Automotive Brake Pad Replacement- Generic Scenario for Estimating Occupational Exposures

-Draft-

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INTRODUCTORY REMARKS

Purpose and background

The U.S. Environmental Protection Agency (EPA) with support from Eastern Research Group, Inc. (ERG) has developed this draft Generic Scenario (GS) on occupational exposures during automotive break pad replacement, including replacement of worn brake pads. Its scope is designed to serve the needs of EPA programs. The Risk Assessment Division (RAD) 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 EPA's Toxic Substances Control Act (TSCA) Chemical Review Programs, including Premanufacture Notice (PMN) reviews.

This document presents methods for estimating occupational exposures to chemical additives in brake pads during lightweight automotive (e.g., cars) brake pad replacement. This draft GS may be periodically updated to reflect changes in the industry and new information available. Users of the document are encouraged to submit comments, corrections, updates, and new information to RAD.

How to use this document

This document may be used to provide conservative, screening-level estimates of occupational exposures to chemical additives in brake pads during automotive brake pad replacement. The reader should note that the estimation methods provided in this document may result in exposure amounts that are likely to be higher, or at least higher than average, than amounts that might occur in real world practice. This is because the GS makes conservative assumptions about facility operations and workplace practices. For example, the GS defaults to the most conservative facility throughput values if the end use is unknown. For occupational exposures, the GS methodology does not account for the use of personal protective equipment.

The users of this draft GS 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 GS-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and methodology

EPA developed this draft GS using relevant data[1] supplemented with standard occupational exposure models[2]. The primary sources of information cited in this draft GS include information published by the U.S. Census Bureau, and various EPA and other government sources (e.g., EPA, OECD, and regional/state pollution prevention organizations).

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[1] Please refer to Section 7 for a list of the specific references used in developing this Generic Scenario.
[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 A to this Generic Scenario.

Data were also obtained from the Occupation Health and Safety (OSHA) Chemical Exposure Health Data website.

The draft GS includes methods for estimating occupational exposures to solid chemical additives used in lightweight automotive brake pads. PMNs submitted to EPA generally represent a distinct chemical substance that may be entering commerce in the United States. EPA maintains a database of the functions and uses of chemicals reviewed under the PMN program (i.e., EPA's new chemicals review program).

The scope of the GS covers any solid chemical additive used in lightweight automotive brake pads. These chemicals can be classified into one of several types of additives such as friction modifiers, wear stabilizers, fillers, binders, etc. Table 1-1 provides additional examples of the types of additives applicable to the GS.

An illustration of the scope of this document within the context of the life cycle of chemical additives is provided in Figure 1 below.

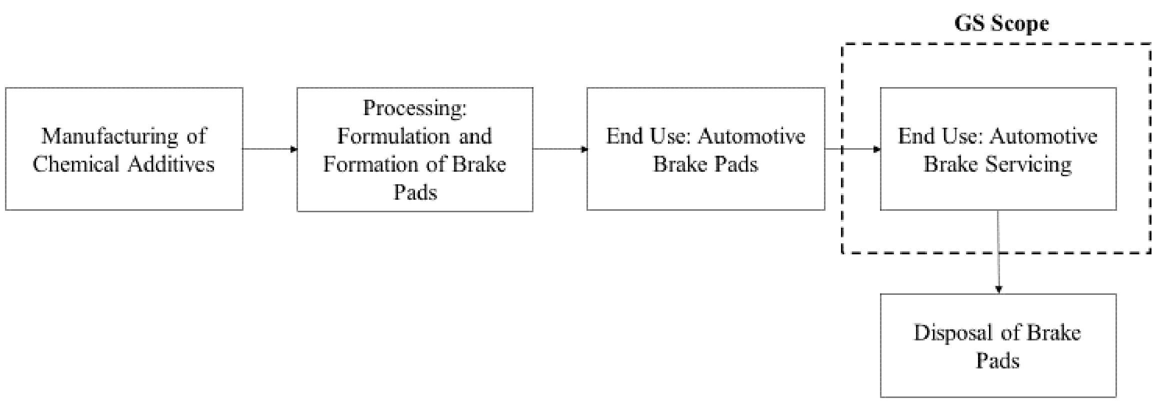

Figure 1. GS Scope on Use of Chemical Additives in Brake Pads

The scope of the GS applies only to additives in brake pads that are serviced by commercial automotive repair shops. Procedures for maintenance and replacement can vary at automotive shops, but generally involve disassembly of the brake system, cleaning of the brake system, the replacement of brake pads (as needed), and reassembly. The scope of this document is limited to the automotive servicing industry.

