of reducer (i.e., thinner) products were sold to and used by the automotive refinishing industry²; therefore, EPA estimates a total of 54,633,000 gallons of automotive refinishing coating products. As discussed in Section 1.4, the 2004 *County Business Patterns* (CBP) reported a total of 36,296 U.S. shops within NAICS code 81121 [USCB, 2004a].

Assuming that the vast majority of the automotive refinishing coatings produced were purchased and used by the automotive refinishing shops included in NAICS code 81121, the following calculation may be used to determine the average annual volume of total coatings purchased at each facility:

$$V_{\text{allcoat_site_yr}} = \frac{V_{\text{allcoat_yr}}}{N_{\text{allsites}}} \quad (3-1)$$

Where:

$$\begin{aligned} V_{\text{allcoat_site_yr}} &= \text{Annual per shop total automotive refinishing coating product use rate (gal all coating products/site-yr)} \\ V_{\text{allcoat_yr}} &= \text{Total U.S. automotive refinishing coating production rate (Default: 54,633,000 gal all refinishing coating products produced/yr [USCB, 2004b])} \end{aligned}$$

¹ This quantity, provided by the U.S. Census Bureau product code 3255107131 as part of the *Special-purpose coatings* category, is separate from the *Product finishes for original equipment manufacturers (OEM)* category and as such, does not include coatings used for OEM automobiles.

² It is also noted that the Paint and Allied Products category the refinish paints category and a separate category for “thinners for lacquers and other solvent-based paint products.” Since it is unknown what portion of these thinners are specifically used with refinish paints, EPA assumes the following amount of thinners (proportional to the refinish paint quantity) is used by the automotive refinishing industry: 3% of 5,329,000 gallons thinner [USCB, 2004b] = 160,000 gallons thinner used with refinish paints.

$$N_{\text{allsites}} = \text{Total number of U.S. automotive refinishing shops} \\ \text{(Default: 36,296 sites [USCB, 2004a])}$$

Based on the latest (2004) U.S. Census data for this industry, EPA assumes an average of 1,505 gallons per shop, per year of refinishing coating products are purchased and used by U.S. automotive refinishing shops. Note that this estimate does not account for coating products that are imported or exported.

Average Daily Facility Volume Use Rate, All Coating Products ($V_{\text{allcoat_site_day}}$)

The average daily facility volume use rate may be estimated by dividing the average annual use rate by the number of operating days, using the following calculation:

$$V_{\text{allcoat_site_day}} = \frac{V_{\text{allcoat_site_yr}}}{\text{TIME}_{\text{working_days}}} \quad (3-2)$$

Where:

$$V_{\text{allcoat_site_day}} = \text{Daily facility total volume automotive refinishing coating product use rate (gal all coating products/site-day) (see Table 3-2 for alternative rates)}$$

$V_{\text{allcoat_site_yr}}$	=	Annual per shop total automotive refinishing coating product use rate (gal all coating products/site-yr) (Default: 1,505 gal/site-yr; see Section 3.3)
$\text{TIME}_{\text{working_days}}$	=	Days of automotive refinishing coating product use per year (days/yr) (See Section 3.2)

In preparing this ESD, EPA searched for available coating use rates within the automotive refinishing industry and found a range of rates, primarily based on the size of the refinishing shop and the number of “jobs” that are completed per day. Table 3-2 summarizes these available data and their sources.

Table 3-2. Summary of Available Automotive Refinishing Coating Use Rates

Volume Use Rate	Equivalent Daily Volume Use Rate ($V_{\text{allcoat site day}}$) (gal/site-day)	Source
605 liters/shop-yr (over 180 days/yr)	0.9	OECD, 2004
10-30 liters/shop-week (over 5 days/week)	0.5-1.6 (mean: 1.0)	USEPA, 2002
Estimated use rates obtained during site visits to five shops: 1 quart/shop-day to 120 gallons/shop-month (assuming over 20 days/month)	0.25-6 (mean: 3.1)	USEPA, 2007b
1,505 gallons/shop-year (over 250 days/year)	6 (Default)	USCB, 2004a USCB, 2004b (see Section 3.3)
Range: 0.6 liter/job (small area (<0.4 m ²) using HVLP and medium solids coating) to 7.5 liters/job (whole car using HVLP and high-solids/waterborne coating) (assuming 10-30 jobs/week, per USEPA, 2002) (over 5 days/week)	0.3-12 (mean: 6.2)	OECD, 2006
<i>Average of available data:</i>	<i>3.4</i>	

Note that the use rates listed in Table 3-2 for the shop visits (Source: USEPA, 2007b) were provided during the visit interview and are rough estimates of the amount of coating the shop uses in a given period of time. While EPA assumed that the shop visit estimates represent the total amount of all coating types used, the estimates were not verified against the shops’ purchase receipts or other records.

The default use rate ($V_{\text{allcoat_site_day}}$), based on U.S. Census data and calculated with Equation 3-2, is at the upper end of the range in use rates found to date and is consistent with the use rate of a large refinishing shop. One reason is that the U.S. Census data on the volume of automotive refinishing coating produced ($V_{\text{allcoat_yr}}$) includes all coating products. In reality, a single automotive refinishing shop

is not likely to use all of these coating product types or all brands within each product type; however, no information was available on what portion of all coatings produced are typically used by a single refinishing shop.

Fraction of Coating Products that Contain the Chemical of Interest ($F_{\text{vol_coatype_prod}}$)

The chemical of interest is not likely to be found in all automotive refinishing products sold to refinishing shops each year. Rather, it is likely to be used within certain types of coatings and, among these, used within particular brands or formulations.

Table 1-1 summarizes the relative amounts of the top selling automotive refinishing products in 2001, in California. Assuming that the relative volumes sold to refinishing shops in California can be extrapolated to all U.S. refinishing shops, these data may be used to adjust the average daily volume use rate for all coating products ($V_{\text{allcoat_site_yr}}$, estimated in Section 3.4) to one that reflects the use rate of those products that are expected to contain the chemical of interest ($F_{\text{vol_coatype}}$).

The recommended default value for $F_{\text{vol_coatype}}$ depends on the particular type of coating product expected to contain the chemical of interest. Figure 3-1 presents a logic diagram that can be used to determine the appropriate default.

If the chemical of interest is contained in more than one coating product type (e.g., used as a pigment in single- and multi-stage color coat products), the appropriate volumetric fractions from Table 1-1 or other source should be added together. For example, if the chemical of interest is incorporated into a pigment, which is used in single-stage and multistage color coat products, $F_{\text{vol_coatype}}$ can be estimated using the CARB data in Table 1-1: 7 percent single-stage color coat products + 11 percent multi-stage color coat product => the chemical of interest-containing pigment is estimated to be used in 18 percent of all refinishing coating products (i.e., $F_{\text{vol_coatype}} = 0.18$).

If it is known that the chemical of interest will be used within a limited number of coating product type formulations or brands, the portion of the coating product type(s) that contains the chemical of interest ($F_{\text{vol_coatype_brand}}$) parameter may be used to adjust the total coating product type amount to reflect only those formulations or brands that contain the chemical. For example, if the chemical is to be used only in DuPont® clearcoats and the relative portion of DuPont® clearcoats is also known, the $F_{\text{vol_coatype_brand}}$ parameter would be set to that portion. However, if specific information about the $F_{\text{vol_coatype_brand}}$ portion is not known, EPA recommends assuming 100 percent of the coating product type(s) sold contains the chemical of interest¹:

$$F_{\text{vol_coatype_prod}} = F_{\text{vol_coatype}} \times F_{\text{vol_coatype_brand}} \quad (3-3)$$

Where:

$F_{\text{vol_coatype_prod}}$	=	Volumetric fraction of all automotive refinishing coating products that contain the chemical of interest (gal coating product containing the chemical of interest/gal all coating products)
$F_{\text{vol_coatype}}$	=	Volumetric fraction of all automotive refinishing coating products that is the particular type of coating product that

¹ Using the upper bound production/purchase rate will provide a conservative (worst-case) assessment for releases, as well as worst-case exposures; however, it will not provide a conservative result in the total number of workers potentially exposed to the chemical of interest (i.e., the total number of shops and thus the number of workers will be minimized).

$F_{\text{vol_coattype_brand}}$ = contains the chemical of interest (gal coating product type/gal all coating products) (see Figure 3-1 for appropriate default value)
Volumetric fraction of the automotive refinishing coating product type that contains the chemical of interest (Default: 1 gal coating product type brand or formulation containing the chemical of interest/gal coating product type)

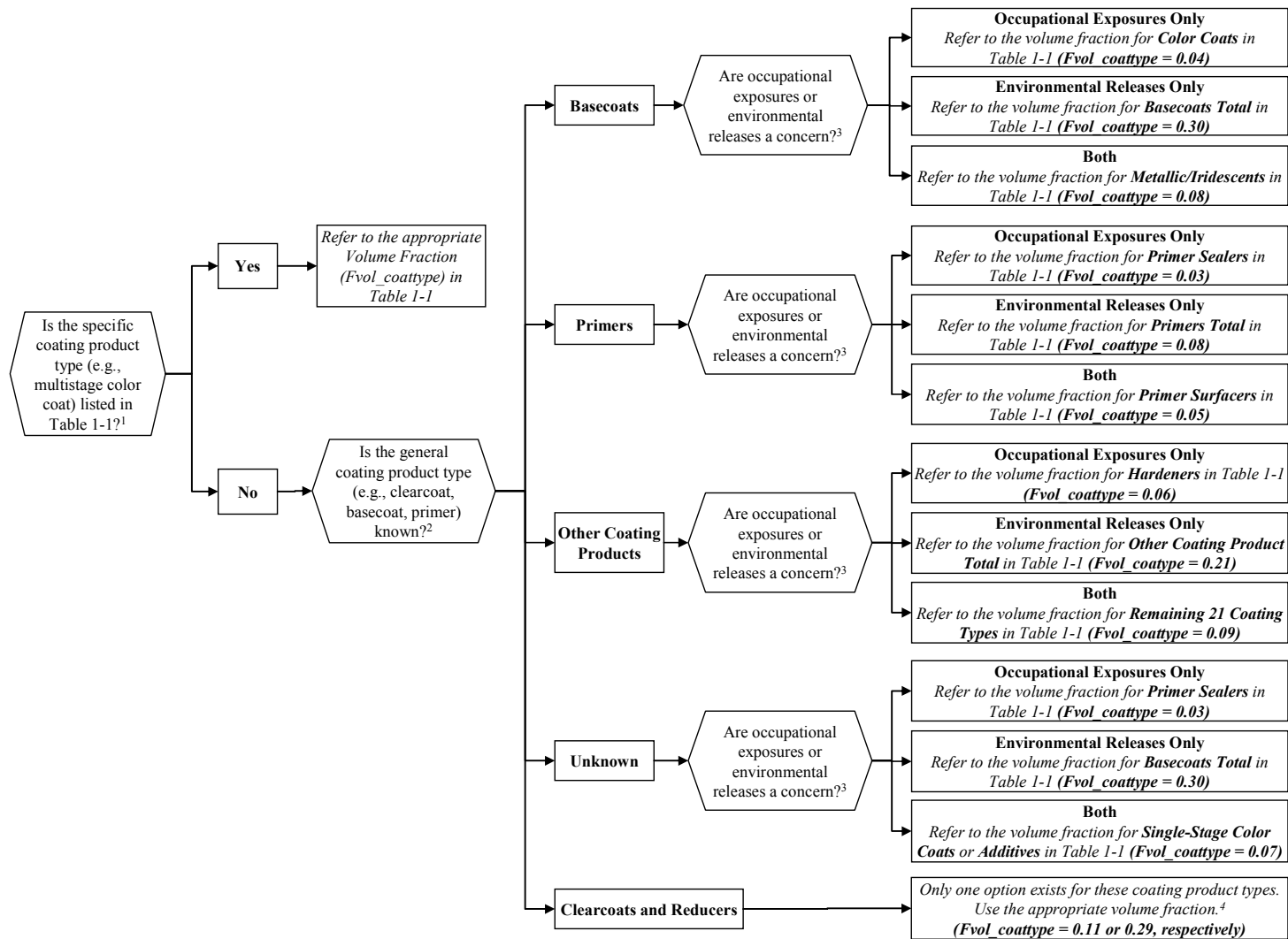


Figure 3-1. Logic Diagram to Determine Appropriate Volumetric Fraction of All Automotive Refinishing Products that is the Chemical-Containing Coating Product Type (Fvol_coatype)

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

Footnotes to Figure 3-1

- 1) If the specific type of coating product (e.g., multistage color coat) containing the chemical of interest is listed in Table 1-1, use the appropriate volume fraction. However, if the specific type of coating product is unknown, then consider the general type of coating product (e.g., primer, basecoat, clearcoat) when selecting the appropriate default volumetric fraction of chemical-containing coating product types ($F_{vol_coattype}$).
- 2) If the general type of coating product (e.g., primer, basecoat, clearcoat) is known, but the specific type is unknown, use data specific for the general coating product type. If the general type of coating product is also unknown, use the methodology shown in Figure 3-1 for “unknown.”
- 3) When selecting volume fractions based on potential concerns, EPA typically uses the following methodology to make conservative assessments. For conservative occupational exposure estimates, facilities with the lowest annual use rates are typically selected. This maximizes the number of use sites and therefore maximizes the number of workers. For conservative environmental release assessments, facilities with the highest annual use rates are typically selected. This maximizes the daily use rate and therefore results in the highest daily release. If both releases and exposures are a concern, median values are typically utilized. EPA used this methodology to select the defaults in Figure 3-1, with one exception. For primers, the volume fraction for *primer sealers* is the lowest, will result in the lowest annual use rate, and was selected for conservative occupational exposure estimates for primers. Conversely, the volume fraction for *primers total* is highest and was selected for conservative environmental release estimates for primers. The volume fraction for *primer surfacers* is the median value available for primers and is used when both occupational exposures and environmental release assessments are conducted.
- 4) Subtypes of clearcoats and reducers were not available. Therefore, use the volumetric fractions for clearcoats and reducers, respectively, for all estimates for chemicals contained in these coating product types.

Daily Facility Mass Use Rate of the Coating Product Containing the Chemical of Interest
($Q_{\text{coatype_day}}$)

The daily facility use rate for the coating product containing the chemical of interest can be estimated by the following calculation:

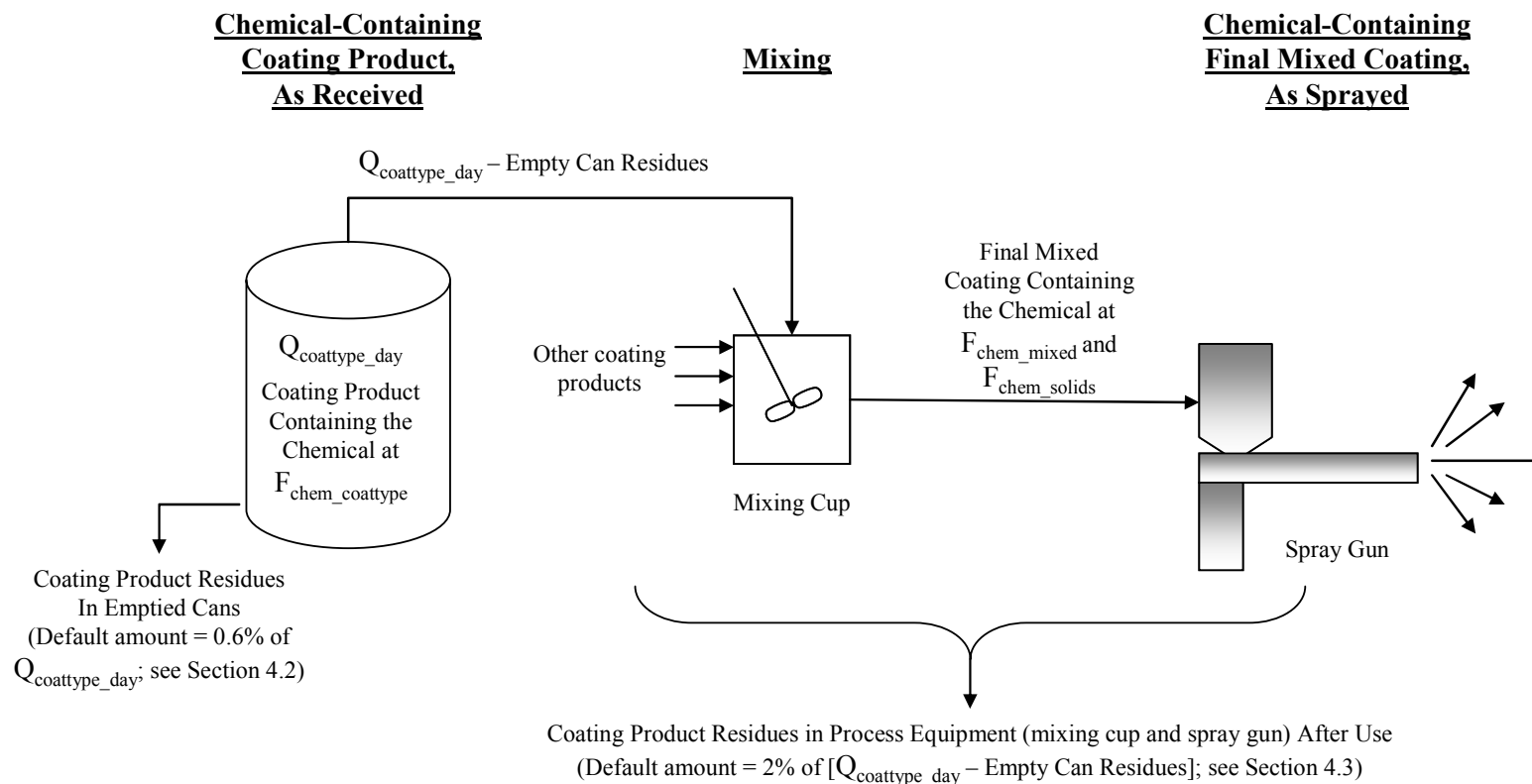
$$Q_{\text{coatype_day}} = \frac{V_{\text{allcoat_site_day}} \times F_{\text{vol_coatype_prod}} \times \text{RHO}_{\text{coatype}}}{2.205 \text{ lbs/kg}} \quad (3-4)$$

Where:

$Q_{\text{coatype_day}}$	=	Daily facility automotive refinishing coating product use rate (kg coating product containing chemical of interest/site-day)
$V_{\text{allcoat_site_day}}$	=	Daily facility total volume automotive refinishing coating product use rate (gal all coating products/site-day) (see Section 3.4)
$F_{\text{vol_coatype_prod}}$	=	Volumetric fraction of all automotive refinishing coating products that contain the chemical of interest (gal coating product containing the chemical of interest/gal all coating products) (see Section 3.5)
$\text{RHO}_{\text{coatype}}$	=	Density of the automotive refinishing coating product type containing the chemical of interest (lbs coating/gal coating) (see Table 1-1 for certain default values, or use 8.3 lbs/gal for unknown density)

Note that, with the exception of the default, the use rates listed in Table 3-2 are most often based on the amounts of coating that are *mixed* or *sprayed*. The default use rate, which is based on the U.S. Census data, represents the amount of coating product that is *received* at the shop. While it is important to note the distinction between the various use rates provided in these sources, they are all interchangeably used in the ESD to represent the quantity of coating, as received. Figure 3-2 illustrates how the chemical-containing coating product use rate and chemical concentrations described in this ESD are used to represent those found in each of the process activities.

The difference between the quantities of coating received vs. mixed vs. sprayed are assumed negligible for the purposes of defining the use rate of the chemical-containing coating, and believed to be within the margin of error of the screening-level estimation methods provided in this ESD.