Methods for estimating the following facility operating parameters and exposures to additive chemicals used in automotive brake pads are discussed in the draft GS:

- Number of sites in the United States that repair or replace automotive brake pads;

- Number of workers that may come into contact with the additive chemical during maintenance or repair of automotive brake pads;

- Inhalation and dermal exposures during brake system disassembly;
- Inhalation and dermal exposures during brake system cleaning;
- Dermal exposures during brake system maintenance and replacements; and,
- Dermal exposures during brake system reassembly.

The estimation methods in this draft scenario apply to any solid chemicals used in automotive brake pads, regardless of their function within the brake pad.

How this document was developed

The U.S. Environmental Protection Agency (EPA), with support from Eastern Research Group, Inc. (ERG), has developed this Generic Scenario on the replacement of automotive brake pads.

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1.0 INDUSTRY SUMMARY AND BACKGROUND

Automotive brake pads stop vehicles by absorbing energy from friction caused by braking. Essentially, brake pads convert kinetic energy of a moving vehicle into heat, then absorbs and dissipates this heat (Jacko, 2000). Brake systems are classified as either disc or drum brakes. Disc brakes are typical in front brakes and drum brakes are typical in rear brakes (Bahrom et al, 2015). Disc brakes are comprised of a disc, caliper, brake pads, and wheel bearings (AMRA, 2014). Drum brakes are comprised of a drum, backing plate, brake shoes (equivalent to brake pad in disc assemblies), wheel cylinder, and wheel bearings.

Over their lifetime, brake pads are converted to brake dust and gases, which is either released to the environment or captured by the brake system. In the case of drum brakes, the dust is captured in the drum chamber. Disc brakes are more exposed and do not have a separate chamber in which dust can collect. However, dust is still likely to be trapped within the brake system. This document does not distinguish between these types of brakes for estimating general facility estimates or occupations exposures during brake pad replacements.

Brake pads replacements can be performed by do-it-yourself (DIY) individuals or at commercial automotive repair shops. The scope of this document covers only worker exposures during replacement at commercial automotive repair shops.

1.1 Chemical Additives in Brake Pads

Additives in lightweight automotive brake pads are added to impart specific properties to the brake pads. Table 1-1 presents types of chemical additives, their functions, and typical concentrations in automotive brake pads. The presented concentrations are ranges typically expected in brake pads. These concentrations are expected to vary between different brake pad manufacturers.

Table 1-1. Overview of Brake Pad Additives, including Typical Compounds, Functions, and Concentrations [a]

Additive Types	Functions	Typical Compounds	Fraction of Additive in Brake Pad
Friction Modifiers/ Lubricants	Provide stable friction at all temperatures and pressures	Graphite, ground rubber, metallic particles, carbon black, cashew nut dust and antimony trisulphide	5-29%
Fillers	Improve thermal and noise pad properties and also reduce the manufacturing cost	Inorganic compounds (barium and antimony sulphate, magnesium and chromium oxides), silicates, ground slag, stone and metal powders	15-70%
Abrasives	Control the build-up of friction films	Aluminum oxide, iron oxides, quartz, silica, zirconium silicate	2-10%
Reinforcement Fibers	Maintain overall composition and reinforce brake pads	copper, steel, brass, potassium titanate, glass, organic material and Kevlar	6-35%

a – (Grigoratos et al, 2015)

1.2 Market Profile

Automotive brake pad replacement falls under the North American Industrial Classification System (NAICS) industry group 8111 (Automotive Repair and Maintenance). This industry group consists of establishments that are primarily involved in providing repair and maintenance services for automotive vehicles. Table 1-2 summarizes U.S. Census data for the number of sites associated with the automotive service industry.