Additional Notes:

$Q_{\text{coatype_day}}$ = Daily use rate of the chemical-containing coating product (see Section 3.6)

$F_{\text{chem_coatype}}$ = Concentration of the chemical within the coating product, as received (see Section 3.7)

$F_{\text{chem_mixed}}$ = Concentration of the chemical within the final mixed coating, as sprayed (see Section 5.5)

$F_{\text{chem_solids}}$ = Concentration of the chemical within the nonvolatile (solids) portion of the coating, as sprayed (see Section 5.7.1)

Figure 3-2. Illustrative Summary of Coating Quantities and Chemical Concentrations by Process Activity

Use Rate of the Chemical of Interest ($Q_{\text{chem_day}}$)

To estimate the amount of chemical of interest contained in the automotive refinishing coating product that is used at each shop, the daily mass use rate of the coating product ($Q_{\text{coattype_day}}$) is multiplied by the chemical's concentration (mass fraction) in the coating product ($F_{\text{chem_coattype}}$). As discussed in Section 1.2, the formulation of ingredients and associated compositions found in these coating products are highly varied, and EPA found very limited data on "typical" automotive refinishing product compositions and chemical concentrations. Formulated, ready-to-use automobile refinishing coatings may contain between 15 and 25 percent solids, with the balance being the reducer/solvent (water or organic solvent) [DuPont, 2007] [Kirk-Othmer, 1993]. Often, the chemical is received at the refinishing shop as part of a coating product or additive that is mixed into the final coating at the shop prior to being sprayed. If specific information about the chemical-containing coating product formulation is not known, EPA recommends assuming 25 percent chemical of interest when performing the calculations in this assessment¹:

$$Q_{\text{chem_day}} = Q_{\text{coattype_day}} \times F_{\text{chem_coattype}} \quad (3-5)$$

Where:

$Q_{\text{chem_day}}$	=	Daily use rate of the chemical of interest, contained in the automotive refinishing coating product to be mixed and sprayed (kg chemical/site-day)
$Q_{\text{coattype_day}}$	=	Daily use rate of the chemical-containing coating product (kg coating product containing chemical of interest/site-day) (See Section 3.6)
$F_{\text{chem_coattype}}$	=	Mass fraction of the chemical of interest in the coating product, as received at the shop (Default: 0.25 kg chemical/kg coating product)

Number of Shops (N_{sites})

The estimated daily use rate for the chemical of interest and its known annual production volume can be used in the following equation to estimate the number of automotive refinishing shops that receive and use the chemical-containing coating product:

$$N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{chem_day}} \times \text{TIME}_{\text{working_days}}} \quad (3-6)$$

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

Where:

N_{sites}^1	=	Number of automotive refinishing shops that use the coating product containing the chemical of interest (sites)
$Q_{\text{chem_yr}}$	=	Annual production volume of the chemical of interest (kg chemical/yr)
$Q_{\text{chem_day}}$	=	Daily use rate of the chemical of interest, contained in the automotive refinishing coating product to be mixed and sprayed (kg chemical/site-day) (See Section 3.7)
$\text{TIME}_{\text{working_days}}$	=	Days of automotive refinishing coating product use per year (days/yr) (See Section 3.2)

Note that the calculated number of shops (N_{sites}) should not exceed the total number of automotive refinishing shops known to operate in the United States. See Section 1.4 for additional information on the total number of U.S. automotive refinishing shops.

Summary of the Relationship of General Facility Parameters

The values for days of operation, daily use rate of the chemical of interest ($Q_{\text{chem_day}}$), and number of sites (N_{sites}) are related. This ESD presents one method for estimating $Q_{\text{chem_day}}$ using estimated default values for: 1) the total U.S. production volume (i.e., use rate) of the chemical-containing coating product ($Q_{\text{coatype_day}}$); 2) the mass fraction of the chemical of interest in the coating product ($F_{\text{chem_coatype}}$); and 3) number of operating days ($\text{TIME}_{\text{working_days}}$).

If N_{sites} and $\text{TIME}_{\text{working_days}}$ are known, $Q_{\text{chem_day}}$ can be calculated directly with Equation 3-6. This alternative calculation is:

$$Q_{\text{chem_day}} = \frac{Q_{\text{chem_yr}}}{N_{\text{sites}} \times \text{TIME}_{\text{working_days}}}$$

However, EPA recommends calculating the chemical of interest use rate based on the methodology presented in Section 3.8 and comparing it to the use rate based on number of sites and operating days, as calculated above.

Annual Number of Coating Product Containers Emptied per Shop ($N_{\text{cont_site_yr}}$)

The number of automotive refinishing coating product containers emptied annually per site can be estimated based on the daily use rate, container size, and concentration of the chemical of interest in the coating product. EPA suggests using a default container size of a one-gallon can in the absence of site-specific information [BASF, 1996]. Engineering judgment should be used to determine if another

¹The value for N_{sites} , calculated using Equation 3-6, should be rounded up to the nearest integer value. $Q_{\text{chem_day}}$ should then be adjusted for the N_{sites} integer value (to avoid errors due to rounding):

$$Q_{\text{chem_day}} = \frac{Q_{\text{chem_yr}}}{N_{\text{sites}} \times \text{TIME}_{\text{working_days}}}$$

Note: If the number of refinishing shops is known, the previous equation may also be used to estimate the resulting average daily use rate ($Q_{\text{chem_day}}$) for use in subsequent calculations.

container type or size is more appropriate (e.g., larger drums). If the density of the coating product is not known, refer to the coating product type values in Table 1-1 or use the density for water as a default (1 kg/L or 8.3 lbs/kg).

$$N_{\text{cont_site_yr}} = \frac{Q_{\text{coatype_day}}}{Q_{\text{cont}}} \times \text{TIME}_{\text{working_days}} \quad (3-7)$$

Where:

$N_{\text{cont_site_yr}}$	=	Annual number of containers emptied containing chemical of interest per site (containers/site-yr)
$Q_{\text{coatype_day}}$	=	Daily use rate of the chemical-containing coating product (kg coating product containing chemical of interest/site-day) (See Section 3.6)
Q_{cont}^1	=	Mass of the chemical-containing coating product in the container (kg coating product/container)
$\text{TIME}_{\text{working_days}}$	=	Days of automotive refinishing coating product use per year (days/yr) (See Section 3.2)

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

$$Q_{\text{cont}} = \frac{V_{\text{cont}} \times \text{RHO}_{\text{coatype}}}{(2.205 \text{ lbs/kg} \times 3.785 \text{ L/gal})}$$

Where:

V_{cont}	=	Volume of coating product per container (Default: 3.785 liters coating/container (1-gallon can); See Table B-3 in Appendix B for alternative default container volumes)
$\text{RHO}_{\text{coatype}}$	=	Density of the coating product (Default: 8.3 lbs coating product/gallon; see also Table 1-1 for alternative default coating product type densities)

ENVIRONMENTAL RELEASE ASSESSMENTS

This section presents approaches for estimating the amount of nonvolatile coating chemicals released from each of the automotive refinishing process sources. The release sources are discussed in the order that they occur in the process (see Figure 2-2), and include most likely receiving media (i.e., air, water, landfill, or incineration). The primary sources of release include container residue, process equipment and spray gun cleaning, and oversprayed coating. Table A-2 in Appendix A lists key default values used for the release estimates, accompanied by their respective references.

Note that the 2004 ESD presented release estimates by receiving media (e.g., air, water, incineration, landfill). This ESD presents estimates by release source (e.g., container cleaning, equipment cleaning, overspray). While the presentation differs, the actual release estimates are the same with one exception. EPA increased the capture efficiency of the emission controls ($F_{\text{eff_control}}$) from 0.9 to 0.96 kg captured/kg overspray based on updated data collected for the Paint Stripping and Surface Coating NESHAP (see Section 4.4).

As discussed in Section 1.2.1, the manufacture and use of *waterborne coatings* are expected to increase in the United States, particularly within particular states or regions. Using a waterborne coating vs. a traditional solvent-based coating results in the same release amounts, but the waterbased coating residues are more likely disposed of to water (as a worst case), as opposed to landfill or incineration. However, for its purpose in reviewing new and existing chemicals, EPA assumes a solvent-based coating unless the chemical use information specifically states that it is to be used in a waterborne coating formulation.¹

All release equations estimate daily rates for a given site. To estimate annual releases for all sites for a given source, the release rates must be multiplied by the number of days of release and by the total number of automotive refinishing shops using the chemical of interest (N_{sites}) (see Section 3.8).

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

Some of the environmental release estimates presented in this document are based on standard EPA release models, except for the methodology described in Sections 4.4 and 4.5 for estimating the amount of release from the oversprayed coating that is either captured within the spray area or emissions control, or that is emitted from the shop. These release estimates are based on available data on spray gun transfer efficiencies and typical emission controls used by the industry. Table 4-1 summarizes the release estimation methods used in this ESD.

Note that the standard model default values cited are current as of the date of this ESD; however, EPA may update these models as additional data become available. EPA recommends using the most current version of the models in these calculations.

¹ The disposal of waterborne coatings to water may be assumed a worst-case scenario for the purposes of this ESD. Many shops are likely cleaning and/or disposing of waterborne coating residues to landfill or incineration (similar to solvent-based coatings); however, there is currently no national mandate that specifically prohibits the waterborne coatings to be disposed to water (although some localities do prohibit this release). As such, there is the possibility that some shops could dispose of waterborne coating residues to water by indirectly discharging to a POTW.

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

Table 4-1. Summary of Automotive Refinishing Spray Coating Release Models

Release Source #	Description	Model Name or Description ^a	Standard EPA Model (✓)
1	Container residue disposed to incineration or landfill	EPA/OPPT Small Container Residual Model	✓
2	Equipment (i.e., mixing cup, spray gun) cleaning residues disposed to incineration or landfill	EPA/OPPT Multiple Process Vessel Residual Model	✓
3	Oversprayed coating dust/mist captured (e.g., in spray booth and dry filter) and disposed to incineration or landfill	Loss rate is based on available industry-specific data	
4	Oversprayed coating dust/mist emitted to air from the shop	Loss rate is based on available industry-specific data	

OPPT – Office of Pollution Prevention and Toxics.

a – Appendix B presents additional detailed descriptions for each of the models presented in this section.

Control Technologies

EPA collected limited data and information on the pollution control technologies that are generally expected to be used by automotive refinishing shops. As described in Section 2, shops have adopted various practices to minimize the coating materials used in the process and consequently reduce their waste. These waste minimization practices include mixing systems/techniques that allow more precise mixing of amounts needed for the job (less excess) and using high-transfer efficiency spray equipment and techniques (e.g., HVLP spray guns). Most shops perform spraying within prep stations, spray booths, or other enclosed areas of the shop. These areas, along with the mixing room, are expected to have some form of general or local ventilation system. Ventilation systems associated with spray coating areas are often equipped with dry filters, which remove most of the oversprayed coating dust/mist from the shop exhaust. Section 2.2.2 discusses the efficiencies of these systems in more detail.

Coating Product Container Residue Disposed to Incineration or Landfill (Release 1)

In most cases, automotive refinishing coating products are supplied to shops in cans or containers ranging from 1 quart to 5 gallons [BASF, 1996]. Potential releases occur from cleanout and/or disposal of the used container. The media of release for this source is uncertain; in these cases, EPA assumes that disposal may be to landfill or incineration [see Section 2.1]. If the chemical is used in a waterborne coating product, EPA recommends assuming that the containers are rinsed with water, which is subsequently discharged from the shop (i.e., waterborne coating product container residues disposed to water) (refer to the discussion of this worst-case release scenario presented in Section 4.0).

The amount of liquid coating product remaining in the containers depends on the size of the container. EPA suggests using a default container size of 1-gallon cans in the absence of site-specific information; therefore, the *EPA/OPPT Small Container Residual Model* may be used to estimate this release. The model assumes that up to 0.6 percent of the liquid originally contained in small containers

remains as residual after unloading [CEB, 1992]. Appendix B further explains the rationale, defaults, and limitations of this and alternative container residual models.

The annual number of containers emptied ($N_{\text{cont_site_yr}}$) is estimated based on the average annual amount of coating product received at each automotive refinishing shop and the container size (see Section 3.9). EPA recommends assuming 1-gallon (3.8-L) cans and a density of 1 kg/L or 8.3 lbs/gal (i.e., density of water) or an appropriate density from Table 1-1 as defaults, if chemical-specific information is unavailable. If the fraction of the chemical in the coating product is unknown, assume 100 percent concentration, consistent with Section 3.7 calculations.

If the $N_{\text{cont_site_yr}}$ value is fewer than the number of working days ($\text{TIME}_{\text{working_days}}$), the days of release equal $N_{\text{cont_site_yr}}$ (as calculated in Section 3.9) and the daily release is calculated based on the following equation:

$$\text{Elocal}_{\text{container_residue_disp}} = Q_{\text{cont}} \times F_{\text{chem_coatype}} \times F_{\text{container_disp}} \times N_{\text{cont_site_day}} \quad (4-1a)$$

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

Where:

$\text{Elocal}_{\text{container_residue_disp}}$	=	Daily release of chemical of interest from container residue (kg chemical released/site-day)
Q_{cont}	=	Mass of the coating product in the container (kg coating product/container) (default: use the same value used to estimate $N_{\text{cont_site_yr}}$ in Section 3.9)
$F_{\text{chem_coatype}}$	=	Mass fraction of the chemical of interest in the coating product, as received at the shop (kg chemical/kg coating product) (See Section 3.7)
$F_{\text{container_disp}}$	=	Mass fraction of coating product remaining in the container as residue (default: 0.006 kg coating product remaining/kg shipped for small containers [CEB, 1992]; see Appendix B for defaults used for other container types)
$N_{\text{cont_site_day}}^1$	=	Number of containers emptied per site, per day (default: 1 container/site-day)

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

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

$$N_{\text{cont_site_day}} = \frac{N_{\text{cont_site_yr}}}{\text{TIME}_{\text{working_days}}}$$

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

Where:

$N_{\text{cont_site_yr}}$	=	Annual number of containers emptied containing chemical of interest per site (containers/site-yr) (See Section 3.9)
$\text{TIME}_{\text{working_days}}$	=	Days of automotive refinishing coating product use per year (days/yr) (See Section 3.2)

$$E_{\text{local_container_residue_disp}} = Q_{\text{chem_day}} \times F_{\text{container_disp}} \quad (4-1b)$$

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

Where:

$E_{\text{local_container_residue_disp}}$	=	Daily release of chemical of interest from container residue (kg chemical released/site-day)
$Q_{\text{chem_day}}$	=	Daily use rate of the chemical of interest, contained in the automotive refinishing coating product to be mixed and sprayed (kg chemical/site-day) (See Section 3.7)
$F_{\text{container_disp}}$	=	Mass fraction of chemical that remains in the container as residue (default: 0.006 kg chemical remaining in container and released/kg received in full container, for bottles [CEB, 1992]; see Appendix B for defaults used for other container types)

Equipment Cleaning Residue Disposed to Incineration or Landfill (Release 2)

The amount of residual coating product remaining in the spray coating equipment (e.g., mixing cup and spray gun) may be estimated using the *EPA/OPPT Multiple Process Vessel Residual Model*. The model assumes that no more than two percent of the daily amount of coating product that is mixed and transferred into the spray gun remains in the mixing equipment and spray gun as residue that is disposed as equipment cleaning waste. The *Multiple Process Vessel Model* is recommended as the default because the mixing cup and associated equipment, as well as the spray gun equipment will be cleaned. These residues may be disposed to incineration or landfill, as discussed in Section 2.4. If the chemical is used in a waterborne coating product, EPA recommends assuming that the equipment is rinsed with water, which is subsequently discharged from the shop (i.e., waterborne coating product equipment residues disposed to water) (refer to the discussion of this worst-case scenario presented in Section 4.0).

As a conservative estimate, daily equipment cleaning may be assumed (i.e., the days of release equal the shop working days ($TIME_{\text{working_days}}$)). The daily release of chemical residue in the process equipment is calculated using the following equation:

$$E_{\text{local_equip_disp}} = Q_{\text{chem_day}} \times (1 - F_{\text{container_disp}}) \times F_{\text{equip_disp}} \quad (4-2)$$

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

Where:

$E_{\text{local_equip_disp}}$	=	Daily release of chemical of interest from equipment cleaning (kg chemical released/site-day)
$Q_{\text{chem_day}}$	=	Daily use rate of the chemical of interest, contained in the automotive refinishing coating product to be mixed and sprayed (kg chemical/site-day) (See Section 3.7)
$F_{\text{container_disp}}$	=	Mass fraction of chemical that remains in the container as residue (kg chemical remaining in container and released/kg received in full container) (See Section 4.2)
$F_{\text{equip_disp}}$	=	Mass fraction of chemical released as residual in process equipment (default = 0.02 kg chemical released/kg chemical dispensed into the equipment) [CEB, 1992].

Oversprayed Coating Captured by Emission Controls and Disposed to Incineration or Landfill (Release 3)

As described in Section 2.2, the total amount of coating that is sprayed or used in the process is either transferred to the automobile surface or is oversprayed. The amount of coating expected to be transferred to the surface is estimated by the transfer efficiency of the spray gun equipment ($F_{\text{eff_spray_gun}}$). The transfer efficiency depends primarily on the type of spray gun used, but also depends on painter technique and other operating parameters (e.g., spray gun operating pressure, viscosity of coating). Section 2.2.1 discusses these factors and spray gun transfer efficiencies in detail.

Lower efficiency conventional spray guns have been used less frequently over the past several years by many automotive refinishing shops [USEPA, 2007a]. However, they have not been entirely replaced by higher efficiency spray guns. The Paint Stripping and Surface Coating NESHAP requires refinishing shops spraying HAP-containing coatings to use HVLP spray guns or equivalent high-efficiency equipment for all spray coating processes [73 FR 1738; January 9, 2008] (see Section 2.2.1). EPA recommends that the range in spray gun transfer efficiencies be used to estimate typical (65 percent for HVLP spray guns) and worst-case (20 percent for conventional spray guns) releases from automotive refinishing spray applications.

The total amount of the chemical of interest that is oversprayed is estimated using the following equation:

$$Q_{\text{chem_overspray_day}} = Q_{\text{chem_day}} \times (1 - F_{\text{container_disp}}) \times (1 - F_{\text{equip_disp}}) \times (1 - F_{\text{eff_spray_gun}}) \quad (4-3)$$

Where:

$Q_{\text{chem_overspray_day}}$	=	Daily amount of chemical of interest that is sprayed, but not transferred to the automobile surface (i.e., is oversprayed) (kg chemical oversprayed/site-day)
$Q_{\text{chem_day}}$	=	Daily use rate of the chemical of interest, contained in the automotive refinishing coating product to be mixed and sprayed (kg chemical/site-day) (See Section 3.7)
$F_{\text{container_disp}}$	=	Mass fraction of chemical that remains in the container as residue (kg chemical remaining in container and released/kg received in full container) (See Section 4.2)
$F_{\text{equip_disp}}$	=	Mass fraction of chemical released as residual in process equipment (kg chemical remaining in equipment and released/kg transferred into equipment) (See Section 4.3)
$F_{\text{eff_spray_gun}}$	=	Transfer efficiency of the spray gun (Defaults: 0.65 kg chemical transferred from the spray gun to the automobile surface/kg chemical sprayed (typical); 0.20 kg chemical transferred/kg chemical sprayed (worst case) [Heitbrink, 1996]; See Section 2.2.1 for alternative defaults)

This oversprayed coating, in the form of a mist, either settles to the floor and walls of the spray booth or other workspace where spraying occurs or is captured by the ventilation system. As described in Section 2.2.2, most spray booths and prep stations used in the automotive refinishing industry use a dry filter to capture coating mist and dust from the exhaust prior to the final emission [DeVilbiss, 1996] [USEPA, 2007a]. The oversprayed coating particles that are captured by the controls are disposed to either incineration or landfill. For example, the captured particles are disposed of along with the waste filter during routine spray booth maintenance and filter change-out.

The amount of overspray that is captured by the ventilation system and emission controls is estimated based on the mist/particle capture efficiency of the area ventilation system ($F_{\text{eff_vent}}$) and the capture efficiency of the emission control (e.g., filter) ($F_{\text{eff_control}}$).

EPA found no specific data in the references reviewed for this ESD with which to estimate how much of the overspray is expected to settle out versus what is captured by the ventilation system. EPA assumed that 50 percent of the overspray settles on the spray area walls, floor, and the masking paper in estimating inorganic HAP and PM emission reductions for the Paint Stripping and Surface Coating NESHAP [USEPA, 2007a]. However, for the purpose of this ESD, EPA recommends assuming all of the oversprayed coating is collected into the ventilation system and passes into the emission control device (e.g., dry filter) because the media of release is assumed to be the same for both waste streams.

For the purposes of this ESD, EPA recommends assuming that shops use a dry filter with an average capture efficiency ($F_{\text{eff_control}}$) of 96 percent (see Section 2.2.2). In some cases, automotive refinishing shops apply coatings outside of a spray booth or do not otherwise use emission controls. In these instances, none of the overspray is captured and is released to air through the stack ($F_{\text{eff_control}} = 0$).

The daily amount of oversprayed chemical that is collected and disposed of from the spray area and captured by emission controls is estimated using the following equation:

$$E_{\text{local_captured_overspray}} = Q_{\text{chem_overspray_day}} \times F_{\text{eff_vent}} \times F_{\text{eff_control}} \quad (4-4)$$

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

Where:

$E_{\text{local_captured_overspray}}$	=	Daily release of chemical of interest from oversprayed coating residues captured by emission controls (kg chemical released/site-day)
$Q_{\text{chem_overspray_day}}$	=	Daily amount of chemical that is sprayed, but not transferred to the automobile surface (i.e., is oversprayed) (kg chemical oversprayed/site-day) (See Equation 4-3)
$F_{\text{eff_vent}}$	=	Fraction of the oversprayed chemical that is captured by the spray area ventilation system (Default: 1 kg chemical captured by ventilation system/kg chemical oversprayed)
$F_{\text{eff_control}}$	=	Fraction of the oversprayed chemical in the ventilation system that is captured by emission controls (Default: 0.96 kg chemical captured/kg ventilated from spray area) [USEPA, 2007a]; See Section 2.2.2 for alternative defaults)

Again, the estimate provided by Equation 4-4 presumes that 100 percent of the oversprayed coating is collected by the spray area or booth ventilation system and is passed through the emission control device (e.g., dry filters). In reality, some portion of the oversprayed coating will likely settle on the walls and floor of the area/booth and will not pass through the emission controls; however, these amounts are expected to be routinely collected for disposal, just as they are collected from the controls and disposed of to the same media.

If the residual settled oversprayed particulates in the spray area are to be quantified separate from the emission control wastes in Equation 4-4, the following equation may be used to estimate the amount of overspray that settles within the spray area and is not captured by the ventilation system and emission control device (note that an alternative $F_{\text{eff_vent}}$ value less than 1 kg/kg is required):

$$E_{\text{local}}_{\text{settled_overspray}} = Q_{\text{chem_overspray_day}} \times (1 - F_{\text{eff_vent}}) \quad (4-5)$$

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

Where:

$E_{\text{local}}_{\text{settled_overspray}}$	=	Daily release of chemical of interest from oversprayed coating residues that settle on the spray area walls and floor (kg chemical released/site-day)
$Q_{\text{chem_overspray_day}}$	=	Daily amount of chemical that is sprayed, but not transferred to the automobile surface (i.e., is oversprayed) (kg chemical oversprayed/site-day) (See Equation 4-3)
$F_{\text{eff_vent}}$	=	Fraction of the oversprayed chemical that is captured by the spray area ventilation system (kg chemical captured by ventilation system/kg chemical oversprayed) (See Equation 4-4)

Oversprayed Coating Vented from Shop and Emitted to Air (Release 4)

The release of the chemical of interest to air is expected to result from the oversprayed coating particles that release into the spray area ventilation system and are not captured by the emission controls, as described in Sections 2.2 and 4.4. The total amount of overspray that is not captured by the emission control device is assumed to be released to air through the shop exhaust stack. The daily amount of oversprayed chemical that is emitted from the spray area to air is estimated using the following equation:

$$E_{\text{local}}_{\text{air_emission}} = Q_{\text{chem_overspray_day}} \times F_{\text{eff_vent}} \times (1 - F_{\text{eff_control}}) \quad (4-6)$$

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

Where:

$E_{\text{local}}_{\text{air_emission}}$	=	Daily release of chemical of interest from oversprayed coating emissions (kg chemical released/site-day)
$Q_{\text{chem_overspray_day}}$	=	Daily amount of chemical that is sprayed, but not transferred to the automobile surface (i.e., is oversprayed) (kg chemical oversprayed/site-day) (See Section 4.4)
$F_{\text{eff_vent}}$	=	Fraction of the oversprayed chemical that is captured by the spray area ventilation system (kg chemical captured by ventilation system/kg chemical oversprayed) (See Section 4.4)
$F_{\text{eff_control}}$	=	Fraction of the oversprayed chemical in the ventilation system that is captured by emission controls (kg chemical captured/kg ventilated from spray area) (See Section 4.4)

Note that this estimate is conservative for the nonvolatile components of the coating product, as it assumes that all oversprayed particles are collected by the spray area ventilation system and passed through the emission control device (see discussion in Section 4.4).

OCCUPATIONAL EXPOSURE ASSESSMENTS

The following section presents estimation methods for occupational exposures to the nonvolatile automotive refinish coating chemicals. Figure 2-2 illustrates the occupational activities performed during automotive refinishing that have the greatest potential for worker exposure to the chemical. These activities include manually transferring and mixing the coating product into the coating to be applied, manually transferring the mixed coating into the spray gun, spraying the coating onto the automobile surface, and cleaning the coating mix cup and spray gun equipment.

The exposure estimates presented in this section incorporate a recent study of dermal exposures during various spray coating processes performed at 18 automotive refinishing shops in Spain. The total number of workers employed by the U.S. automotive refinishing industry was obtained from 2004 data collected by the U.S. Census Bureau. The remaining occupational exposure estimates presented in this document are based on standard EPA exposure models. Table 5-1 summarizes the exposure estimation methods used in this ESD.

Note that the 2004 ESD only presented a single dermal and inhalation exposure estimate for all activities. This ESD presents separate exposure estimates for each worker activity (e.g., paint mixing, spray gun cleaning, coating application). Additionally, EPA updated its analysis of available coating mist concentration and associated spray activity duration data, which resulted in revisions to the recommended default values used in the spraying activity exposures. The dermal exposure estimates have also been revised based on the recent industry-specific dermal monitoring data instead of the previous use of the *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model*.

The standard model default values cited are current as of the date of this ESD; however, EPA may update these models as additional data become available. EPA recommends using the most current version of the models in these calculations.

EPA has developed a software package (ChemSTEER) containing these models as well as all current EPA defaults. Because of the complexity of the inhalation exposure to vapor models, ChemSTEER is recommended for estimating these exposures. Appendix B provides additional information on ChemSTEER, including information on obtaining the program, background information, model equations, and default values for several parameters for all standard EPA models.

Table 5-1. Summary of Automotive Refinishing Scenario Exposure Models

Exposure Activity	Description	Route of Exposure / Physical Form	Model Name or Description^a	Standard EPA Model (✓)
A	Manually transferring and mixing liquid coating products	Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
B	Exposure to liquid coating products during container cleaning	Dermal exposure to liquid chemical	EPA/OPPT 2-Hand Dermal Contact with Liquid Model	✓
C	Exposure to mixed coating during transfer from mixing cup to spray gun	Dermal exposure to liquid chemical	Dermal exposure based on industry-specific monitoring data	
D	Exposure to mixed coating during equipment cleaning	Dermal exposure to liquid chemical	Dermal exposure based on industry-specific monitoring data	
E	Exposure to oversprayed coating mists	Inhalation of chemical contained in coating mist	Mist concentration based on industry-specific monitoring data	
		Dermal exposure to liquid chemical	Dermal exposure based on industry-specific monitoring data	

a – Appendix B of this ESD provides additional detailed descriptions for each of the models presented in this section.

Personal Protective Equipment

Many different personal protective equipment options exist for painters to lower exposure potential. Workers typically wear air-purifying respirators or air-supplied respirators to minimize inhalation exposure to coating mists. Gloves (typically latex or nitrile), paint suits, and face masks/eye protection are available to painters to limit dermal exposure to coatings. One study of several automotive refinishing shops located in Spain observed that most painters wore paint suits during the spray gun filling, spraying, and spray gun cleaning activities; however, gloves were often only worn during spray gun cleaning [Delgado, 2004].

The State of Washington Department of Labor and Industries conducted an assessment of the collision repair industry in the State of Washington. The authors published the results of this assessment in December 2005. The 2005 State of Washington industry study presents tables summarizing the percent usage of personal protective equipment (PPE) from 494 job shops in the automotive refinishing industry [Whittaker, 2005]. Tables 5-2, 5-3, and 5-4 summarize these results.

Table 5-2. Personal Protective Equipment (PPE) Workers Used While Spraying Two-Part Clearcoats

PPE Used	Number of Shops*	Percent of Shops
Respirator	482	98%
Gloves	422	85%
Shoot suit	411	83%
Safety glasses	292	59%
Head socks	267	54%
Cloth or leather work boots	228	46%
Earplugs or muffs	197	40%
Goggles	184	37%
Disposable coveralls	151	31%
Fabric coveralls	141	29%
Disposable boot covers	67	14%
Rubber boots	43	9%
*The total (2,885) exceeds the number of shops (494) because some shops use more than one type of PPE.		

Table 5-3. Gloves Used While Spraying Two-Part Clearcoats

Glove Type	Number of Shops*	Percent of Shops
Latex	253	51%
Nitrile	195	40%
Neoprene	39	8%
Natural rubber	24	5%
PVC	5	1%
Laminated polyethylene	4	<1%
Cloth/Leather	3	<1%
Other	5	1%
None	11	2%
Don't know	42	9%
*The total (581) exceeds the number of shops (493) because some shops use more than one glove type.		

Table 5-4. Respirators Used While Spraying Two-Part Clearcoats

Respirator Type	Number of Shops*	Percent of Shops
Half-face type with replaceable cartridges	227	46%
Full-face type with an air supply hose	128	26%
Disposable half-face type with cartridges	114	23%
Hood or head covering with air supply hose	87	18%
Full-face type with cartridges	79	16%
Half-face type with an air supply hose	70	14%
Hood-type powered air-purifying respirator (PAPR)	40	8%
Dust masks (filtering face pieces)	16	3%
None	0	0%
Don't know	2	<1%
Other	1	<1%
*The total (764) exceeds the number of shops (494) because some shops use more than one type of respirator.		

The exposure estimates presented in this document are conservative because they assume the painters do not wear gloves or respirators for any of the exposure activities.

Number of Workers Exposed Per Site

Usually, the painters employed by a shop (especially small shops) conduct all of the automotive refinishing activities: preparing surfaces, mixing the coatings, loading spray guns, spraying, and cleaning. One reference estimates that a typical automotive refinishing shop has an average of 7.8 employees [BSB, 2000]. Census data from 2004 for NAICS code 811121 show 227,489 people were paid employees for the 36,296 shops [USCB, 2004a] (see Table 1-2), which averages approximately 6.3 workers per site. It is expected that not all of these employees would be painters; however, Census data are not available on the specific number of painters or production workers.¹ In the absence of data, 8 painters per site is assumed as a conservative estimate.

Most refinishing shops typically operate for one eight-hour shift per day. This may fluctuate depending on the volume of business [USEPA, 2003]. This ESD presents estimates for the duration of exposure for each worker activity as needed for the exposure estimates discussed in the remainder of this section (based on standard EPA defaults and methodology).

Dermal Exposure from Transferring and Mixing Liquid Chemicals in Coating Products (Exposure A)

Painters manually pour the coating products from transport containers into a mixing cup, according to specified “recipes” provided by the coating manufacturer to achieve the desired color or effect, or to aid in the application or curing of the coating.

Dermal exposure to the chemical contained in the coating product is expected during this activity. If the concentration of the chemical in the coating product ($F_{\text{chem_coattype}}$) is unknown, 100 percent concentration may be assumed as conservative, as previously discussed in Section 3.7. Inhalation

¹Note: Neither the CBP [USCB, 2004a] nor the *Repair and Maintenance: 2002 Economic Census Other Services Industry Series* (latest edition; <http://www.census.gov/prod/ec02/ec0281i01.pdf>) included the percentage of “production” workers among the total number of employees.

exposure is expected to be negligible for nonvolatile chemicals within the coating products during this activity.

The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid coating product formulation during the transfer and mixing activities. Appendix B further explains the rationale, defaults, and limitations of this model.

The model uses the following equation to estimate potential painter dermal exposure to the chemical of interest in a liquid coating product for this activity:

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

This exposure will occur over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid coating product remaining on skin (Defaults: 2.1 mg coating product/cm ² -incident (high end) and 0.7 mg coating product/cm ² -incident (low end) for routine or incidental contact [CEB, 2000])
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 840 cm ² for 2 hands [CEB, 2000])
$N_{\text{exp_incident}}^1$	=	Number of exposure incidents per day (Default: 1 incident/day [CEB, 2000])
$F_{\text{chem_coatype}}$	=	Mass fraction of the chemical of interest in the coating product (mg chemical/mg coating product) (See Section 3.7)

Note that the exposure days per site, per year should be consistent with the shop operating days; EPA recommends a maximum of 250 days per year for each painter. This exposure duration maximum default is based on full-time employment and considers an individual painter's vacation, sick, and weekend time (i.e., a 40-hour week over 50 weeks per year).

Dermal Exposure to Liquid Chemicals in Coating Products during Cleaning/Handling Empty Containers (Exposure B)

Workers may be exposed while rinsing or otherwise handling the empty containers used to transport the coating product. To perform a conservative assessment, EPA recommends that the containers are assumed to be rinsed by the painters at the automobile refinishing shops (consistent with Release 1 described in Section 4.2).

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

Dermal exposure to the liquid chemical in the coating product is expected to occur during this activity. If the concentration of the chemical in the coating product ($F_{\text{chem_coattype}}$) is unknown, 100 percent concentration may be assumed as a conservative default, as previously discussed in Section 3.7. Inhalation exposure is expected to be negligible for nonvolatile chemicals within liquid paint products during this activity.

The *EPA/OPPT 2-Hand Dermal Contact with Liquid Model* may be used to estimate dermal exposure to the chemical of interest in a liquid formulation during these activities. Appendix B explains the rationale, defaults, and limitations of this model.

The model uses the following equation to estimate potential painter dermal exposure to the chemical of interest in a liquid coating product for this activity:

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

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

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{liquid_skin}}$	=	Quantity of liquid coating product remaining on skin (Defaults: 2.1 mg component/cm ² -incident (high end) and 0.7 mg coating product/cm ² -incident (low end) for routine or incidental contact [CEB, 2000])
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 840 cm ² for 2 hands [CEB, 2000])
$N_{\text{exp_incident}}$	=	Number of exposure incidents per day (Default: 1 incident/day [CEB, 2000]) (see footnote to Equation 5-1)
$F_{\text{chem_coattype}}$	=	Mass fraction of the chemical of interest in the coating product (mg chemical/mg coating product) (See Section 3.7)

Note that the exposure days per site, per year should be consistent with the release days for Release 1 (container residue); however, EPA recommends a maximum of 250 days per year for each painter, as discussed in Section 5.3.

Dermal Exposure to Liquid Chemicals in Mixed Coating during Transfer into the Spray Gun (Exposure C)

Painters may be exposed to the chemical while pouring the mixed coating from the mix cup into the spray gun cup. This activity may be repeated several times before application of that coating is complete [Delgado, 2004].

Dermal exposure to the liquid chemical in the mixed coating is expected to occur during this activity. If the concentration of the chemical in the mixed coating ($F_{\text{chem_mixed}}$) is unknown, 25 percent concentration may be assumed as a high-end, conservative default. As discussed in Section 1.2, coating formulations as sprayed are highly varied. One source provided that automotive refinishing coatings may contain 25 percent nonvolatile components [Kirk-Othmer, 1993]; therefore, this default assumes that the

entire nonvolatile portion of the coating is the chemical of interest. Inhalation exposure is expected to be negligible for nonvolatile chemicals within liquid paint products during this activity.

The *Automotive Refinishing Coating Transfer Dermal Model* may be used to estimate dermal exposure to the chemical of interest in the mixed coating during this activity. This model is based on a dermal monitoring study that was conducted in four large shops and 14 small- and medium-sized shops located in Spain. The study collected 60 glove samples and 330 body samples for this activity. Table 5-2 summarizes the data presented in the study for potential dermal exposure on the hand. The study found no exposure to the body during this activity. The mean sampling time for transferring mixed coating into the spray cup was 2.56 minutes, which often included repeat fillings during a single spraying episode. The Delgado study also used dermal surface areas ($AREA_{\text{surface}}$) consistent with the EPA's *Exposure Factors Handbook*¹. [Delgado, 2004]

Table 5-2. Hand Surface Loading Rates During Coating Transfer to Spray Gun

Statistic	Potential Surface Loading Rate ($\mu\text{g}/\text{cm}^2\text{-min}$) ($Q_{\text{coating skin}}$)
Median	18.8
Arithmetic Mean	76.2
Standard Deviation	140
Geometric Mean (typical default)	24.4
Geometric Standard Deviation	4.58
Range	0.68-589
75 th Percentile	63.1
95th Percentile (high-end default)	499

Source: Delgado, 2004.

The geometric mean (GM) surface loading rate for hands of 24.4 μg mixed coating/ $\text{cm}^2\text{-min}$ can be used to estimate *typical* dermal exposure during coating transfer. EPA selected the GM value for typical exposure estimates because it suppresses the influence of outliers. The 95th percentile surface loading rate of 499 μg mixed coating/ $\text{cm}^2\text{-min}$ is recommended for *high-end* estimates.

If the total amount of time spent by each painter per day filling the spray gun ($TIME_{\text{spray_gun_fill}}$) is not known, EPA recommends assuming that one spraying episode involving the chemical occurs per painter, per day (one episode involves a single coating type: primer, basecoat, or clearcoat); therefore, the total duration for filling the spray gun equipment each day can be estimated as approximately three minutes (i.e., 2.56 minutes, rounded up to 3 minutes), per the Delgado et al. study. This estimate conservatively assumes that each painter completes one refinishing job involving the chemical of interest per day.

The model uses the following equation to estimate potential painter dermal exposure to the chemical of interest in a liquid coating product for this activity:

¹The standard surface areas published in the EPA's *Exposure Factors Handbook* have also been adapted into the OECD's standard guidance for exposure assessments.

$$EXP_{\text{dermal}} = \frac{Q_{\text{coating_skin}}}{1,000 \mu\text{g/mg}} \times AREA_{\text{surface}} \times TIME_{\text{spray_gun_fill}} \times F_{\text{chem_mixed}} \quad (5-3)$$

This exposure will occur over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.

Where:

EXP_{dermal}	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{coating_skin}}$	=	Quantity of liquid coating product remaining on skin (Defaults: 499 μg coating / cm^2 -minute (high end) and 24.4 μg coating/ cm^2 -minute (typical) [Delgado, 2004])
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 840 cm^2 for 2 hands [Delgado, 2004])
$TIME_{\text{spray_gun_fill}}$	=	Daily exposure duration per painter for filling spray guns (Default: 3 minutes/day [Delgado, 2004])
$F_{\text{chem_mixed}}$	=	Mass fraction of the chemical of interest in the mixed coating as sprayed (Default: 0.25 mg chemical/mg mixed coating [Kirk-Othmer, 1993])

Note that the exposure days per site, per year should be consistent with the release days for Release 3 (Overspray); however, EPA recommends a maximum of 250 days per year for each painter, as discussed in Section 5.3.

Dermal Exposure to Liquid Chemicals in Mixed Coating during Mix Cup and Spray Gun Equipment Cleaning (Exposure D)

Painters may be exposed to the chemical while cleaning/rinsing the empty mix cup and the spray gun equipment following the spraying episode. The cup and equipment may be cleaned by hand rinsing and wiping down the equipment, using an enclosed automatic spray gun cleaning system, or a combination of manual and automatic cleaning methods (see Section 2.1 and Section 2.4).