Table 1-2. Number of Automotive Service Sites Based on 2012 U.S. Census Data

NAICS Code	NAICS Code Description	Sites[a]
8111	Automotive repair and maintenance	157,149

[a] (US CB, 2012)

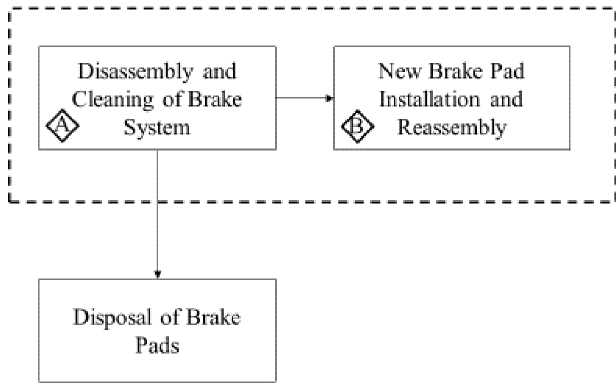
Total U.S. demand for automotive repair services is estimated at $64 billion of revenue, with an annual growth rate of 2.5% between 2012 and 2017 (IBIS, 2017). The industry is expected to continue to grow over the next five years.

2.0 PROCESS DESCRIPTION

The maintenance and replacement of lightweight automotive brake pads occurs at commercial automotive maintenance and repair shops by mechanics. Procedures for brake pad replacement can vary at automotive shops, but generally involve brake system disassembly, brake system cleaning, brake pad(s) replacement, used brake pad(s) disposal, and reassembly. This document is focused on worker exposures during replacement activities, therefore, the disposal of brake pads is not within the scope of this document. Figure 2-1 illustrates the general process for automotive brake pad replacement, including its associated occupational exposures, with a dashed box around the activities within the scope of this document. Exposures are discussed in greater detail in Section 4.0.

Because dust has likely collected within the brake system by the time brake pad replacement is necessary, brake system disassembly will likely involve handling dusts that are respirable by the mechanic. Upon disassembly, the brake system, including the brake chamber for drum brakes, are cleaned. This cleaning can be performed using compressed air or solvent mist, a dry brush, a wet brush, a water squirt bottle, a rag, a high-efficiency particulate air (HEPA) vacuum unit, or a brake washing assembly unit (ICF, 1988). Depending on the method of cleaning used, dust particulates can become airborne, entering the breathing zone of the worker. A HEPA vacuum unit and washing unit provide more engineering control of dust emissions that methods involving compressed air, brushing, or wiping.

Following the cleaning of the brake parts, worn brake pads are removed and replaced with new brake pads and the brake system is reassembled. Note that this scenario assumes that worn pads are replaced with identical pads (i.e., the worn pad and new pad both contain the chemical of interest). The installation of new brake pads is not expected to involve grinding or drilling of brake pads (ICF, 1988). Additionally, the new brake pads are not expected to generate dusts because the component substances are pressed into (entrained within) the brake pad. Thus, inhalation exposure to dusts is less likely during replacement and reassembly activities. Dermal exposure to chemical components in the new brake pad is possible, but non-quantifiable because these substances are entrained within the solid brake pad.



<u>Occupational Exposures:</u>
A. Dermal and inhalation exposure during disassembly and cleaning
B. Dermal exposure during replacement and reassembly

Figure 2-1. Typical Exposure Points During Automotive Brake Pad Replacement

3.0 OVERALL APPROACH AND GENERAL FACILITY ESTIMATES

This draft GS presents EPA's standard approach for estimating worker exposures to chemical additives during the replacement of automotive brake pads.

The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible. However, EPA acknowledges several areas in which additional industry data would enhance the estimates presented herein. These data needs are summarized in Section 6.0. It should be noted that default values cited throughout this document are intended to be used only when appropriate, site-specific or industry-specific information is not available.

This section of the draft GS presents general facility calculations for replacement of automotive brake pads, including daily replacement rate, number of automotive servicing sites, and the number of operating days at these sites.