Dermal exposure to the liquid chemical in the mixed coating is expected to occur during this activity. If the concentration of the chemical in the mixed coating ($F_{\text{chem_mixed}}$) is unknown, 25 percent concentration may be assumed as a high-end, conservative default. As discussed in Section 1.2, coating formulations as sprayed are highly varied. One source stated that automotive refinishing coatings may contain 25 percent nonvolatile components [Kirk-Othmer, 1993]; therefore, this default assumes that the entire nonvolatile portion of the coating is the chemical of interest. Inhalation exposure is expected to be negligible for nonvolatile chemicals within liquid paint products during this activity.

The *Automotive Refinishing Coating Equipment Cleaning Dermal Model* may be used to estimate dermal exposure to the chemical of interest in the mixed coating during this activity. This model is based on a dermal monitoring study that was conducted in four large shops and 14 small- and medium-sized shops located in Spain. The study collected 60 glove samples and 330 body samples for this activity. Table 5-3 summarizes the data presented in the study for potential dermal exposure on the hand. There was minimal exposure to the body during this activity, although it is possible that some splashing can occur. The mean sampling time for cleaning the spray gun equipment was 3.69 minutes, which is

assumed to include a single cleaning after one spraying episode. The Delgado study also used dermal surface areas ($AREA_{\text{surface}}$) consistent with the EPA's *Exposure Factors Handbook*¹ [Delgado, 2004].

Table 5-3. Hand Surface Loading Rates During Spray Gun Cleaning

Statistic	Potential Surface Loading Rate ($\mu\text{g}/\text{cm}^2\text{-min}$) ($Q_{\text{coating_skin}}$)
Median	18.7
Arithmetic Mean	37.2
Standard Deviation	47.1
Geometric Mean (typical default)	16.7
Geometric Standard Deviation	4.26
Range	0.44-213
75 th Percentile	46.8
95th Percentile (high-end default)	161

Source: Delgado, 2004.

The GM surface loading rate for hands of $16.7 \mu\text{g}$ mixed coating/ $\text{cm}^2\text{-min}$ can be used to estimate *typical* dermal exposure during spray gun cleaning. EPA selected the GM value for typical exposure estimates because it suppresses the influence of outliers. The 95th percentile surface loading rate of $161 \mu\text{g}$ mixed coating/ $\text{cm}^2\text{-min}$ is recommended for *high-end* estimates.

If the total amount of time spent by each painter per day cleaning the mixing cup and spray gun equipment ($TIME_{\text{eqpt_clean}}$) is not known, EPA recommends assuming that cleaning the mixing cup takes the same amount of time as cleaning the spray gun equipment, and that one spraying episode involving the chemical occurs per painter, per day (one episode involves a single coating type: primer, basecoat, or clearcoat); therefore, the total duration for cleaning the mixing cup and spray gun equipment each day can be estimated as approximately eight minutes (i.e., $2 \times 3.69 \text{ minutes} = 7.4 \text{ minutes}$, rounded up to 8 minutes), per the Delgado et al. study. This estimate conservatively assumes that each painter completes one refinishing job involving the chemical per day.

The model uses the following equation to estimate potential painter dermal exposure to the chemical of interest in a liquid coating product for this activity:

$$EXP_{\text{dermal}} = \frac{Q_{\text{coating_skin}}}{1,000 \mu\text{g}/\text{mg}} \times AREA_{\text{surface}} \times TIME_{\text{eqpt_clean}} \times F_{\text{chem_mixed}} \quad (5-4)$$

This exposure will occur over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.

Where:

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

¹The standard surface areas published in the EPA's *Exposure Factors Handbook* have also been adapted into the OECD's standard guidance for exposure assessments.

$Q_{\text{coating_skin}}$	=	Quantity of liquid coating product remaining on skin (Defaults: 161 $\mu\text{g coating/cm}^2\text{-minute}$ (high end) and 16.7 $\mu\text{g coating/cm}^2\text{-minute}$ (typical) [Delgado, 2004])
$AREA_{\text{surface}}$	=	Surface area of contact (Default: 840 cm^2 for 2 hands [Delgado, 2004])
$TIME_{\text{eqpt_clean}}$	=	Daily exposure duration per painter for cleaning mixing cups and spray gun equipment (Default: 8 minutes/day [Delgado, 2004])
$F_{\text{chem_mixed}}$	=	Mass fraction of the chemical of interest in the mixed coating as sprayed (mg chemical/mg mixed coating) (See Section 5.5)

Note that the exposure days per site, per year should be consistent with the release days for Release 2 (Equipment Cleaning); however, EPA recommends a maximum of 250 days per year for each painter, as discussed in Section 5.3.

Exposure to Chemical Mists in Oversprayed Coating during Spraying (Exposure E)

Painters may be exposed to the chemical of interest contained in the mists generated by the oversprayed coating during the spraying activity. This exposure includes both inhalation of and dermal exposure to the oversprayed mists/particles. The following subsections describe how these potential exposures may be estimated.

Inhalation Exposure

The inhalation exposure estimate ($EXP_{\text{inhalation}}$) presented in this subsection is applicable to the nonvolatile chemical of interest contained in the sprayed coating (e.g., a pigment or a resin). The estimate is based on painters' exposure to the nonvolatile fraction of the coating when it is manually sprayed on the surface with either a conventional or HVLP spray gun. This ESD does not provide estimates for worker exposures to the volatile components of the coating.

The *Automotive Refinishing Spray Coating Mist Inhalation Model* may be used to estimate inhalation of the chemical of interest contained in the oversprayed coating mists/particles during this activity. This model is based on the concentration of the chemical in the nonvolatile portion of the sprayed coating ($F_{\text{chem_solids}}$), the concentration of the oversprayed coating mist within the spraying area (e.g., spray booth) ($C_{\text{coat_mist}}$), and the duration of the spraying activity ($TIME_{\text{spray}}$). The bases and default values for each of these parameters are described in the subsections following the model equation below.

Inhalation exposure to the chemical of interest during spray coating operations is estimated using the following equation:

$$EXP_{\text{inhalation}} = C_{\text{coat_mist}} \times F_{\text{chem_solids}} \times RATE_{\text{breathing}} \times \frac{TIME_{\text{spray}}}{60 \text{ min/hr}} \quad (5-5)$$

This exposure will occur over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.

Where:

$EXP_{\text{inhalation}}$	=	Potential inhalation exposure to the chemical of interest per day (mg chemical/day)
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$C_{\text{coat_mist}}$	=	Oversprayed coating mist concentration in the air within painters' breathing zone (Defaults: 1 mg nonvolatile component mist or particulate/m ³ air in painters' breathing zone (typical); 32 mg nonvolatile mist or particulate/m ³ air (high end) (See Table 5-4 for alternative default values))
$F_{\text{chem_solids}}$	=	Mass fraction of chemical of interest in the nonvolatile portion of the sprayed coating (mg chemical of interest/mg nonvolatile components) (See Equation 5-6)
$\text{RATE}_{\text{breathing}}$	=	Typical worker breathing rate (Default: 1.25 m ³ air in breathing zone/hr [CEB, 1991])
$\text{TIME}_{\text{spray}}$	=	Daily exposure duration per painter for spray coating (Defaults: 28 minutes/day (typical); 141 minutes/day (high end) (See Table 5-5 for alternative default values))

Note that the exposure days per site, per year should be consistent with the release days for Release 3 (captured overspray); however, EPA recommends a maximum of 250 days per year for each painter, as discussed in Section 5.3.

Worker inhalation exposures to polyisocyanate components during the application of coatings was presented as an attachment to the *1996 Generic Scenario for Automobile Spray Coating* draft report. EPA recommends using the attachment (included as Appendix D in this scenario) for the 1996 generic scenario if the chemical of interest is a polyisocyanate and using Equation 5-5 for all other nonvolatile coating components.

Coating Mist Concentration during Spray Coating ($C_{\text{coat_mist}}$)

EPA obtained coating mist concentrations ($C_{\text{coat_mist}}$) within the spray booth through a search of available OSHA In-Depth Surveys of the Automotive Refinishing Shop Industry and other relevant studies. These data are summarized in Appendix E and are used as the basis for this inhalation exposure estimate. The mist concentrations depend upon the type of spray gun used and the particular spray booth configuration. See Section 2.2 for additional information about spray guns and spray booth/prep station configurations.

EPA analyzed the available concentration data to determine the range, 95th percentile, and GM of data representing each of five spray coating scenarios. These scenarios are based upon various combinations of engineering control/spray booth ventilation configuration (i.e., crossdraft, downdraft, or semi-downdraft booths) and spray gun type (i.e., conventional or HVLP). Table 5-4 summarizes the mist concentration data (i.e., range, 95th percentile, and GM) for each of these scenarios.

Table 5-4. Summary of Mist Concentration Data for Spray Painting Scenarios

Scenario	Scenario Description	Coating Mist Concentrations (mg/m ³) (C _{coat mist})	
1	Crossdraft booth and conventional spray gun	Range: 2 to 35 95 th ‰: 28 GM: 9	Crossdraft booth (conventional or HVLP): Range: 2 to 35 95th‰: 32 (high-end default) GM: 9
2	Crossdraft booth and HVLP spray gun	Range: 4 to 34 95 th ‰: 33 GM: 13	
3	Downdraft booth and conventional spray gun	Range: 0.2 to 9 95 th ‰: 6 GM: 1	Downdraft booth (conventional or HVLP): Range: <0.01 to 18 95 th ‰: 7 GM: 1
4	Downdraft booth and HVLP spray gun	Range: <0.01 to 18 95 th ‰: 6 GM: 1 (typical default)	
5	Semi-downdraft booth and conventional spray gun	Range: 0.29 to 24 95 th ‰: 15 GM: 5	

Source: Refer to Appendix E of this ESD for the individual data points used in the analysis.

Table notes:

1) Some studies provided only a GM concentration and number of samples. These GMs were weighted appropriately (by number of samples) and used with the individual sample points in determining the GM for the Scenario or Booth data set; however, they were excluded in determining the 95th percentiles. The GM-only data were excluded because they are a measure of central tendency and do not accurately represent the range or variability in the individual concentration data they represent.

2) The downdraft booth-specific data analysis included two additional GMs found in one study of the combined use of both HVLP and conventional spray guns in a downdraft booth. These GMs were not included in the analysis of Scenario 3 or Scenario 4 data, because the GM concentrations were not spray gun type-specific.

Because HVLP spray guns use lower pressures to atomize the coatings, more of the coating is transferred to the surface with less overspray [Heitbrink, 1996]. HVLP guns are more efficient, producing less mist and lower expected mist concentrations and therefore lower exposures. Despite this understanding, the mist concentration data presented in Table 5-4 suggest that the spray gun type may have less of an effect on the worker breathing zone mist concentrations than does the spray booth ventilation configuration. One of the studies also noted that spray gun use may be less of a factor in mist concentration than the time spent spraying and paint type [NIOSH, 1993b].

To further illustrate this point, Table E-1 in Appendix E presents the worker breathing zone mist concentration data from three studies of HVLP spray gun use in a downdraft booth. The highest individual coating mist concentration data point for the downdraft booth and HVLP spray gun configuration (Scenario 4) obtained from these three studies is 18 mg/m³ [Heitbrink, 1993]. This data point is twice as large as the highest sample point found in two studies of conventional spray gun use in a downdraft booth (Scenario 3); however, upon further analysis, these data sets were found to have equivalent 95th percentiles and GMs. In addition, the 95th percentile for Scenario 4 (6 mg/m³) seems to suggest that the maximum concentration (18 mg/m³) may be an outlier as it is less than half of the maximum. Analysis of the data sets for Scenarios 1 and 2 reveal only a small difference in concentrations between HVLP and conventional spray gun use within a crossdraft booth.

Because the available data did not differ significantly between spray gun type within the same spray booth configuration, EPA also combined the data into spray booth configuration-specific sets and performed an analysis to determine the range, 95th percentile, and GM for each spray booth type (see Table 5-4). No data were found to represent HVLP spray gun use in a semi-downdraft booth. Also, this analysis included two additional GMs found in one study of the combined use of both HVLP and conventional spray guns in a downdraft booth. These GMs were not included in the analysis of Scenario 3 or Scenario 4 data, because the GM concentrations were not spray gun type-specific.

The recommended default scenarios are based in part on the following statistics from 1995 [BSB, 1995]:

- 30 percent of shops use crossdraft booths;
- 50 percent of shops use downdraft booths; and
- 64 percent of shops use HVLP spray guns.

In addition, more recent information collected about the automotive refinishing industry in support of the Paint Stripping and Surface Coating NESHAP indicates that HVLP spray gun use may be as high as 90 percent today and is considered to be GACT for this industry [USEPA, 2007a]. Refer to Section 2.2.1 for a more detailed discussion.

The GM of available data representing Scenario 4 (HVLP spraying in a downdraft booth) should be used as a *typical* default. EPA selected the GM value for typical exposure estimates because it suppresses the influence of outliers. In addition, the 95th percentile of available data representing Scenarios 1/2 (spraying in a crossdraft booth with either gun type) should be used as a *high-end* default in the absence of more detailed information on the automotive refinishing shops that use the chemical of interest in coating products.

Mass Fraction of the Chemical in the Nonvolatile Portion of the Sprayed Coating ($F_{\text{chem_solids}}$)

When spray applied, the solvent portion of the coating will volatilize and will not be present in the mist; therefore, the mass fraction of the chemical in the nonvolatile portion of the sprayed coating must be estimated and applied in this exposure. If the concentration of the chemical in the mixed coating ($F_{\text{chem_mixed}}$) or the total concentration of all nonvolatile components in the mixed coating ($F_{\text{solids_coat}}$) is unknown, 25 percent concentration may be assumed as a high-end, conservative default for both. As discussed in Section 1.2, coating formulations as sprayed are highly varied. One source stated that automotive refinishing coatings may contain 25 percent nonvolatile components [Kirk-Othmer, 1993]; therefore, this default assumes that the entire nonvolatile portion of the coating is the chemical of interest.

The following equation estimates the weight fraction of the chemical of interest in the nonvolatile portion of the coating:

$$F_{\text{chem_solids}} = \frac{F_{\text{chem_mixed}}}{F_{\text{solids_coat}}} \quad (5-6)$$

Where:

$F_{\text{chem_solids}}$ = Mass fraction of chemical of interest in the nonvolatile portion of the sprayed coating (mg chemical of interest/mg nonvolatile components)

$F_{\text{chem_mixed}}$	=	Mass fraction of the chemical of interest in the mixed coating as sprayed (mg chemical/mg mixed coating) (See Section 5.5)
$F_{\text{solids_coat}}$	=	Mass fraction of nonvolatile components within the mixed coating as sprayed (Default = 0.25 mg nonvolatile components/mg mixed coating [Kirk-Othmer, 1993])

Duration of the Spray Coating Activity ($\text{TIME}_{\text{spray}}$)

Many of the sources in Appendix E reported the duration for each spraying episode for which the coating mist concentrations were monitored. Some studies monitored only when active spraying was occurring, others monitored the painters' total time of exposure to the mist. This total duration includes both active spraying, as well as during other activities performed within the booth during the spraying activity (e.g., refilling the spray gun). Some studies reported both total sample duration and spraying duration.

In addition to the spray painting mist concentration studies summarized in Appendix E, a recent painter dermal exposure monitoring study was conducted at four large shops and 14 small- and medium-sized shops located in Spain. This study found that the mean duration for a single spraying episode was 16 minutes. This mean represents the duration of active spraying and excludes time for other activities [Delgado, 2004].

EPA analyzed the available spray activity durations from the coating mist concentrations studies summarized in Appendix E. Table 5-5 summarizes the results of this analysis. Note that the Delgado mean duration was not used in this analysis. It is cited here solely as a reference.

The spraying durations in the available data ranged from 3 minutes to 190 minutes with a GM of 28 minutes. The duration data from which the Table 5-5 statistics were derived included both active spraying durations and total sample durations. Where both durations were provided in the study, EPA used the total sample duration in the analysis to provide more conservative results. The total sample duration also corresponds to the coating mist concentration data used in this ESD. The duration of a spraying episode depends primarily on the coating characteristics, as well as the size of the area to be coated.

Table 5-5. Summary of Available Spray Activity Duration Data

Statistic	Spray Duration (minutes) (TIME _{spray})
Median	22
Arithmetic Mean	45
Standard Deviation	44
Geometric Mean (typical default)	28
Geometric Standard Deviation	3
Range	3 to 190
75 th Percentile	61
95th Percentile (high-end default)	141

Source: Refer to Appendix E of this ESD for the individual data points used in the analysis.

If the total amount of time spent by each painter spraying the chemical-containing coating per day (TIME_{spray}) is not known, EPA recommends assuming that one spraying episode involving the chemical occurs per painter, per day (one episode involves a single coating type: primer, basecoat, or clearcoat). Based on the results of the data analysis, EPA also recommends that 28 minutes be used as the typical default spraying duration. EPA selected the GM value for typical exposure estimates because it suppresses the influence of outliers. In addition, EPA recommends that 141 minutes be used as the high-end default spraying duration. These defaults conservatively assume that each painter completes one refinishing job per day.

Dermal Exposure

As previously described, painters may be exposed to the chemical while spraying the mixed coating. Painters' hands and bodies are expected to be exposed to the liquid chemical in the mixed coating during this activity. If the concentration of the chemical in the mixed coating, as sprayed (F_{chem_mixed}) is unknown, 25 percent concentration may be assumed as a high-end, conservative default. As discussed in Section 1.2, coating formulations as sprayed are highly varied. One source stated that automotive refinishing coatings may contain 25 percent nonvolatile components [Kirk-Othmer, 1993]; therefore, this default assumes that the entire nonvolatile portion of the coating is the chemical of interest.

The *Automotive Refinishing Spray Coating Dermal Model* may be used to estimate dermal exposure to the chemical of interest in the mixed coating during this activity. This model is based on a dermal monitoring study that was conducted in four large shops and 14 small- and medium-sized shops located in Spain. The study collected 60 glove samples and 330 body samples for this activity. Table 5-6 summarizes the data presented in the study for potential dermal exposure on the hand and body. The mean sampling time for a single spraying episode was 16 minutes, which excludes time for other activities such as refilling the spray gun. The Delgado study also used dermal surface areas (AREA_{surface}) consistent with the EPA's *Exposure Factors Handbook*¹ [Delgado, 2004].

¹The standard surface areas published in the EPA's *Exposure Factors Handbook* have also been adapted into the OECD's standard guidance for exposure assessments.

Table 5-6. Hand and Body Surface Loading Rates During Spray Application

Statistic	Hand Surface Loading Rate ($\mu\text{g}/\text{cm}^2\text{-min}$) ($Q_{\text{coating_hand}}$)	Body Surface Loading Rate ($\mu\text{g}/\text{cm}^2\text{-min}$) ($Q_{\text{coating_body}}$)
Median	3.22	0.92
Arithmetic Mean	3.98	1.21
Standard Deviation	3.43	1.07
Geometric Mean (typical default)	2.63	0.86
Geometric Standard Deviation	2.74	2.34
Range	0.40-13.4	0.20-4.35
75 th Percentile	5.94	1.53
95th Percentile (high-end default)	12.7	3.86

Source: Delgado, 2004.

The GM surface loading rates of 2.63 μg nonvolatile components/ $\text{cm}^2\text{-min}$ for hands and 0.86 μg nonvolatile components/ $\text{cm}^2\text{-min}$ for body can be used to estimate *typical* dermal exposure during spray application. EPA selected the GM value for typical exposure estimates because it suppresses the influence of outliers. The 95th percentile surface loading rates of 12.7 μg nonvolatile components/ $\text{cm}^2\text{-min}$ for hands and 3.86 μg nonvolatile components/ $\text{cm}^2\text{-min}$ for body are recommended for *high-end* estimates.

Default values for the spraying duration used to estimate the dermal exposure ($\text{TIME}_{\text{spray}}$) should be consistent with those used to estimate the associated inhalation exposure, as described in Section 5.7.1.

The model uses the following equation to estimate potential painter dermal exposure to the chemical of interest in a liquid coating product for this activity:

$$\text{EXP}_{\text{dermal}} = \left[\left(\frac{Q_{\text{coating_hand}}}{1,000 \mu\text{g}/\text{mg}} \times \text{AREA}_{\text{hand}} \right) + \left(\frac{Q_{\text{coating_body}}}{1,000 \mu\text{g}/\text{mg}} \times \text{AREA}_{\text{body}} \right) \right] \times \text{TIME}_{\text{spray}} \times F_{\text{chem_solids}} \quad (5-7)$$

This exposure will occur over [the lesser of $\text{TIME}_{\text{working_days}}$ or 250 (consistent with Section 5.7.1)] days per year.

Where:

$\text{EXP}_{\text{dermal}}$	=	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
$Q_{\text{coating_hand}}$	=	Quantity of liquid coating product remaining on hands (Defaults: 12.7 μg coating/ $\text{cm}^2\text{-minute}$ (high end) and 2.63 μg coating/ $\text{cm}^2\text{-minute}$ (typical) [Delgado, 2004])
$\text{AREA}_{\text{hand}}$	=	Surface area of contact (Default: 840 cm^2 for 2 hands [Delgado, 2004])
$Q_{\text{coating_body}}$	=	Quantity of liquid coating product remaining on the body (Defaults: 3.86 μg coating/ $\text{cm}^2\text{-minute}$ (high end) and 0.86 μg coating/ $\text{cm}^2\text{-minute}$ (low end) [Delgado, 2004])
$\text{AREA}_{\text{body}}$	=	Surface area of contact (Default: 18,720 cm^2 for total body area (excluding hands) [Delgado, 2004])
$\text{TIME}_{\text{spray}}$	=	Daily exposure duration per painter for spraying (minutes/day) (See Section 5.7.1)

$$F_{\text{chem_solids}} = \text{Mass fraction of chemical of interest in the nonvolatile portion of the sprayed coating (mg chemical of interest/mg nonvolatile components) (See Equation 5-6)}$$

Note that the exposure days per site, per year should be consistent with the release days for Release 3 (captured overspray); however, EPA recommends a maximum of 250 days per year for each painter, as discussed in Section 5.3.

SAMPLE CALCULATIONS

This section presents an example of how the equations introduced in Sections 3, 4, and 5 might be used to estimate releases of and exposures to a nonvolatile chemical found in an unknown automotive refinishing coating product. 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. The following data are used in the example calculations:

1. Chemical of interest production volume ($Q_{\text{chem_yr}}$) is 20,555 kg chemical/yr and is formulated into *activators, accelerators, and hardeners*¹.
2. The mass fraction of the chemical within the unknown automotive refinishing product ($F_{\text{chem_coattype}}$) is 0.50 kg chemical/kg coating product (nondefault; assumed to be known in this example).
3. Both environmental releases and occupational exposures are a concern.

General Facility Estimates

Average Annual Facility Volume Use rate, All Coating Products ($V_{\text{allcoat_site_yr}}$)

If the use rate of the chemical-containing coating product is unknown, it may be derived using averaged national data for the automotive refinishing industry, beginning with the annual volume of all automotive refinishing coating products ($V_{\text{allcoat_yr}}$) averaged by the total number of U.S. automotive refinishing shops (N_{allsites}):

$$V_{\text{allcoat_site_yr}} = \frac{V_{\text{allcoat_yr}}}{N_{\text{allsites}}} \quad [\text{Eqn. 3-1}]$$

$$V_{\text{allcoat_site_yr}} = \frac{54,633,000 \text{ gal all coating products/yr}}{36,296 \text{ shops}}$$

$$V_{\text{allcoat_site_yr}} = 1,505 \text{ gal all coating products/site - yr}$$

Average Daily Facility Volume Use rate, All Coating Products ($V_{\text{allcoat_site_day}}$)

The average daily facility volume use rate may be estimated by dividing the average annual use rate by the number of operating days ($\text{TIME}_{\text{working_days}}$). If the operating days is not known, EPA recommends assuming a default of 250 days per year:

$$V_{\text{allcoat_site_day}} = \frac{V_{\text{allcoat_site_yr}}}{\text{TIME}_{\text{working_days}}} \quad [\text{Eqn. 3-2}]$$

¹ The production volume and formulation for the example chemical of interest is based on recent cases submitted for EPA's new chemical review.

$$V_{\text{allcoat_site_day}} = \frac{1,505 \text{ gal all coating products/site - yr}}{250 \text{ days/yr}}$$

$$V_{\text{allcoat_site_day}} = 6 \text{ gal all coating products/site - day}$$

Fraction of Coating Products that Contain the Chemical of Interest ($F_{\text{vol_coattype_prod}}$)

Using the decision logic presented in Figure 3-1, the exact specific type of coating product is not known; however, the general type of coating product is known to be “Other Additives and Coatings”. Since both environmental releases and occupational exposures are a concern, the volume fraction for “Remaining 21 Coating Types” (*0.09 gallons of the coating product type/gallon total coatings*) should be used for the volume fraction ($F_{\text{vol_coattype}}$). In addition, it is assumed that all coating product brands of that type contain the chemical of interest (i.e., $F_{\text{vol_coattype_brand}}$ is *1 gallon chemical-containing coating product brand/gallon total coating product type*):

$$F_{\text{vol_coattype_prod}} = F_{\text{vol_coattype}} \times F_{\text{vol_coattype_brand}} \quad [\text{Eqn. 3-3}]$$

$$F_{\text{vol_coattype_prod}} = \frac{0.09 \text{ gal coating type}}{\text{gal all coatings}} \times \frac{1 \text{ gal chem - containing coating brand}}{\text{gal coating type}}$$

$$F_{\text{vol_coattype_prod}} = 0.09 \text{ gal chem - containing coating product brand/gal all coatings}$$

Daily Facility Mass Use rate of the Coating Product Containing the Chemical of Interest ($Q_{\text{coattype_day}}$)

Since the chemical-containing coating product type and associated properties are unknown, a density ($\text{RHO}_{\text{coattype}}$) of *8.3 pounds per gallon* is assumed:

$$Q_{\text{coattype_day}} = \frac{V_{\text{allcoat_site_day}} \times F_{\text{vol_coattype_prod}} \times \text{RHO}_{\text{coattype}}}{2.205 \text{ lbs/kg}} \quad [\text{Eqn. 3-4}]$$

$$Q_{\text{coattype_day}} = \frac{\frac{6 \text{ gal all coatings}}{\text{site - day}} \times \frac{0.09 \text{ gal chem - containing coating product}}{\text{gal all coatings}} \times \frac{8.3 \text{ lbs}}{\text{gal}}}{2.205 \text{ lbs/kg}}$$

$$Q_{\text{coattype_day}} = 2.0 \text{ kg chemical - containing coating product/site - day}$$

Use rate of the Chemical of Interest ($Q_{\text{chem_day}}$)

In this example, the concentration of the chemical of interest in the coating product ($F_{\text{chem_coattype}}$) is assumed known to be *0.50 kg chemical/kg coating product*:

$$Q_{\text{chem_day}} = Q_{\text{coattype_day}} \times F_{\text{chem_coattype}} \quad [\text{Eqn. 3-5}]$$

$$Q_{\text{chem_day}} = 2.0 \text{ kg chem - containing coating product/site - day} \times 0.5 \text{ kg chem/kg coating product}$$

$$Q_{\text{chem_day}} = 1.0 \text{ kg chemical/site - day}$$

Number of Shops (N_{sites})

$$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_day} \times TIME_{working_days}} \quad [Eqn. 3-6]$$

$$N_{sites} = \frac{20,555 \text{ kg chem./yr}}{1.0 \text{ kg chem/site - day} \times 250 \text{ days/yr}}$$

$$N_{sites} = 82.2 \text{ sites}$$

Round N_{sites} up to next integer (83 *automotive refinishing shops*) and recalculate Q_{chem_day} :

$$Q_{chem_day} = \frac{20,555 \text{ kg chem/yr}}{83 \text{ sites} \times 250 \text{ days/yr}}$$

$$Q_{chem_day} = 1.0 \text{ kg chem/site - day}$$

Annual Number of Coating Product Containers Emptied per Shop ($N_{cont_site_yr}$)

It is assumed that the coating product (which is known to contain 50% chemical of interest) is shipped to the automotive refinishing shops in one-gallon cans, as a default. A density of 8.3 lbs/gal is also assumed for the coating product. The mass capacity for each of the cans is calculated as:

$$Q_{cont} = \frac{V_{cont} \times RHO_{coatype}}{2.205 \text{ lbs/kg} \times 3.785 \text{ L/gal}} = \frac{\frac{3.785 \text{ L coating}}{\text{container}} \times \frac{8.3 \text{ lbs coating}}{\text{gal}}}{2.205 \text{ lbs/kg} \times 3.785 \text{ L/gal}} = \frac{3.8 \text{ kg coating product}}{\text{container}}$$

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

$$N_{cont_site_yr} = \frac{Q_{coatype_day}}{Q_{cont}} \times TIME_{working_days} \quad [Eqn. 3-7]$$

$$N_{cont_site_yr} = \frac{2.0 \text{ kg coating product/site - day}}{3.8 \text{ kg coating product/container}} \times 250 \text{ days/yr}$$

$$N_{cont_site_yr} = 132 \text{ containers/site - yr}$$

Release Assessments**Coating Product Container Residue Released to Incineration, or Landfill (Release 1)**

Since $N_{cont_site_yr}$ is less than $TIME_{working_days}$, it is assumed that each container is rinsed or disposed on the day it is emptied (i.e., residues from a single can are released over $[N_{cont_site_yr}]$ days per year). The following equation is used to estimate the daily release:

$$E_{local_container_residue_disp} = Q_{cont} \times F_{chem_coatype} \times F_{container_disp} \times N_{cont_site_day} \quad [Eqn. 4-1a]$$

Since the container is assumed to be a one-gallon can by default, the *EPA/OPPT Small Container Residual Model* is used to estimate this release. The default fraction of liquid chemical that remains in the empty container ($F_{\text{container_disp}}$) is 0.006 kg chemical remaining/kg chemical in full container (see Table B-3 in Appendix B):

$$\begin{aligned} \text{Elocal}_{\text{container_residue_disp}} &= \frac{3.8 \text{ kg coating}}{\text{container}} \times \frac{0.5 \text{ kg chem}}{\text{kg coating}} \times \frac{0.006 \text{ kg chem remain}}{\text{kg chem full}} \times \frac{1 \text{ container}}{\text{site - day}} \\ \text{Elocal}_{\text{container_residue_disp}} &= \frac{0.011 \text{ kg chem released}}{\text{site - day}} \\ &\dots \text{over 132 days/year from 83 sites.} \end{aligned}$$

Equipment Cleaning Residue Released to Incineration or Landfill (Release 2)

$$\text{Elocal}_{\text{equip_disp}} = Q_{\text{chem_day}} \times (1 - F_{\text{container_disp}}) \times F_{\text{equip_disp}} \quad [\text{Eqn. 4-2}]$$

$$\begin{aligned} \text{Elocal}_{\text{equip_disp}} &= \frac{1.0 \text{ kg chem}}{\text{site - day}} \times \left(1 - \frac{0.006 \text{ kg chem remain}}{\text{kg chem full}} \right) \times \frac{0.02 \text{ kg chem released}}{\text{kg chem used}} \\ \text{Elocal}_{\text{equip_disp}} &= \frac{0.020 \text{ kg chem released}}{\text{site - day}} \\ &\dots \text{over 250 days/year from 83 sites.} \end{aligned}$$

Oversprayed Coating Captured by Emissions Controls and Released to Incineration or Landfill (Release 3)

First, the total amount of chemical that is contained in the oversprayed coating mist is estimated using the following equation (*conventional spray guns* are assumed as the default):

$$\begin{aligned} Q_{\text{chem_overspray_day}} &= Q_{\text{chem_day}} \times (1 - F_{\text{container_disp}}) \times (1 - F_{\text{equip_disp}}) \times (1 - F_{\text{eff_spray_gun}}) \quad [\text{Eqn. 4-3}] \\ Q_{\text{chem_overspray_day}} &= \frac{1.0 \text{ kg chem}}{\text{site - day}} \times \left(1 - \frac{0.006 \text{ kg chem remain}}{\text{kg chem full}} \right) \times \left(1 - \frac{0.02 \text{ kg chem released}}{\text{kg chem used}} \right) \times \left(1 - \left[\frac{0.2 \text{ to } 0.65 \text{ kg chem transferred}}{\text{kg chem sprayed}} \right] \right) \\ Q_{\text{chem_overspray_day}} &= \frac{0.34 \text{ to } 0.78 \text{ kg chem oversprayed}}{\text{site - day}} \end{aligned}$$

The amount of overspray that either settles within the spray area or is captured by the ventilation system and associated controls is estimated using the following equation:

$$\text{Elocal}_{\text{captured_overspray}} = Q_{\text{chem_overspray_day}} \times F_{\text{eff_vent}} \times F_{\text{eff_control}} \quad [\text{Eqn. 4-4}]$$

$$\begin{aligned} \text{Elocal}_{\text{captured_overspray}} &= \left[\frac{0.34 \text{ to } 0.78 \text{ kg chem oversprayed}}{\text{site} - \text{day}} \right] \times \frac{1 \text{ kg chem in vent}}{\text{kg chem oversprayed}} \times \frac{0.96 \text{ kg chem on filter}}{\text{kg chem in vent}} \\ \text{Elocal}_{\text{captured_overspray}} &= \frac{0.33 \text{ to } 0.75 \text{ kg chem captured and released from controls}}{\text{site} - \text{day}} \end{aligned}$$

...over 250 days/year from 83 sites.

Since 100 percent of the overspray is assumed to be collected into the ventilation system, Equation 4-5 is not used in this example (i.e., all settled and captured coating is disposed to the same media, so these portions are not separated and $F_{\text{eff_vent}}$ defaults to 1 kg/kg).

Oversprayed Coating Vented from the Shop and Emitted to Air (Release 4)

$$\text{Elocal}_{\text{air_emission}} = Q_{\text{chem_overspray_day}} \times F_{\text{eff_vent}} \times (1 - F_{\text{eff_control}}) \quad [\text{Eqn. 4-6}]$$

$$\begin{aligned} \text{Elocal}_{\text{air_emission}} &= \left[\frac{0.34 \text{ to } 0.78 \text{ kg chem oversprayed}}{\text{site} - \text{day}} \right] \times \frac{1 \text{ kg chem in vent}}{\text{kg chem oversprayed}} \times \left(1 - \frac{0.96 \text{ kg chem on filter}}{\text{kg chem in vent}} \right) \\ \text{Elocal}_{\text{captured_overspray}} &= \frac{0.014 \text{ to } 0.031 \text{ kg chem emitted to air}}{\text{site} - \text{day}} \end{aligned}$$

...over 250 days/year from 83 sites.

As mentioned in Section 6.2.3, 100 percent of the overspray is assumed to be collected into the ventilation system (i.e., $F_{\text{eff_vent}}$ defaults to 1 kg/kg). This assumption results in a conservative, high-end estimate for the amount released to air.

Occupational Exposure Assessments

Total Number of Workers Potentially Exposed to the Chemical

It is assumed that eight painters are potentially exposed to the chemical at each site; therefore, the total number of painters (workers) is calculated as:

$$8 \frac{\text{workers}}{\text{site}} \times N_{\text{sites}} = 8 \frac{\text{workers}}{\text{site}} \times 83 \text{ sites} = 664 \text{ total automotive refinishing painters}$$

Dermal Exposure from Transfer and Mixing of Liquid Chemicals in Coating Products (Exposure A)

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

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_coatype}} \quad [\text{Eqn. 5-1}] \\ &= \left[\frac{0.7 \text{ to } 2.1 \text{ mg coating}}{\text{cm}^2 - \text{incident}} \right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.5 \text{ mg chem}}{\text{mg coating}} \end{aligned}$$

$$\text{EXP}_{\text{dermal}} = \frac{294 - 882 \text{ mg chem}}{\text{day}}$$

...over 250 days/year

Dermal Exposure to Liquid Chemicals in Coating Products during Cleaning/Handling Empty Containers (Exposure B)

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

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= Q_{\text{liquid_skin}} \times \text{AREA}_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_coattype}} \quad [\text{Eqn. 5-2}] \\ &= \left[\frac{0.7 \text{ to } 2.1 \text{ mg coating}}{\text{cm}^2 - \text{incident}} \right] \times 840 \text{ cm}^2 \times \frac{1 \text{ incident}}{\text{day}} \times \frac{0.5 \text{ mg chem}}{\text{mg coating}} \\ \text{EXP}_{\text{dermal}} &= \frac{294 - 882 \text{ mg chem}}{\text{day}} \\ &\quad \dots \text{over 250 days/year} \end{aligned}$$

Dermal Exposure to Liquid Chemicals in Mixed Coating during Transfer into the Spray Gun (Exposure C)

The potential worker exposure to the chemical within the mixed coating is calculated using dermal monitoring data collected from painters performing this activity in automotive refinishing shops:

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= \frac{Q_{\text{coating_skin}}}{1000 \text{ } \mu\text{g/mg}} \times \text{AREA}_{\text{surface}} \times \text{TIME}_{\text{spray_gun_fill}} \times F_{\text{chem_mixed}} \quad [\text{Eqn. 5-3}] \\ &= \left[\frac{24.4 \text{ to } 499 \text{ } \mu\text{g coating/cm}^2 - \text{minute}}{1000 \text{ } \mu\text{g/mg}} \right] \times 840 \text{ cm}^2 \times \frac{3 \text{ minutes}}{\text{day}} \times \frac{0.25 \text{ mg chem}}{\text{mg coating}} \\ \text{EXP}_{\text{dermal}} &= \frac{15.3 \text{ to } 314 \text{ mg chem}}{\text{day}} \\ &\quad \dots \text{over 250 days/year} \end{aligned}$$

Dermal Exposure to Liquid Chemicals in Mixed Coating during Mix Cup and Spray Gun Equipment Cleaning (Exposure D)

The potential worker exposure to the chemical within the mixed coating is calculated using dermal monitoring data collected from painters cleaning spray guns in automotive refinishing shops:

$$\begin{aligned} \text{EXP}_{\text{dermal}} &= \frac{Q_{\text{coating_skin}}}{1000 \text{ } \mu\text{g/mg}} \times \text{AREA}_{\text{surface}} \times \text{TIME}_{\text{equip_clean}} \times F_{\text{chem_mixed}} \quad [\text{Eqn. 5-4}] \\ &= \left[\frac{16.7 \text{ to } 161 \text{ } \mu\text{g coating/cm}^2 - \text{minute}}{1000 \text{ } \mu\text{g/mg}} \right] \times 840 \text{ cm}^2 \times \frac{8 \text{ minutes}}{\text{day}} \times \frac{0.25 \text{ mg chem}}{\text{mg coating}} \\ \text{EXP}_{\text{dermal}} &= \frac{28 - 270 \text{ mg chem.}}{\text{day}} \end{aligned}$$

...over 250 days/year

Exposure to Chemical Mists in Oversprayed Coating during Spraying (Exposure E)

Inhalation Exposure to Oversprayed Coating Mist:

Using coating mist concentration data collected for conventional spray guns used within crossdraft spray booths (conservative default scenario), the inhalation exposure to those oversprayed mists is calculated using the following equations:

$$F_{\text{chem_solids}} = \frac{F_{\text{chem_mixed}}}{F_{\text{solids_coat}}} \quad [\text{Eqn. 5-6}]$$

$$F_{\text{chem_solids}} = \frac{0.25 \text{ mg chem/mg coating}}{0.25 \text{ mg nonvolatiles/mg coating}}$$

$$F_{\text{chem_solids}} = 1 \text{ mg chem/mg nonvolatiles}$$

$$\text{EXP}_{\text{inhalation}} = C_{\text{coat_mist}} \times F_{\text{chem_solids}} \times \text{RATE}_{\text{breathing}} \times \frac{\text{TIME}_{\text{spray}}}{60 \text{ min/hr}} \quad [\text{Eqn. 5-5}]$$

$$EXP_{\text{inhalation}} = \left[\frac{1 \text{ to } 32 \text{ mg nonvolatile mist}}{\text{m}^3 \text{ air}} \right] \times \frac{1 \text{ mg chem}}{\text{mg nonvol mist}} \times \frac{1.25 \text{ m}^3 \text{ air}}{\text{hr}} \times \left[\frac{28 \text{ to } 141 \text{ minutes/day}}{60 \text{ minutes/hr}} \right]$$

$$EXP_{\text{inhalation}} = 0.58 \text{ to } 94 \text{ mg chem/day} \\ \dots \text{over } 250 \text{ days/year.}$$

Dermal Exposure to Oversprayed Coating Mist:

The potential worker exposure to the chemical within the mixed coating is calculated using dermal monitoring data collected from painters spraying coatings in automotive refinishing shops:

[Eqn. 5-7]

$$EXP_{\text{dermal}} = \left[\left(\frac{Q_{\text{coating_hand}}}{1000 \text{ } \mu\text{g/mg}} \times \text{AREA}_{\text{hand}} \right) + \left(\frac{Q_{\text{coating_body}}}{1000 \text{ } \mu\text{g/mg}} \times \text{AREA}_{\text{body}} \right) \right] \times \text{TIME}_{\text{spray}} \times F_{\text{chem_solids}}$$

$$= \left[\left(\frac{2.63 \text{ to } 12.7 \text{ } \mu\text{g coating/cm}^2 \text{ - min}}{1000 \text{ } \mu\text{g/mg}} \times 840 \text{ cm}^2 \right) + \left(\frac{0.86 \text{ to } 3.86 \text{ } \mu\text{g coat/cm}^2 \text{ - min}}{1000 \text{ } \mu\text{g/mg}} \times 18720 \text{ cm}^2 \right) \right] \times \left[\frac{28 \text{ to } 141 \text{ min}}{\text{day}} \right] \times \frac{1 \text{ mg chem}}{\text{mg nonvols}}$$

$$EXP_{\text{dermal}} = \frac{513 - 11,700 \text{ mg chem.}}{\text{day}} \\ \dots \text{over } 250 \text{ days/year}$$

DATA GAPS/UNCERTAINTIES AND FUTURE WORK

This ESD includes extensive information collected through years of EPA's Design for the Environment's (DfE's) partnership with the automotive refinishing industry. In addition, this revision incorporates the information collected in support of EPA's recently promulgated Paint Stripping and Surface Coating NESHAP. Both the DfE project and the Paint Stripping and Surface Coating NESHAP information were collected through shop visits and other contacts with industry experts, including manufacturers and suppliers of automotive refinishing coating products. Information collected from these sources allows EPA to provide in this ESD a thorough overview of the industry and its refinishing practices and provide a sound basis for the general facility estimates and the number of workers potentially exposed.