Section 4.0 of the draft GS presents occupational exposure assessments from the replacement of automotive brake pads. The assessments reference the general facility estimates presented in this section to estimate activity-specific worker exposures during the replacement of automotive brake pads.

This interim approach assumes that 100% of repairs of used brake pads containing the chemical of interest occur in the smallest possible number of shops where 100% of repairs involve used brake pads containing the chemical of interest. Also, each of these shops employ one worker to handle all of these brake jobs, and this worker is exposed every work day. These assumptions will result in bounding estimates of inhalation exposure.

3.1 Introduction to General Facility Estimates

Throughout the remainder of this section, EPA utilized available industry and U.S. Census data to estimate the number of automotive servicing sites in the U.S. This section also describes the methods and assumptions used to estimate typical replacement rates at these sites. Replacement rates can be estimated using several facility parameters, including the annual facility replacement rates, days of operation, and number of servicing sites.

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

Table 3-1. Summary of General Facility Parameters Used in the GS

Parameter	Parameter Description	Section
$TIME_{operating\_days}$	Annual operating days at automotive service sites (day/yr)	3.2
N_{pads_job}	Number of brake pads replaced per brake job (pads/job)	3.3
H_{job_worker}	Length of time per brake job (hours/job)	3.4
$N_{jobs\_worker\_day}$	Number of brake jobs conducted by a worker per day (jobs/worker-day)	3.5
W_{pad}	Weight of brake pad (kg/pad)	3.6
$F_{chem\_additive}$	Mass fraction of chemical of interest within the additive (kg chemical/kg additive)	3.7
$F_{additive\_dust}$	Mass fraction of additive within the dust (kg additive/kg dust)	3.8
F_{chem}	Mass fraction of chemical of interest within the brake dust (kg chemical/kg dust)	3.9
$F_{dust\_generated}$	Mass fraction of dust generated from brake pad wear (kg dust generated/kg pad)	3.10
$F_{dust\_in\_brake}$	Mass fraction of generated brake pad remains in brake system (kg dust in brake system/kg dust generated)	3.11
Q_{dust_job}	Amount of additive in dust form that is handled by a worker during one brake job (kg dust/job)	3.12
N_{jobs_year}	Number of annual number of brake jobs (jobs/year)	3.13
$N_{service\_sites}$	Number of automotive service sites replacing pads with the chemical of interest (sites)	3.14

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

The number of operating days associated with automotive repair sites can be estimated from employment data obtained through the U.S. Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW) and Occupational Employment Statistics (OES) Survey (US BLS, 2013 and 2014). Table 3-2 lists the QCEW and OES data used to estimate the number of operating days for automotive servicing sites. Dividing the average employee annual wage by the mean hourly wage yields an estimated average $TIME_{use\_operating\_days}$ of 260 days/year, assuming an eight-hour work day.

Table 3-2. Estimated Annual Operating Days for Automotive Service Sites

NAICS Code	NAICS Description	Average Employee Annual Wage (USD)[a]	Mean Hourly Wage (USD)[b]	Estimated Annual Operating Days[c]
8111	Automotive repair and maintenance	$34,640	$16.65	260

USD – U.S. Dollars
[a] US BLS, 2013
[b] US BLS, 2014
[c] Estimated by dividing average employee annual wage by mean hourly wage and an assumed eight-hour work day.

Note that the U.S. Economic Census only provides production worker data for the manufacturing industry sector (i.e., NAICS sectors 31 through 33). Other industry sectors do not include worker data that similarly dis-aggregate administrative vs. non-administrative employment statistics. For this reason, $TIME_{operating\_days}$ was estimated using the U.S. BLS as an alternate data source.

3.3 Number of Brake Pad Replacements per Job (N_{pads_job})

When replacement occurs, brake pads are usually replaced on an entire axle, consisting of four brake pads (two per tire) (IFC, 1988). Thus, for this parameter, a brake job consists of replacing all brake pads on one axle of a lightweight vehicle.

N_{pads_job}	=	Number of brake pads replaced per brake job (Default: 4 pads/job)

3.4 Hours per Job (H_{job_worker})

The length of time for one brake job conducted by one worker varies depending on the type of brake (disc or drum) and car on which the replacement occurs. The 1988 Asbestos Exposure Assessment (ICF, 1988) assumes that it takes an average of 1.1 hours for a disc brake job and 1.5 hours for a drum brake job. Thus, for disc brakes, the default for this parameter is 1.1 hours; for drum brakes, the default for this parameter is 1.5 hours; and, for unknown brake type, the default for this parameter is a mid-range of 1.3 hours.

H_{job_worker}	=	Length of time per brake job (Default: 1.1 hours/job-worker (disc brakes); 1.3 hours/job-worker (unknown brake type); 1.5 hours/job-worker (drum brakes))

3.5 Number of Brake Jobs per Worker per Day ($N_{jobs\_worker\_day}$)

Assuming an average working day of 8 hours, the number of brake jobs conducted by one worker per day can be calculated as:

$$N_{jobs\_worker\_day} = \frac{8\,\frac{hrs}{day}}{H_{job\_worker}} \qquad \text{(Eqn. 3-1)}$$

Where,

$N_{jobs\_worker\_day}$	=	Number of brake jobs conducted by a worker per day (jobs/worker-day)
H_{job_worker}	=	Length of time per brake job (Default: 1.1 hours/job)

3.6 Weight of Brake Pad (W_{pad})

The weight of commercial brake pads varies depending on the type of materials that the pads are comprised of. In general, commercial brake pads seem to range in weight from 113 grams to 320 grams each (Kukutschová et al, 2009; Bahrom et al, 2015). The most recent source indicates that the weight of ceramic commercial brake pads (which are the most common brake pad types in newer vehicles) is 176 grams (Ikpambese et al, 2016). EPA recommends 176 grams/brake pad as the default value for W_{brake}.

W_{pad} = Weight of one brake pad (Default: 176 g/brake pad)

3.7 Mass Fraction of Chemical of Interest within the Additive ($F_{chem\_additive}$)

The chemical of interest may constitute only a fraction of the additive that is blended into the brake pad. $F_{chem\_additive}$ represents the concentration of the chemical of interest within the additive prior to blending. If this concentration is not known, assessment calculations should assume 100 percent as a conservative-case assumption:

$F_{chem\_additive}$ = Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive)

3.8 Mass Fraction of Additive within the Brake Dust ($F_{additive\_dust}$)

This value represents the mass fraction of additive within the brake pad. If $F_{additive\_pad}$ is unknown, refer to Table 1-1 for suitable values. This will require knowledge of how the chemical of interest is used (i.e., its additive type). If unknown, assume a default value of 0.7 kg additive/kg pad, which is the highest value from Table 1-1.

$F_{additive\_dust}$ = Mass fraction of additive within the brake dust (Default: 0.7 kg additive/kg dust)

3.9 Mass Fraction of Chemical of Interest within the Brake Dust (F_{chem})

This value represents the mass fraction of the chemical of interest in the brake pad, calculated using the following equation:

$$F_{chem} = F_{chem\_additive} \times F_{additive\_dust} \qquad \text{(Eqn. 3-2)}$$

Where:

F_{chem}	=	Mass fraction of chemical of interest in the brake dust (kg chemical/kg dust)
$F_{chem\_additive}$	=	Mass fraction of chemical of interest within the additive (kg chemical/kg additive) (Default: 1 kg chemical/kg additive)
$F_{additive\_dust}$	=	Mass fraction of additive within the brake pad (Default: 0.7 kg additive/kg dust)

3.10 Fraction of Brake Dust Generated from Brake Pad Wear ($F_{dust\ generated}$)

During the lifetime of the brake pad, the action of braking results in loss in mass of the brake pad from wear, causing the thickness of the brake pad to decrease. This parameter represents the fraction of brake pad that is intact on the vehicle when replacement occurs. Brake pads are recommended to be changed when the remaining thickness is approximately 3 to 4 millimeters (NAPA, 2015). As compared with the original thickness of 12 mm, it can be estimated that 25% of the brake pad is left intact upon replacement of the brake pad; therefore 75% of the brake pad would be converted to brake dust. Thus, the default value of $F_{dust\_generated}$ is 0.75. If industry or site-specific information is available, it should be used in lieu of this default value.