However, EPA wishes to make this ESD as detailed and up to date as possible, such that the risk-screening assessments reflect current industrial practices. Reviewers should feel free to provide additional information and data that could further enhance and improve the methods described in this scenario, as well as to recommend additional resources that may be useful to the development of this scenario.

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

The ESD incorporates a national average use rate that accounts for all coating products sold in the United States, and estimates the relative portion of that total rate attributed to particular coating product types using data collected for California. EPA combined these data to estimate the facility-level automobile refinishing coating use rate. The quality of these use rates could be improved with additional data and information on typical coating product purchase or usage rates at individual shops and the factors that most drive these rates.

EPA found limited information on the concentrations of various chemicals within the automotive refinishing coating products, although it is noted that these formulations are expected to be variable. The information presented in this ESD is limited to the relative portions of nonvolatile vs. volatile/solvent chemicals found within solvent-based and waterborne coatings, as sprayed. Additional formulation data that could be used to generally demonstrate typical concentrations of the various types of nonvolatile chemicals used in each coating type (e.g., clearcoat, basecoat, primer) would further enhance the calculations.

The ESD assumes a standard EPA estimate for the annual days of operation at automotive refinishing shops. Industry-specific information on the typical or range of operating days would further improve the general facility and release estimates.

The ESD incorporates data from several monitoring studies conducted by NIOSH in estimating painter inhalation exposures in a variety of spraying scenarios; however, EPA has not found coating mist concentration data representative of the use of HVLP guns in semi-downdraft booths. Additional data for this and the other spraying scenarios would further enhance the inhalation exposure estimate.

The ESD assumes a standard EPA loss fraction for residues cleaned from mixing and spray coating equipment. Industry-specific information on the typical portions of

coatings mixed and sprayed that are disposed as equipment residues would further improve the general facility and release estimates.

REFERENCES

EPA researched the following specific information in developing this document: process description, operating information, chemicals used, wastes generated, worker activities, and exposure information. Categories of sources checked were EPA sources, other government agencies (e.g., NIOSH and OSHA), journals, trade associations, and web searches. References listed in the original 1996 generic scenario were updated in the 2004 scenario with the information available as of June 2003, including information from Kirk-Othmer Encyclopedia of Technology, the NIOSHtic database, the OSHA web site for automatic repair and refinishing, and the Body Shop Business web site. This latest revision of the ESD incorporates additional data and information collected by CARB, EPA's OAQPS in the development of the Paint Stripping and Surface Coating NESHAP, and 2004 U.S. Census Bureau data. EPA obtained updated information on waterborne coatings through a web search.

While these resources were reviewed for information, not all provided information specific to the use of coatings in the automotive refinishing industry. The references specifically cited in this ESD are listed below:

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Appendix A

ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES

Summary of Release and Exposure Estimation Equations

Table A-1 summarizes the equations introduced in Sections 3 through 5 of this document. These equations may be used in evaluating the releases of and exposures to chemicals that are spray painted as a component of automotive refinishing coating products. Table A-2 describes each input variable and associated default.

**Table A-1. Automotive Refinishing Spray Coating
Release and Exposure Calculation Summary**

General Facility Estimates	
Average Annual Facility Volume Use Rate, All Coating Products (gallons/site-yr) ($V_{\text{allcoat_site_yr}}$):	
$V_{\text{allcoat_site_yr}} = \frac{V_{\text{allcoat_yr}}}{N_{\text{allsites}}}$	(Eqn. 3-1)
Average Daily Facility Volume Use Rate, All Coating Products (gallons/site-day) ($V_{\text{allcoat_site_day}}$):	
$V_{\text{allcoat_site_day}} = \frac{V_{\text{allcoat_site_yr}}}{\text{TIME}_{\text{working_days}}}$	(Eqn. 3-2)
Fraction of Coating Products that Contain the Chemical of Interest (gallon/gallon) ($F_{\text{vol_coattype_prod}}$):	
$F_{\text{vol_coattype_prod}} = F_{\text{vol_coattype}} \times F_{\text{vol_coattype_brand}}$	(Eqn. 3-3)
Daily Facility Mass Use Rate of the Chemical-Containing Coating (kg/site-day) ($Q_{\text{coattype_day}}$):	
$Q_{\text{coattype_day}} = \frac{V_{\text{allcoat_site_day}} \times F_{\text{vol_coattype_prod}} \times \text{RHO}_{\text{coattype}}}{2.205 \text{ lbs/kg}}$	(Eqn. 3-4)
Use Rate of the Chemical of Interest (kg/site-day) ($Q_{\text{chem_day}}$):	
$Q_{\text{chem_day}} = Q_{\text{coattype_day}} \times F_{\text{chem_coattype}}$	(Eqn. 3-5)

General Facility Estimates
<p>Number of Shops (N_{sites})¹:</p> $N_{\text{sites}} = \frac{Q_{\text{chem_yr}}}{Q_{\text{chem_day}} \times \text{TIME}_{\text{working_days}}} \quad (\text{Eqn. 3-6})$ <p>The value for N_{sites}, calculated using Equation 3-6 should be rounded up to the nearest integer value. $Q_{\text{chem_day}}$ should then be adjusted for the N_{sites} integer value (to avoid errors due to rounding):</p> $Q_{\text{chem_day}} = \frac{Q_{\text{chem_yr}}}{N_{\text{sites}} \times \text{TIME}_{\text{working_days}}}$ <p>¹Note: If the number of automotive refinishing shops is known, the previous equation may also be used to estimate the resulting average daily purchase rate for use in subsequent calculations.</p>
<p>Annual Number of Coating Product Containers Emptied per Shop (containers/site-year) ($N_{\text{cont_site_yr}}$):</p> $N_{\text{cont_site_yr}} = \frac{Q_{\text{chem_yr}}}{F_{\text{chem_coattype}} \times Q_{\text{cont}} \times N_{\text{sites}}} \quad (\text{Eqn. 3-7})$

Release Calculations		
Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Container Residue	Landfill Incineration	<p>If $N_{\text{cont_site_yr}}$ is fewer than $\text{TIME}_{\text{working_days}}$:</p> $\text{Elocal}_{\text{container_residue_disp}} = Q_{\text{cont}} \times F_{\text{chem_coatype}} \times F_{\text{container_disp}} \times N_{\text{cont_site_day}}$ <p>... released over $[N_{\text{cont_site_yr}}]$ days/year from $[N_{\text{sites}}]$ sites (Eqn. 4-1a)</p> <p>If $N_{\text{cont_site_yr}}$ is greater than $\text{TIME}_{\text{working_days}}$:</p> $\text{Elocal}_{\text{container_residue_disp}} = Q_{\text{chem_day}} \times F_{\text{container_disp}}$ <p>... released over $[\text{TIME}_{\text{working_days}}]$ days/year from $[N_{\text{sites}}]$ sites (Eqn. 4-1b)</p>
Process Equipment Residue	Landfill Incineration	$\text{Elocal}_{\text{equip_disp}} = Q_{\text{chem_day}} \times (1 - F_{\text{container_disp}}) \times F_{\text{equip_disp}}$ <p>... released over $[\text{TIME}_{\text{working_days}}]$ days/year from $[N_{\text{sites}}]$ sites (Eqn. 4-2)</p>
Oversprayed Coating Mists	Air Landfill Incineration	<p>The portion of release that settles out* or is captured by the control technology:</p> $\text{Elocal}_{\text{captured_overspray}} = Q_{\text{chem_overspray_day}} \times F_{\text{eff_vent}} \times F_{\text{eff_control}}$ <p>... released over $[\text{TIME}_{\text{working_days}}]$ days/year from $[N_{\text{sites}}]$ sites (Eqn. 4-4)</p> <p>Where:</p> $Q_{\text{chem_overspray_day}} = Q_{\text{chem_day}} \times (1 - F_{\text{container_disp}}) \times (1 - F_{\text{equip_disp}}) \times (1 - F_{\text{eff_spray_gun}}) \quad (\text{Eqn. 4-3})$ <p>*If the amount of overspray that settles within the spray area is to quantified separately, the following equation is used:</p> $\text{Elocal}_{\text{settled_overspray}} = Q_{\text{chem_overspray_day}} \times (1 - F_{\text{eff_vent}})$ <p>... released over $[\text{TIME}_{\text{working_days}}]$ days/year from $[N_{\text{sites}}]$ sites (Eqn. 4-5)</p> <p>The portion of release that will not be captured by the control technology and released to air:</p> $\text{Elocal}_{\text{air_emission}} = Q_{\text{chem_overspray_day}} \times F_{\text{eff_vent}} \times (1 - F_{\text{eff_control}})$ <p>... released over $[\text{TIME}_{\text{working_days}}]$ days/year from $[N_{\text{sites}}]$ sites (Eqn. 4-6)</p>

Table A-1 (Continued)

Occupational Exposure Calculations	
Dermal Exposure from Transfer and Mixing of Liquid Chemicals in Coating Products:	
$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_coattype}}$ <p>... over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.</p>	(Eqn. 5-1)
Dermal Exposure to Liquid Chemicals in Coating Products during Cleaning/Handling Empty Containers:	
$EXP_{\text{dermal}} = Q_{\text{liquid_skin}} \times AREA_{\text{surface}} \times N_{\text{exp_incident}} \times F_{\text{chem_coattype}}$ <p>... over [the lesser of $N_{\text{cont_site_yr}}$ or $TIME_{\text{working_days}}$ (consistent with Section 4.2), up to 250] days per year.</p>	(Eqn. 5-2)
Dermal Exposure to Liquid Chemicals in Mixed Coating during Transfer into the Spray Gun:	
$EXP_{\text{dermal}} = \frac{Q_{\text{coating_skin}}}{1,000 \mu\text{g/mg}} \times AREA_{\text{surface}} \times TIME_{\text{spray_gun_fill}} \times F_{\text{chem_mixed}}$ <p>... over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.</p>	(Eqn. 5-3)
Dermal Exposure to Liquid Chemicals in Mixed Coating during Mix Cup and Spray Gun Equipment Cleaning:	
$EXP_{\text{dermal}} = \frac{Q_{\text{coating_skin}}}{1,000 \mu\text{g/mg}} \times AREA_{\text{surface}} \times TIME_{\text{eqpt_clean}} \times F_{\text{chem_mixed}}$ <p>... over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.</p>	(Eqn. 5-4)
Inhalation Exposure to Chemical Mists in Oversprayed Coating during Spraying:	
$EXP_{\text{inhalation}} = C_{\text{coat_mist}} \times F_{\text{chem_solids}} \times RATE_{\text{breathing}} \times \frac{TIME_{\text{spray}}}{60 \text{ min/hr}}$ <p>... over [the lesser of $TIME_{\text{working_days}}$ (consistent with Section 3.2) or 250] days per year.</p> <p>Where:</p>	(Eqn. 5-5)
$F_{\text{chem_solids}} = \frac{F_{\text{chem_mixed}}}{F_{\text{solids_coat}}}$	(Eqn. 5-6)
Dermal Exposure to Chemical Mists in Oversprayed Coating during Spraying:	
$EXP_{\text{dermal}} = \left[\left(\frac{Q_{\text{coating_hand}}}{1,000 \mu\text{g/mg}} \times AREA_{\text{hand}} \right) + \left(\frac{Q_{\text{coating_body}}}{1,000 \mu\text{g/mg}} \times AREA_{\text{body}} \right) \right] \times TIME_{\text{spray}} \times F_{\text{chem_solids}}$ <p>... over [the lesser of $TIME_{\text{working_days}}$ or 250 (consistent with Section 5.7.1)] days per year.</p>	(Eqn. 5-7)

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

Variable	Variable Description	Default Value	Data Source
AREA _{body}	Surface area of contact on the body, excluding hands (cm ²)	18,720	Delgado, 2004
AREA _{hand}	Surface area of contact on the hands (cm ²)	840 (2 hands)	Delgado, 2004
AREA _{surface}	Surface area of contact (cm ²)	840 (2 hands)	CEB, 2000 Delgado, 2004
C _{coat_mist}	Oversprayed coating mist concentration in the air within painters' breathing zone (mg nonvolatile mist/m ³ air in breathing zone)	1 (typical) 32 (high end)	See Appendix E
F _{chem_coatype}	Mass fraction of the chemical of interest in the automotive refinishing coating product (kg chemical/kg coating product)	1	EPA assumption
F _{chem_mixed}	Mass fraction of the chemical of interest in the mixed coating, as sprayed (mg chemical/mg mixed coating)	0.25	Kirk-Othmer, 1993
F _{solids_coat}	Mass fraction of the nonvolatile components within the mixed coating, as sprayed (mg nonvolatile components/mg mixed coating)	0.25	Kirk-Othmer, 1993
F _{container_disp}	Fraction of coating product remaining in the container as residue (kg coating product remaining/kg coating in full container)	0.006	CEB, 1992
F _{eff_control}	Fraction of the oversprayed chemical in the ventilation system that is captured by the emission controls (kg chemical captured by controls system/kg ventilated from spray area)	0.96	USEPA, 2007
F _{eff_spray_gun}	Transfer efficiency of the spray gun (kg coating transferred to surface/kg sprayed)	0.65 (typical) 0.20 (worst case)	Heitbrink, 1996
F _{eff_vent}	Fraction of the oversprayed chemical that is captured by the spray area ventilation system (kg chemical captured by ventilation system/kg oversprayed)	1	EPA assumption
F _{equip_disp}	Fraction of mixed coating released as residual in mix cup and spray gun process equipment (kg coating released/kg capacity)	0.02	CEB, 1992
F _{vol_coatype}	Volumetric fraction of all coating products that represents the particular type of product that contains the chemical of interest (gallon chemical-containing coating product type/gallons all coating products)	0.07 (unknown coating product type)	CARB, 2005 See Table 1-1

Variable	Variable Description	Default Value	Data Source
$F_{vol_coattype_brand}$	Volumetric fraction of the coating product type that contains the chemical of interest (gallon chemical-containing coating product brand/gallons all coating product type)	1	EPA assumption
$N_{allsites}$	Total number of U.S. automotive refinishing shops	36,296	USCB, 2004a
$N_{exp_incident}$	Number of exposure incidents per day (incidents/day)	1	CEB, 2000
$N_{workers_site}$	Number of workers exposed per site	8	BSB, 2000
$Q_{coating_body}$	Quantity of liquid coating product remaining on body from spraying ($\mu\text{g}/\text{cm}^2$ -minute)	0.86 (typical) 3.86 (high end)	Delgado, 2004
$Q_{coating_hand}$	Quantity of liquid coating product remaining on hands from spraying ($\mu\text{g}/\text{cm}^2$ -minute)	2.63 (typical) 12.7 (high end)	Delgado, 2004
$Q_{coating_skin}$	Quantity of liquid coating product remaining on skin ($\mu\text{g}/\text{cm}^2$ -minute)	For filling spray guns: 24.4 (typical) 499 (high end) For cleaning equipment: 16.7 (typical) 161 (high end)	Delgado, 2004
Q_{liquid_skin}	Quantity of liquid coating product remaining on skin (mg/cm^2 -incident)	0.7 (low end) 2.1 (high end)	CEB, 2000
$RATE_{breathing}$	Typical worker breathing rate (m^3/hr)	1.25	CEB, 1991
$RHO_{coattype}$	Density of the automotive refinishing coating product (lbs/gal)	8.3	EPA assumption See Table 1-1
$TIME_{eqpt_clean}$	Daily exposure duration per painter for cleaning mixing cups and spray gun equipment (minutes/day)	8	Delgado, 2004
$TIME_{spray}$	Daily exposure duration per painter for spraying coating (minutes/day)	28 (typical) 141 (high end)	See Appendix E
$TIME_{spray_gun_fill}$	Daily exposure duration per painter for filling spray guns (minutes/day)	3	Delgado, 2004
$TIME_{working_days}$	Days of automotive refinishing product use per year (days/yr)	250	EPA assumption
$V_{allcoat_yr}$	Total U.S. automotive refinishing coating production rate (gallons coating product/yr)	54,633,000	USCB, 2004b
V_{cont}	Volume of automotive refinishing coating product per container (liters coating product/container)	3.785 (1-gallon can)	EPA assumption

Appendix B

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

INTRODUCTION

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

Section B.2: Chemical Vapor Releases & Associated Inhalation Exposures;

Section B.3: Container Residue Release Models (non-air);

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

Section B.5: Dust Emissions from Transferring Solids Model;

Section B.6: Chemical Particle Inhalation Exposure Models; and

Section B.7: Dermal Exposure Models.

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

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

<http://www.epa.gov/opptintr/exposure/docs/chemsteer.htm>

CHEMICAL VAPOR RELEASES & ASSOCIATED INHALATION EXPOSURES

This section discusses the models used by EPA to estimate chemical vapor generation rates and the resulting volatile releases to air and worker inhalation exposures to that chemical vapor. The volatile air release models (discussed in B.2.1) calculate both a vapor generation rate ($Q_{\text{vapor_generation}}$; g/sec) and the resulting daily release rate of the chemical vapors to air. The *EPA/OPPT Mass Balance Inhalation Model* (discussed in Section B.2.2) uses the value of $Q_{\text{vapor_generation}}$, calculated by the appropriate release model, to estimate the resulting inhalation exposure to that released vapor.