$F_{dust\_generated}$	=	Mass fraction of dust generated from brake pad wear (Default: 0.75 kg dust generated /kg pad)

3.11 Fraction of Brake Pad Dust in Brake System ($F_{dust\_in\_brake}$)

As brake pads become worn, the lost mass is turned into braking dust. This braking dust can become airborne, be deposited on road surfaces, intermingle with oil and grease residue on the vehicle, or become trapped within the braking system. The amount of dust trapped within the braking system is the amount that can potentially become airborne during brake jobs, and thus be available for inhalation by workers. This parameter represents that fraction of brake pad that remains as dust in the brake system after wear, and is therefore handled by workers during replacement of worn brake pads.

The fraction of brake wear dust that becomes airborne ranges widely. Literature reports values as low as 50% (Grigoratos et al, 2014; Kukutschová et al, 2011) up to 98% (Iijima et al, 2008). EPA conservatively assumes that the remaining mass of generated brake wear dust that does not become airborne remains trapped in the brake system, in drum chambers or within other brake system parts.

Disc brakes are more open to the environment, thus more brake wear dust is likely to become airborne than drum brakes, which have a chamber in which dust can collect. Because of this, the default values for this parameter depends on the type of brake pad that is likely to contain the chemical of interest. Note: site-specific information on the type of brake system is the preferred method when determining the amount of brake dust remaining. However, the estimates provided below may be used where information on the brake type is unknown. Engineering judgment can also be used to select the brake type to meet assessment needs. For disc brakes, EPA recommends a default assumption that 2% of generated dust does not become airborne, and is thus handled by workers. For drum brakes or for unknown brake types, EPA recommends a high-end default assumption that 50% of generated dust does not become airborne, and is thus handled by workers. If industry or site-specific information is available, it should be used in lieu of a default value.

$F_{dust\_in\_brake}$	=	Mass fraction of generated brake pad remains in brake system (Default: 0.02 kg dust in brake system/kg dust generated (disc brakes); 0.5 kg dust in brake system/kg dust generated (drum brakes or unknown brake type))

3.12 Amount of Additive in Dust Form Handled per Worker per Brake Job (Q_{dust_job})

The amount of brake dust that is handled by a worker during one brake job is estimated using the following equation:

$$Q_{dust\_job} = N_{pads\_job} \times W_{pad} \times \frac{1\ kg}{1000\ g} \times F_{dust\_generated} \times F_{dust\_in\_brake}$$

(Eqn. 3-3)

Where:

Q_{dust_job}	=	Amount of additive in dust form that is handled by a worker during one brake job (kg dust/job)
N_{pads_job}	=	Number of brake pads replaced per brake job (Default: 4 pads/job; see Section 3.3)
W_{pad}	=	Weight of brake pad (Default: 176 grams/pad; see Section 3.6)
$F_{dust\_generated}$	=	Mass fraction of dust generated from brake pad wear (kg dust generated/kg pad; Default: 0.75; see Section 3.10)
$F_{dust\_in\_brake}$	=	Mass fraction of generated brake pad remains in brake system (Default: 0.02 kg dust in brake system/kg dust generated (disc brakes); 0.5 kg dust in brake system/kg dust generated (drum brakes or unknown brake type); see Section 3.11)

3.13 Number of Total Brake Jobs per Year (N_{jobs_year})

This parameter represents the total number of expected brake jobs for brake pads containing the chemical of interest from a given production volume, assuming that the number of replacements is equal to the total number of brake pads that can be produced with the production volume of the chemical of interest. This equation additionally assumes that the composition of the brake dust is the same as the composition of the brake pad. The total annual number of brake jobs can be estimated using the following equation:

$$N_{jobs\_year} = Q_{chem\_yr} \Big/ \left(W_{pad} \times \frac{1\ kg}{1000\ g} \times F_{chem} \times N_{pads\_job} \right)$$

(Eqn. 3-4)

Where:

N_{jobs_year}	=	Number of annual number of brake jobs (jobs/year)
Q_{chem_yr}	=	Annual production volume of chemical of interest (kg chemical/yr)
W_{pad}	=	Weight of brake pad (Default: 176 grams/pad; see Section 3.6)
F_{chem}	=	Mass fraction of chemical of interest within the brake dust (kg chemical in the brake dust/kg dust) (see Section 3.9 for appropriate typical and high-end defaults)
N_{pads_job}	=	Number of brake pads replaced per brake job (Default: 4 pads/job; see Section 3.3)

3.14 Number of Servicing Sites ($N_{service\_sites}$)

This parameter represents the number of sites replacing brake pads containing the chemical of interest. This parameter assumes that there is one worker conducting brake pad replacements per site (see Section 4.2). This parameter additionally assumes that all brake pad replacements at these sites are of brake pads containing the chemical of interest. The number of sites replacing brake pads containing the chemical of interest is estimated using the following equation:

$$N_{service\_sites} = {N_{jobs\_year}} \Big/ \left(N_{jobs\_worker\_day} \times 1\,\frac{worker}{site} \times TIME_{operating\_days}\right) \quad \text{(Eqn. 3-5)}$$

Where:

$N_{service\_sites}$	=	Number of automotive service sites replacing pads with the chemical of interest (sites)
N_{jobs_year}	=	Number of annual number of brake jobs (jobs/year) (see Section 3.13)
$N_{jobs\_worker\_day}$	=	Number of brake jobs conducted by a worker per day (jobs/worker-day)) (see Section 3.5)
$TIME_{operating\_days}$	=	The number of operating days associated with automotive repair sites (Default: 260 days/year; see Section 3.2)

The calculated value of $N_{service\_sites}$ should not exceed the total number of automotive service sites known to operate in the U.S. (i.e., 157,149 sites, per Table 1-2).

4.0 OCCUPATIONAL EXPOSURE ASSESSMENTS

This section presents approaches for estimating worker exposures to brake pad additive chemicals. Exposure sources are presented in the order discussed in Section 2.0. Figure 2-1 illustrates the occupational activities with the greatest potential for worker exposures during brake pad replacement.

Table 4-1 summarizes the models used in this document. Note that the standard model default values cited are current as of the date of this document; however, EPA may update these models as additional data become available. It is recommended that the most current version of the models be used in the calculations.

Table 4-1. Summary of Exposure Models Used in the GS

Exposure Activity	Description	Route of Exposure and Physical Form	Model Name[a]	Standard EPA Model (✓)
A	Exposure during brake system disassembly and brake parts cleaning	Inhalation of solid powder dust	*EPA Small Volume Handling Model*	✓
		Dermal exposure to solid chemical	*EPA/OPPT 2-Hand Dermal Contact with Solids Model*	✓
B	Exposure during replacement and reassembly	Dermal exposure to solid chemical	*Not applicable*	NA

EPA – U.S. Environmental Protection Agency
OSHA – Occupational Safety and Health Administration
OPPT – Office of Pollution Prevention and Toxics
[a] See Appendix B for additional detailed descriptions of each model.

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

4.1 Personal Protective Equipment

EPA identified limited information on PPE practices typical of automotive service sites replacing the brake pads. Workers are likely to wear disposable gloves and protective footwear. They may also use protective headwear when working in pits, under lifts, or hoisting machinery. Breathing protection may include dust masks or respirators, if working with highly volatile substances or large amounts of dust.

EPA does not assess the effectiveness of PPE at mitigating occupational exposures. Exposure mitigation by PPE is affected by many factors including availability, cost, worker compliance, impact on job performance, chemical and physical properties of the substance and protective clothing, and the use, decontamination, maintenance, storage, and disposal practices applicable to the industrial operation (EPA, 1997). Therefore, the conservative, screening-level occupational exposure estimates presented in this document do not account for PPE. Actual occupational exposures may be significantly less than the estimates presented herein.