Vapor Generation Rate and Volatile Air Release Models

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

EPA/OPPT Penetration Model – evaporative releases from an exposed liquid surface located indoors;

EPA/OPPT Mass Transfer Coefficient Model – evaporative releases from an exposed liquid surface located outdoors; and

EPA/OAQPS AP-42 Loading Model – releases of volatile chemical contained in air that is displaced from a container being filled.

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

EPA/OPPT Penetration Model

Model Description and Rationale:

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

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

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

Model Equations:

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

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

Where:

$Q_{\text{vapor_generation}}$ = Average vapor generation rate (g of chemical/sec)
 MW_{chem} = Molecular weight of the chemical of interest (g/mol)

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

$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default = 1) ¹
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
$RATE_{\text{air_speed}}$	=	Air speed (EPA default = 100 feet/min; value must be < 100 feet/min for this model)
$AREA_{\text{opening}}$	=	Surface area of the static pool or opening (cm^2 ; $B \times D_{\text{opening}}^2 / 4$)
$TEMP_{\text{ambient}}$	=	Ambient temperature (EPA default = 298 K)
D_{opening}	=	Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)
P_{ambient}	=	Ambient pressure (EPA default = 1 atm)
Note: The factor 8.24×10^{-8} in Equation B-1 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.		

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

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

Where:

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

References:

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

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

EPA/OPPT Mass Transfer Coefficient Model

Model Description and Rationale:

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

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

Model Equations:

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

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

Where:

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

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

²The default vapor pressure correction factor, $F_{\text{correction_factor}}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{\text{correction_factor}} \times VP_{\text{chem}}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{\text{chem}}$), thus the $F_{\text{correction_factor}}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

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

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

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

$$E_{\text{local_air}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3,600 \text{ sec/hour}}{1,000 \text{ g/kg}} \quad [\text{B-4}]$$

Where:

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

References:

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

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

EPA/OAQPS AP-42 Loading Model

Model Description and Rationale:

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

This model is used as the default for estimating volatile air releases during both loading activities and unloading activities. This model is used for unloading activities because it is assumed while

one vessel is being unloaded another is assumed to be loaded. The *EPA/OAQPS AP-42 Loading Model* is used because it provides a more conservative estimate than either the *EPA/OPPT Penetration Model* or the *Mass Transfer Coefficient Model* for unloading activities.

Model Equations:

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

$$Q_{\text{vapor_generation}} = \frac{F_{\text{saturation_factor}} \times MW_{\text{chem}} \times \left(V_{\text{cont_empty}} \times \frac{3,785.4 \text{ cm}^3}{\text{gal}} \right) \times \left(\frac{\text{RATE}_{\text{fill}}}{3,600 \text{ sec/hour}} \right) \times F_{\text{correction_factor}} \times \left(\frac{VP_{\text{chem}}}{760 \text{ torr/atm}} \right)}{R \times \text{TEMP}_{\text{ambient}}} \quad [\text{B-5}]$$

Where:

$Q_{\text{vapor_generation}}$	=	Average vapor generation rate (g of chemical/sec)
$F_{\text{saturation_factor}}$	=	Saturation factor (See Table B-1 for appropriate EPA default values)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)
$V_{\text{cont_empty}}$	=	Volume of the container (gallons; see Table B-1 for appropriate EPA default values)
$\text{RATE}_{\text{fill}}$	=	Fill rate (containers/hour; see Table B-1 for appropriate EPA default values)
$F_{\text{correction_factor}}$	=	Vapor pressure correction factor (EPA default = 1) ¹
VP_{chem}	=	Vapor pressure of the chemical of interest (torr)
R	=	Universal Gas Constant (82.05 atm-cm ³ /mol-K)
$\text{TEMP}_{\text{ambient}}$	=	Ambient temperature (EPA default = 298 K)

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

$$\text{Elocal}_{\text{air}} = Q_{\text{vapor_generation}} \times \text{TIME}_{\text{activity_hours}} \times \frac{3,600 \text{ sec/hour}}{1,000 \text{ g/kg}} \quad [\text{B-6}]$$

Where:

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

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

Reference:

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

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

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

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

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

Chemical Vapor Inhalation Model

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

EPA/OPPT Mass Balance Model

Model Description and Rationale:

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

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

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

Model Equations:

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

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

Where:

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

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

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

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

Where:

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

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

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

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

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

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

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

Where:

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

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

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

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

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

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

Where:

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

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

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

References:

Fehrenbacher, M.C. and Hummel, A.A.¹ “Evaluation of the Mass Balance Model Used by the EPA for Estimating Inhalation Exposure to New Chemical Substances”. *American Industrial Hygiene Association Journal*. June 1996. 57: 526-536.

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

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

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

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

Activity Type (Location)	V _{cont empty} (gallons)	RATE _{fill} (containers/hour)	RATE _{air speed} (feet/min)	RATE _{ventilation} ^a	F _{mixing factor}	TIME _{exposure} (hours/day)
Other Activities:						
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate models with the <i>Mass Balance Inhalation Model</i> described in this section, the ESD will describe the models and provide appropriate default values for the model parameters.				Typical: 0.5 Worst Case: 0.1	<8
Batch Operation						

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

CONTAINER RESIDUE RELEASE MODELS (NON-AIR)

Model Description and Rationale:

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

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

Model Equation:

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

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

Where:

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

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

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

The default frequency with which the container residues are released ($\text{TIME}_{\text{days_container_residue}}$, days/site-year) must be appropriately “paired” with the total daily quantity of chemical contained in the containers ($Q_{\text{total_daily_container}}$) used in calculating the daily release. Thus, Table B-4 also contains the appropriate EPA default values for $\text{TIME}_{\text{days_container_residue}}$.

References:

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

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

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

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

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

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

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

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

PROCESS EQUIPMENT RESIDUE RELEASE MODELS (NON-AIR)

Model Description and Rationale:

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

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

Model Equation:

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

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

Where:

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

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

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

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

References:

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

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

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

Model Title	$F_{\text{equip residue}}^a$
<i>EPA/OPPT Single Process Vessel Residual Model</i>	Conservative: 0.01 (for pumping process materials from the vessel) *Alternative defaults: Central Tendency: 0.0007 High End to Bounding: 0.002 (alternative defaults for gravity-draining materials from the vessel)
<i>EPA/OPPT Multiple Process Vessel Residual Model</i>	Conservative: 0.02

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

Table B-6. Standard EPA Methodology for Calculating Default $Q_{\text{equip_chem_capacity}}$ and $\text{TIME}_{\text{days_equip_residue}}$ Values for Use in the Process Equipment Residual Models

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

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

DUST EMISSIONS FROM TRANSFERRING SOLIDS MODEL

EPA has developed the *EPA/OPPT Dust Emissions from Transferring Solids Model* to estimate the releases from dust generation during the unloading/transferring of solid powders. While there are multiple potential industrial sources of dust (e.g., grinding, crushing), the scope of this model is limited to transferring/unloading of solids. Specifically, this can be defined as activities where packaging/transport materials are opened and contents are emptied either into a feed system and conveyed or directly added into a process tank (e.g., reactor, mixing tank).

Model Description and Rationale:

The EPA/OPPT Dust Emissions from Transferring Solids Model estimates that 0.5% of the solid powder transferred may be released from dust generation. This model is based on 13 sources, including site visit reports, Organisation for Economic Co-operation and Development (OECD) Emission Scenario Documents (ESD), EPA's AP-42 Emission Factors, and Premanufacture Notice submissions (EPA's new chemicals review program). Each source contained estimates of the quantity of solid powder that may be lost during transfers for a specific industry. The different sources contained dust loss data or loss fraction estimates from a variety of industries including paint and varnish formulation, plastic manufacturing, printing ink formulation, rubber manufacturing, and chemical manufacturing. These estimates ranged from negligible to 3% of the transferred volume. The mean of the upper bound from each data set was 0.5%.

Additionally, dust generation test data were reviewed. A study by Plinke, et al. investigated key parameters for developing a theoretical approach for estimating dust losses based on moisture content, particle size, drop height, and material flow (Plinke, 1995). Dust generation rates during unloading and transfers were measured for four materials. The highest measured dust generation rate was 0.5%. These data further justified the adoption of a 0.5% loss fraction as a conservative estimate.

For the media of release of the dust generated, most facilities utilize some type of control device(s) to collect fugitive emissions. Many facilities collect fugitive dust emissions from these operations in filters and dispose of the filters in landfills or by incineration. Wet scrubbers may also be utilized by industry. However, in some cases, uncontrolled/uncollected particulates may be small enough to travel several miles from the facility, resulting in environmental and human exposures to the chemical of interest beyond the boundaries of the site. Fugitive dust emissions may also settle to facility floors and are disposed of when floors are cleaned (water if the floors are rinsed or land or incineration if the floors are swept). Therefore, as a conservative assumption the model assumes an uncontrolled release to air, water, incineration, or landfill.

If facility-specific information states a control technology is employed, the release may be partitioned to the appropriate media. If the control technology efficiency information is not available, the *CEB Engineering Manual* may be utilized for control technology efficiencies. Table B-7 provides estimated efficiencies for common control technologies.

Table B-7. Default Control Technology Efficiencies

Control Technology	Default Control Technology Capture Efficiency (%)	Notes/Source	Default Media of Release for Controlled Release
None (default)	0	No control technology should be assumed as conservative.	N/A
Filter (such as a baghouse)	99	For particles > 1 um. CEB Engineering Manual.	Incineration or Land
Cyclone/Mechanical Collectors	80	For particles > 15 um CEB Engineering Manual.	Incineration or Land
Scrubber	Varies 95 may be assumed	Consult Table 7-1 of the CEB Engineering Manual.	Water

Model Equation:

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

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

Where:

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

The following equation estimates the portion of dust release captured by the control technology. The default media of release for this material should be selected based on the information presented in Table B-7.

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

Where:

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

assume capture efficiency = 0 kg captured/kg processed,
see Table B-7).

References:

- U.S. EPA. Chemical Engineering Branch. "Generic Model to Estimate Dust Releases from Transfer/Unloading Operations of Solid Powders". November 2006.
- U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (page 4-11). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.
- Plinke, Marc A.E., et al. "Dust Generation from Handling Powders in Industry." *American Industrial Hygiene Association Journal*. Vol. 56: 251-257, March 1995.

CHEMICAL PARTICLE INHALATION EXPOSURE MODELS

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

EPA/OPPT Small Volume Solids Handling Inhalation Model; and

OSHA Total Particulates Not Otherwise Regulated (PNOR) Permissible Exposure Limit (PEL)-Limiting Model.

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

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

For amounts up to (and including) 54 kg/worker-shift, the *EPA/OPPT Small Volume Solids Handling Inhalation Model* is used, as it more accurately predicts worker exposures to particulates within this range than the *OSHA Total PNOR PEL-Limiting Model*. The *Small Volume Solids Handling Inhalation Model* is based on exposure monitoring data obtained for workers handling up to 54 kg of powdered material. Beyond this data-supported limit, EPA assumes that exposures within occupational work areas are maintained below the regulation-based exposure limit for "particulates, not otherwise regulated".

The *EPA/OPPT Small Volume Solids Handling Model* is also the exclusive model used for any solids sampling activity. Each of these models is described in detail in the following sections.

EPA/OPPT Small Volume Solids Handling Inhalation Model

Model Description and Rationale:

The *EPA/OPPT Small Volume Solids Handling Inhalation Model* utilizes worst case and typical exposure factors to estimate the amount of chemical inhaled by a worker during handling of *small volumes*¹ (i.e., <54 kg/worker-shift) of solid/powdered materials containing the chemical of interest. The handling of these small volumes is presumed to include scooping, weighing, and pouring of the solid materials.

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

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

Model Equation:

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

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

Where:

$\text{EXP}_{\text{inhalation}}$	=	Inhalation exposure to the particulate chemical per day (mg chemical/worker-day)
$Q_{\text{shift_handled}}$	=	Quantity of the solid/particulate material containing the chemical of interest that is handled by workers each shift (kg/worker-shift; see Table B-8 for appropriate EPA default values; must be ≤ 54 kg/worker-shift for this model to be valid)
N_{shifts}^2	=	Number of shifts worked by each worker per day (EPA default = 1 shift/day)

¹Worker inhalation exposures to particulates handled in amounts *greater than 54 kg/worker-shift* are calculated using the *OSHA Total PNOR PEL-Limiting Model* (see the description provided in this section of Appendix B).

²Note that this value is the number of shifts worked by *each worker* per day. This value would only be greater than one if a worker worked for over eight hours in a given day.

F_{chem}	=	Weight fraction of the chemical of interest in the particulate material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
F_{exposure}	=	Exposure factor; amount of total particulate handled that is expected to be inhaled (EPA defaults: 0.0477 mg/kg (typical) and 0.161 mg/kg (worst case))

Table B-8. Standard EPA Default Values for $Q_{\text{daily_handled}}$ in the EPA/OPPT Small Volume Solids Handling Inhalation Model

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

References:

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

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

U.S. EPA. Economics, Exposure and Technology Division². *Textile Dye Weighing Monitoring Study*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington D.C., EPA 560/5-90-009. April 1990.

¹The appropriate quantity of material handled by each worker on each day may vary from these standard CEB defaults, per the particular scenario. Be sure to consult the discussion presented in the ESD activity description in determining the most appropriate default value for $Q_{\text{daily_handled}}$.

²Note: This reference is currently available for viewing in the ChemSTEER Help System.

OSHA Total PNOR PEL-Limiting Model

Model Description and Rationale:

The *OSHA Total Particulates Not Otherwise Regulated (PNOR) Permissible Exposure Limit (PEL)-Limiting Model* estimates the amount of chemical inhaled by a worker during handling of solid/powdered materials containing the chemical of interest. The estimate assumes that the worker is exposed at a level no greater than the OSHA PEL for *Particulate, Not Otherwise Regulated*, total particulate. Operations are generally expected to comply with OSHA's federal regulation regarding total particulate exposures. This model assumes that the exposure concentration is the same as the concentration of the chemical of interest in the airborne particulate mixture.

The *OSHA Total PNOR PEL-Limiting Model* is used in cases where workers are handling quantities of solid/powdered materials *in excess of 54 kg/worker-shift*¹. As stated in Section B.6.1, the *Small Volume Solids Handling Model*, based on monitoring data, provides a more realistic estimate of worker inhalation exposures to smaller quantities particulate material. The data used by the *Small Volume Solids Handling Model* are supported up to and including 54 kg solid material handled per worker-shift. Beyond this amount, EPA assumes the occupational exposures are maintained below the regulatory exposure limit contained in the *OSHA Total PNOR PEL-Limiting Model*, although the exposures provided by this model are considered to be worst-case, upper-bounding estimates.

Refer to Table B-8 for the standard EPA assumptions used in determining the appropriate quantity of particulate material handled to determine the applicability of this model to a given activity.

NOTE: The OSHA Total PNOR PEL (used as the basis for the model calculations) is an 8-hour time-weighted average (TWA); therefore, *worker exposures must be assumed to occur over an 8-hour period* for the *OSHA Total PNOR PEL-Limiting Model* estimate to be valid basis for the calculated inhalation exposure estimate.

Model Equations:

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

$$C_{\text{chem_mass}} = C_{\text{total_mass}} \times F_{\text{chem}} \quad [\text{B-16}]$$

Where:

$C_{\text{chem_mass}}$	=	Mass concentration of the chemical in air (mg/m ³)
$C_{\text{total_mass}}$	=	Mass concentration of total particulate (containing the chemical) in air (EPA default = 15 mg/m ³ , based on the OSHA Total PNOR PEL, 8-hr TWA)
F_{chem}	=	Weight fraction of the chemical of interest in the particulate material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)

¹ Worker inhalation exposures to particulates handled in amounts *up to and including 54 kg/worker-shift* are calculated using the *EPA/OPPT Small Volume Handling Inhalation Model* (see the description provided in this section of Appendix B).

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

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

Where:

$\text{EXP}_{\text{inhalation}}$	=	Inhalation exposure to the airborne particulate chemical per day (mg chemical/worker-day)
$C_{\text{chem_mass}}$	=	Mass concentration of the particulate chemical in air (mg/m ³ ; see Equation B-17)
$\text{RATE}_{\text{breathing}}$	=	Typical worker breathing rate (EPA default = 1.25 m ³ /hr)
$\text{TIME}_{\text{exposure}}$	=	Duration of exposure for the activity (EPA default = 8 hours/worker-day ¹)

References:

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

DERMAL EXPOSURE MODELS

Model Description and Rationale:

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

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

Model Equation:

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

¹Since the OSHA Total PNOR PEL is an 8-hr TWA, the exposure duration must be assumed as 8 hours/worker-day for the model defaults to apply.

$$EXP_{\text{dermal}} = AREA_{\text{surface}} \times Q_{\text{remain_skin}} \times F_{\text{chem}} \times N_{\text{event}} \quad [B-18]$$

Where:

EXP_{dermal}	=	Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)
$AREA_{\text{surface}}$	=	Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm ² ; see Table B-9 for appropriate EPA default values)
$Q_{\text{remain_skin}}$	=	Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm ² -event; see Table B-9 for appropriate EPA default values)
F_{chem}	=	Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
N_{event}^1	=	Frequency of events for the activity (EPA default = 1 event/worker-day)

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

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

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

References:

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

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

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

Table B-9. Standard EPA Default Values for Use in the Worker Dermal Exposure Models

Default Model	Example Activities	AREA _{surface} ^a (cm ²)	Q _{remain skin} ^b (mg/cm ² -event)	Resulting Contact AREA _{surface} × Q _{remain skin} (mg/event)
Physical Form: Liquids				
<i>EPA/OPPT 1-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> Liquid sampling activities Ladling liquid/bench-scale liquid transfer 	420 (1 hand mean)	Low: 0.7 High: 2.1	Low: 290 High: 880
<i>EPA/OPPT 2-Hand Dermal Contact with Liquid Model</i>	<ul style="list-style-type: none"> Maintenance Manual cleaning of equipment and containers Filling drum with liquid Connecting transfer line 	840 (2 hand mean)	Low: 0.7 High: 2.1	Low: 590 High: 1,800
<i>EPA/OPPT 2-Hand Dermal Immersion in Liquid Model</i>	<ul style="list-style-type: none"> Handling wet surfaces Spray painting 	840 (2 hand mean)	Low: 1.3 High: 10.3	Low: 1,100 High: 8,650
Physical Form: Solids				
<i>EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model</i>	<ul style="list-style-type: none"> Handling bags of solid materials (closed or empty) 	No defaults	No defaults	<1,100 ^c
<i>EPA/OPPT 2-Hand Dermal Contact with Solids Model</i>	<ul style="list-style-type: none"> Solid sampling activities Filling/dumping containers of powders, flakes, granules Weighing powder/scooping/mixing (i.e., dye weighing) Cleaning solid residues from process equipment Handling wet or dried material in a filtration and drying process 	No defaults	No defaults	<3,100 ²³

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

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

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

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

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

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

Appendix C

GERMAN DATA FOR AUTOMOTIVE COATING

Table C-1. Coating in Series at Car Manufacturers

Facility	Capacity	Working Time	Area of Car Body	Process	Amount Coating	Coating Sludge
Volkswagen p.354	138,000 vehicles/a 600 vehicles/d	4,600 h/a 230 days/a 5-day week 2.5 shifts/d	69 m ²	Base coat	5.47 kg/car body uni- and metallic coating	4 kg/car body
dto				Clear coat	2.3 kg/car body	208 t/a
BMW p. 366	200,000 vehicles/a 905 vehicles/d	3,536 h/a 221 d/a 2 shifts/d	13.5 m ²	Powder coat	1.63 kg/car body	17 t/a 102 g/car body
Daimler- Chrysler p. 370	192,769 vehicles/a	5460 h/a 105 h/week	70 m ²	Base coat	2.7 kg/car body	327 t/a 1.7 kg/car body

Source: DFIU report (2002)

Table C-2. Coating in Automotive Refinishing (Small and Medium Facilities)

Facility	Capacity	Working Time	Area of Car Body	Process	Amount Coating	Coating Sludge
Facility 1 p. 81, 220	3.5 persons/facility 640 repair jobs/a	One day	not relevant	coating repairs	day 1: 1130.9 g/d day 2: 2622.5 g/d	50 g/d about 2 % of used coating/d
Study CORLEY/ TOUSSAINT (1993) p. 61	15 persons/facility 4000 repair jobs/a	One year	not relevant	coating repairs	3816 kg/a 17345 g/d (*)	no data
Study Schläpfer (1998) p. 61	4 persons/facility 1220 repair jobs/a	One year	not relevant	coating repairs	328 L/a 1491 g/d (*)	60 L/a
Facility 1 (1997), p. 81	640 repair jobs/a	One year (1997)	not relevant	coating repairs	1039 kg/a 4722 g/d (*)	200 L/a
Facility 2 (1997), p. 81	500 repair jobs/a	One year (1997)	not relevant	Coating repairs	1116 kg/a 5072 g/d (*)	1300 kg/a

Source: Rentz et al (2000)

(*) The daily consumption is calculated with 220 workdays/a (German value).

Mean consumption of coating in these 5 automotive finishing facilities: 2739 g/d. The value of 17345 g/d was excluded from the equation. This value is in good agreement with the default of the US Draft ESD): 2.7 L/d (density of 1 kg/L assumed). If the value of 17345 g/d is included, the mean value would be 5397 g/d.

Table C-3. Consumption in Germany for Automotive Coating

Industry Branch	Consumption [tonne/a] Solvent Based Coating	Consumption [tonne/a] Water Based Coating	Consumption [tonne/a] Powder Base Coating	Sum Consumption [tonnes/a]
1995				
Car manufacturer	34,000	41,000	0	75.000
Automotive refinishing	30,000	300	0	30.300
Forecast 2007				
Car manufacturer	13,000	18,000	1.000	32.000
Automotive refinishing	16,500	8,500	not known	25,000

Source: BMU (1997)

Varnish production in Germany in 1996: 1.800.000 t/a, of which is consumed

89000 t/a for car coating at manufacturers (5%)

33700 t/a for automotive refinishing (2%)

Source: DFIU report (2002), p. 8, 9

Germany has 9,500 automotive refinishing facilities that offer coating.

Source: Rentz et al. (2000), p. 45

Average area of a car body, inner and outer parts [m²]: 70 - 80 m²

Source: DFIU report (2002), see Table above.

Table C-4. Processing Conditions at Car Series Manufacturer and Automotive Refinishing

Car series manufacturer	Automotive refinishing
Industrial process	Professional process
Automatic coating	Manual coating
High number of pieces with low change of colour	Low number of pieces with high change of colour
High continuous consumption of coating	Low and variable consumption of coating
Continuous air flux loaded with solvents	Low flux of air that is loaded only sometimes with low concentration of solvents
Drying at high temperature (120 – 180 °C)	Drying at low temperatures (20 – 60 °C)

Source: Rentz et al. (2000), p. 42

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Appendix D

INHALATION EXPOSURE TO POLYISOCYANATE IN PAINT

A summary of available isocyanate exposure data and other related measured isocyanate concentrations extracted from various documents is presented in Table D-1. Both polyisocyanate and monomer isocyanate data is presented. The data is sorted by type of engineering control (e.g., crossdraft of downdraft paint spray booth) and type of spray gun (e.g., HVLP or conventional).

Note that in some instances results were presented as 8-hr time-weighted averages; preparation and other non-spraying activities were included. In other instances, results were normalized to reflect exposures only while spraying paint. The samples were collected and analyzed according to various methods too numerous to describe. Consequently, a direct comparison of the data may be misleading.

The data in Table D-1 show a lowering of worker exposure to isocyanate in downdraft paint booths compared with crossdraft booths. The data also show a lowering of isocyanate exposure when using HVLP spray guns as compared to conventional spray guns.

The following scenarios present exposure estimates under different combinations of engineering control and spray gun. The concentrations presented represent approximate midpoints in available data. Guidance in selecting a scenario is presented in Section 3.3.2 of this generic scenario.

A “What if” Potential Dose Rate (mg/d) = polyisocyanate concentration (mg/m^3) \times duration (hr) \times 1.25 m^3/hr breathing rate. Note that chemical of interest concentration is not a variable. This is because the polyisocyanate concentration in the paint is unknown for the sampling data in Appendix B. The default duration is 8 hours, although shorter durations can be used as explained in the main body of this report.

Scenario 1. *Crossdraft booth and conventional spray gun*--(Crossdraft hood with paint spray filters or waterfall and air atomization paint-spray gun). Measured concentration range during spraying operations <0.05-18.4 mg/m^3 (Janko, 1992 and Lesage, 1992).

Scenario 2. *Downdraft booth and conventional spray gun.* Measured concentration range during spraying operations 0.01-3.7 mg/m^3 (Goyer 1995 and Lesage, 1992). Goyer presented only mean values, so the range of actual measurements is unknown.

Scenario 3. *Crossdraft booth and HVLP spray gun.* Measured concentration range during spraying operations 1.0-5.2 mg/m^3 (Rudzinski 1995).

Scenario 4. *Downdraft booth and HVLP spray gun.* Estimated range of polyisocyanate concentration 0.6-1.4 during spraying operations. Based on paint mist data from Table II of Heitbrink (1995), 1.9-4.7 mg/m^3 during spraying operations, and the assumption that approximately 30% of particulate overspray is from a polyisocyanate for a typical HDI based paint system (Rudzinski, 1995).

Table D-1. Isocyanate Concentration

Industry	Isocyanate Sampled	Eng Control/ Gun Type	Activity Description	Airborne Concentration (mg/m ³)	Reference ³⁵
Automobile painting (crash repair workshop)	Active isocyanate	none/NA	Paint mixing & Spray gun washing	0.001 (P) (number of sample not provided)	Pisaniello & Muriale, 1989 (#10)
Automobile painting (crash repair workshop)	Active isocyanate	none/NA	Dry rubbing with mechanical sander (when new coat is few hours old)	0.006-0.02 (P) (2 samples collected) sample periods were approx 18 min duration	Pisaniello & Muriale, 1989 (#10)
USAF Automobile & Miscellaneous parts	HDI	crossdraft/HVLP	Spray painting of large vehicles and objects	0.017-0.22 (P) (2 samples collected) 0.004-0.14 (A) (4 samples collected) sample period not reported	Rudzinski et. al., 1995 (#12)
Keesler AFB	N-75 (aliphatic polyisocyanates)	crossdraft/HVLP	Spray painting trucks	1.0-1.9 (P) (2 samples collected) 1.6-4.1 (A) (4 samples collected) sample period not reported	Rudzinski et. al., 1995 (#12)
Langley AFB	N-75 (aliphatic polyisocyanates)	crossdraft/HVLP	Spray painting aircraft ground equipment	4.7-5.2 (P) (2 samples collected) 4.9-13.9 (A) (4 samples collected) sample period not reported	Rudzinski et. al., 1995 (#12)
Car Paint Shops	Oligomer HDI	downdraft/ conventional	Spray paint operations(measured at various heights above floor)	5 in. - 2.6 (A) 32 in. - 2.9 (A) 43 in. - 1.9 (A) 55 in. - 1.4 (A)	Lesage et al, 1992 (#53)
USAF vehicle painting	TDI	crossdraft/ conventional	Spray painting operations	3.0 (P) (3 samples collected) sample period not reported	Dept. of the Army Medical Command, 1996 (#69)
Paint Manufacturing & Application Operations using PUR coatings	HDI and HDI-based polyisocyanates	no information	Transportation After market	0.0006-0.015 (P) (geometric mean = 0.03) (35 samples collected) sample period not reported	H.E. Myer et al, 1993 (#70)

³⁵ Complete citations for the data sources listed are provided in Section 8 of the ESD.

Industry	Isocyanate Sampled	Eng Control/ Gun Type	Activity Description	Airborne Concentration (mg/m ³)	Reference ³⁵
Car Spray painting	HDI polyisocyanate	Downdraft/no info	Spray painting	0.25 - 3.0 (P) (12 samples collected) sample period not reported	Maitre et al, 1996 (#54)
Paint Manufacturing & Application Operations using PUR Coatings	HDI	no information	Heavy Equipment/Military	0.04 (geom mean) (25 samples collected) (P)	H.E. Myer et al, 1993 (#70)
Paint Manufacturing & Application Operations using PUR coatings	HDI	no information	Maintenance/Construction	0.05 (geom mean) (16 samples collected) (P)	H.E. Myer et al, 1993 (#70)
Paint Manufacturing & Application Operations using PUR coatings	HDI	no information	Wood/Furniture	0.02 (geom mean) (11 samples collected) (P)	H.E. Myer et al, 1993 (#70)
Industrial Spray Operations	HDI monomers & HDI polyisocyanates	crossdraft/conventional	Spray Painting & Related Operations	HDI monomer 0.007 (P) (geom mean) (24 samples collected) HDI polyisocyanates 0.70-12.2 (P) (geom mean = 3.87) (# = 24)	M. Janko et al, 1992 (#76)
Auto Body Shops	HDI monomers & HDI polyisocyanates	crossdraft/conventional	Spray Painting & Related Operations	HDI monomer 0.014 (P) (geom mean) (55 samples collected) HDI polyisocyanates ND-18.4 (P) (geom mean = 1.60) (55 samples collected)	M. Janko et al, 1992 (#76)
Spray Finishing of Large Objects	HDI monomers & HDI polyisocyanates	crossdraft/conventional	Spray Painting & Related Operations	HDI monomer 0.007 - 0.11 (P) (31 samples collected) HDI polyisocyanates 2.09-15.9 (P) (31 samples collected)	M. Janko et al, 1992 (#76)
Auto Refinishing	HDI Oligomer	downdraft/no info		0.1-2.16 mg/m ³ sample period twa	(#91)

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Appendix E

PAINT MIST CONCENTRATION DATA

Table E-1. Downdraft Spray Booth Coating Mist Concentration Data

Geometric Mean Coating Mist Concentration (mg/m ³), Sample Type and Number of Samples	Individual Coating Mist Concentration Data Points (mg/m ³)	Sample Duration (min)	Data Source ³⁶	Notes
Spray Gun Type: HVLP				
4.7 Sample type: Personal Number of samples: 7	Individual data points not reported in this document. Geometric average is given.	Not provided	(Heitbrink, 1995)	1) Spray-painting autobody parts that had been set in the booth. 2) Observed concentration was divided by fraction of time spent painting, which was 0.49.
2.3 Range: 0.26 to 18 Sample type: Personal Numbers of samples: 7 (NOTE: The GM provided above was published in the study; however, it does not correspond to the GM (2.5) calculated from the individual mist concentrations.)	18.3	46	(Heitbrink, 1993)	1) "Some concentrations measured on the workers lapel exceeded the OSHA PEL for total dust of 15mg/m ³ for an 8-hour day. Because these samples were taken over a fraction of an 8-hour day and the PEL is based upon an 8-hour day, this result does not necessarily indicate that the exposure exceeds the PEL" Page 20. 2) At this shop most of the painting was done for parts hanging from the ceiling at head height. 3) Study provided both sample and painting durations. The sample durations were used in the ESD analysis as they are most representative of the mist concentrations, as well as providing a more conservative estimate of the spraying activity.
	5.64	38		
	5.63	91		
	3.0	20		
	2.54	38		
	0.50	18		
0.53 Range: <0.1 to 3.68 Sample type: Personal Number of Samples: 17 (Summary statistics above presented in document. Source does not provide all 17 data points. Available individual points are included)	0.26	19	(NIOSH, 1993b)	1) Appendix D of data source provides sampling duration and results for every trial. Two covariates were found to significantly affect total dust concentrations: time spent painting and paint type. The statistical analysis also found that spray gun type did not significantly affect total dust concentrations. The median concentrations based upon the least squares means were: HVLP: 0.43 mg/m ³ and non-HVLP: 0.90 mg/m ³ 2) Study provided both sample and painting durations. The sample durations were used in the ESD analysis as they are most representative of the mist concentrations, as well as providing a more conservative estimate of the spraying activity.
	1.8	12		
	0.91	19		
	0.78	22		
	0.76	20		
	0.66	20		
	0.56	13		
	0.16	32		
	0.14	9		
	0.12	26		

³⁶ Complete citations for the data sources listed are provided in Section 8 of the ESD.

Geometric Mean Coating Mist Concentration (mg/m3), Sample Type and Number of Samples	Individual Coating Mist Concentration Data Points (mg/m3)	Sample Duration (min)	Data Source ³⁶	Notes
	0.1	12		
	0.066	19		
	<0.01	21		
	<0.01	14		
Spray Gun Type: Conventional				
2.0 Range: 0.4 to 9.0 Sample type: Personal Number of samples: 10	9.0	15	(NIOSH, 1996)	
	4.6	47		
	3.6	74		
	3.1	21		
	3.0	42		
	1.8	176		Application of primer.
	1.7	47		
	1.1	49		Application of primer.
	0.6	102		Application of primer.
	0.4	64		Application of primer, color, and clearcoat.
	0.68 Range: 0.17 to 1.45 Sample type: Personal Number of samples: 6 (Summary statistics above presented in document. Source does not provide all 6 data points. Available individual points are included)	1.4		12
1.0		17		
0.39		44		
0.16		20		

Geometric Mean Coating Mist Concentration (mg/m ³), Sample Type and Number of Samples	Individual Coating Mist Concentration Data Points (mg/m ³)	Sample Duration (min)	Data Source ³⁶	Notes
Spray Gun Type: Conventional and HVLP				
2.7 Sample type: Personal Number of samples: 16	Individual data points not reported in this document. Geometric average is given.	Not provided	(Heitbrink, 1995)	1) Experienced spray instructor repeatedly painting an entire car body. 2) Observed concentration was divided by fraction of time spent painting, which was 0.66. 3.) Both gravity-fed conventional and HVLP spray guns used.
1.9 Sample type: Personal Number of samples: 23	Individual data points not reported in this document. Geometric average is given.	Not provided	(Heitbrink, 1995)	1) Spray-painting the side of cars. 2) Observed concentration was divided by fraction of time spent painting, which was 0.29. 3.)Both siphon cup conventional and HVLP spray guns used.

Table E-2. Crossdraft Spray Booth Coating Mist Concentration Data

Geometric Mean Coating Mist Concentration (mg/m3), Sample Type and Number of Samples	Individual Coating Mist Concentration Data Points (mg/m3)	Sample Duration (min)	Data Source ³⁷	Notes
Spray Gun Type: HVLP				
31 Range: 28 to 34 Sample type: Personal Number of samples: 2	34	15 to 60	(Rudzinski, 1995)	1) Crossdraft booth type was assumed based on description of booth, collected from spray painting half of a generator at Langley AFB. This concentration is on a total particulate basis. Data are derived from Table II: Comparison of Polyisocyanate Concentrations in Spray Painting Operations of the data source. 2) The study only provided the range in sample duration. These ranges were not included in the ESD analysis.
	28	15 to 60		
6 Range: 4 to 8 Sample type: Personal Number of samples: 2	8	15 to 60	(Rudzinski, 1995)	1) Crossdraft booth type was assumed based on description of booth, collected from spray painting wheels, signs, a generator, and aircraft wing parts at Kessler AFB. This concentration is on a total particulate basis. Data are derived from Table II: Comparison of Polyisocyanate Concentrations in Spray Painting Operations of the data source. 2) The study only provided the range in sample duration. These ranges were not included in the ESD analysis.
	4	15 to 60		
Spray Gun Type: Conventional				
23 Sample type: Personal Number of samples: 5	Individual data points not reported in this document. Geometric average is given.	Not provided	(Heitbrink, 1995)	1) Spray-painting parts of the car. 2) Observed concentration was divided by the fraction of time spent painting, which was 0.26. 3) Siphon cup conventional spray gun.

³⁷ Complete citations for the data sources listed are provided in Section 8 of the ESD.

Geometric Mean Coating Mist Concentration (mg/m3), Sample Type and Number of Samples	Individual Coating Mist Concentration Data Points (mg/m3)	Sample Duration (min)	Data Source ³⁷	Notes
12 Range: 4.1 to 35 Sample type: Personal Number of samples: 8	35	51	(NIOSH, 1995a)	Booth was termed “side-draft”. This booth was assumed to be cross-draft based on the booth description provided in the data source.
	30	61		
	12	95		
	12	40		
	9.1	100		
	8.6	66		
	7.0	110		
	4.1	106		
6.4 Range 3.1 to 18 Sample type: Personal Number of samples: 11 GM is provided for each of two brands of crossdraft booths tested. Appendix A provides each individual mist concentration point, but does not designate which booth was tested for each.	17.55	59	(NIOSH, 1993c)	
	11.29	90		
	10.48	90		
	9.61	135		
	7.5	60		
	6.50	25		
	4.34	111		
	4.26	60		
	3.79	146		Two samples were combined into a single data point for the analysis: 4.52 mg/m3 over 39 minutes and 3.53 mg/m3 over 107 minutes.
	3.20	80		
	3.12	141		
4.6 Range: 2.0 to 6.7 Sample type: Personal Number of samples: 6	6.7	162	(NIOSH, 1995b)	Booth was termed “side-man.” This booth was assumed to be cross-draft based on the booth description provided in the data source.
	6.7	141		
	5.1	190		
	4.3	84		
	3.0	33		
	2.0	40		

Table E-3. Semi-Downdraft Spray Booth Coating Mist Concentration Data

Geometric Mean Coating Mist Concentration (mg/m3), Sample Type	Individual Coating Mist Concentration Data Points (mg/m3)	Sample Duration (min)	Data Source ³⁸	Notes
Spray Gun Type: Conventional				
9.7 Sample type: Personal Number of samples: 12	Individual data points not reported in this document. Geometric average is given.	Not provided	(Heitbrink, 1995)	1) Spray-painting parts of the car. 2) Observed concentration was divided by the fraction of time spent painting, which was 0.30. 3) Siphon cup conventional spray gun.
7.9 Sample type: Personal Number of samples: 7	Individual data points not reported in this document. Geometric average is given.	Not provided	(Heitbrink, 1995)	1) Spray-painting parts of the car. 2) Observed concentration was divided by the fraction of time spent painting, which was 0.36. 3) Siphon cup conventional spray gun.
5.7 Range: 1.1 to 24 Sample type: Personal Number of samples: 13	24.15	5	(NIOSH, 1993a)	1) Statistical analysis in Appendix E of the data source showed that sampling location and type of paint affected the total dust concentration. 2) Siphon cup conventional spray gun. 3) “Drive-thru” semi-downdraft spray booth.
	15.89	7		
	8.75	21		
	4.69	7		
	3.9	9		
	3.55	14		
	2.69	23		
	2.53	4		
	2.0	3		
	1.5	5		
	1.49	11		
	1.4	11		

³⁸ Complete citations for the data sources listed are provided in Section 8 of the ESD.

Geometric Mean Coating Mist Concentration (mg/m3), Sample Type	Individual Coating Mist Concentration Data Points (mg/m3)	Sample Duration (min)	Data Source ³⁸	Notes
	1.13	14		
4.8 Range: 0.29 to 11 Sample type: Personal Number of samples: 7	10.52	11	(NIOSH, 1993a)	1) Statistical analysis in Appendix E of the data source showed that sampling location and type of paint affected the total dust concentration. 2) Siphon cup conventional spray gun. 3) "Drive-in" semi-downdraft spray booth.
	8.35	22		
	6	7		
	5.63	13		
	1.78	13		
	1.03	20		
	0.29	18		
2.4 Range: 0.32 to 8.2 Sample type: Personal Number of samples: 5 (The summary statistics presented above were reported in the document. The minimum from these statistics does not correspond to the individual data points)	8.2	8	(NIOSH, 1993b)	Spray painting of automotive parts in semi-downdraft prep station.
	4.7	17		
	3.8	5		
	2.2	30		
	1.8	15		