4.2 Number of Workers Exposed per Site

EPA did not identify current data that was specific to the automotive service industry. The estimate provided in Table 4-2 is based on data collected from the U.S Census Bureau. The 1988 Asbestos Exposure Assessment (ICF, 1988) includes information on the number of total mechanics at servicing shops and the number of those mechanics that actually perform the brake pad replacements. The ratio of mechanics performing brake jobs to the total number of employees was applied to more current U.S. Census Bureau data on the total number of employees within the NAICS code of interest to determine the number of employees per site expected to conduct brake jobs. Therefore, in the absence of industry information, each activity should assume one worker.

No information was found on typical operating hours or the number of shifts; therefore, this section presents exposure duration estimates for each worker activity based on standard EPA defaults and methodology.

Table 4-2. Number of Workers Potentially Exposed during Replacement of Brake Pads at Automotive Service Sites

NAICS Code	NAICS Code Description	Annual Average Employment[a]	Number of Establishments[b]	Average Number of Workers per Establishment[c]	Workers Doing Brake Pad Replacements per Establishment [d]
8111	Automotive Repair and Maintenance	825,520	157,149	5	1

[a] US BLS, 2014.
[b] US CB, 2012.
[c] Calculated by dividing annual average employment by the number of establishments.
[d] Calculated by multiplying the average number of workers per establishment by 0.25, the ratio of mechanics performing brake replacements to the total per facility (ICF, 1988), and rounding to the nearest whole number.

4.3 Exposure during Brake System Disassembly and Cleaning (Exposure A)

Workers will manually take apart brake systems to expose and remove the brake pads that need replacement and may clean the system. These brake systems may retain brake dust residue containing the chemical of interest. If the concentration of the chemical of interest in the brake pad and dust (F_{chem_pad}) is not known, determine the most appropriate default value by referencing Section 3.9.

Inhalation Exposure:

The disassembly of used brakes and brake system cleaning is expected to generate particulates. The degree of inhalation exposure to particulates depends on the concentration of the chemical of interest in the used brake pads (F_{chem_pad}), the potential concentration of additive containing the chemical of interest in the worker's breathing zone ($C_{particulate}$), and the total amount of additive containing the chemical of interest that the worker is exposed to per day in performing this activity ($Q_{additive\_dust\_site\_day}$).

The daily handling rate for one worker of the additive in dust form containing the chemical of interest may be estimated using the following equation:

$$Q_{dust\_worker\_day} = Q_{dust\_job} \times N_{jobs\_worker\_day} \qquad \text{(Eqn. 4-1)}$$

Where:

$Q_{dust\_worker\_day}$	=	Daily amount of additive in dust form in the process (kg dust/day)
Q_{dust_job}	=	Amount of additive in dust form that is handled by a worker during one brake job (kg dust/job; see Section 3.12)
$N_{jobs\_worker\_day}$	=	Number of brake jobs conducted by a worker per day (jobs/day; see Section 3.5)

Selection of the appropriate model to assess inhalation exposure should be based on the amount of total dust containing the chemical of interest the worker is exposed to per day ($Q_{additive\_dust\_worker\_day}$), not the amount of the chemical of interest the worker is exposed to. The OSHA Total PNOR PEL-Limiting Model conservatively assumes an airborne particulate concentration equal to that of the OSHA PEL for PNOR (total dust). However, due to the small volume of chemical being handled by workers during each brake job, the OSHA Total PNOR PEL-Limiting would yield an over estimation of inhalation exposures if the maximum amount of dust for exposure availability is fairly low (higher default values indicate less than 2 kg/day).

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

$$EXP_{inhalation} = Q_{dust\_worker\_day} \times F_{chem} \times F_{exposure} \qquad \text{(Eqn. 4-2)}$$

This exposure will occur over $TIME_{operating\_days}$.

Where:

$EXP_{inhalation}$	=	Inhalation exposure to chemical per day (mg chemical/day)
$Q_{dust\_worker\_day}$	=	Daily amount of additive containing chemical of interest in dust form in the process (kg dust/day)
F_{chem}	=	Mass fraction of chemical of interest within the brake dust (See Section 3.9)
$F_{exposure}$	=	Weight fraction of the total particulate in the worker breathing zone (Default: 0.0477 (typical) to 0.161 (worst) mg chemical/kg chemical handled (CEB, 1992))

Note that a further explanation, including the background and model defaults, of this standard EPA model used to estimate inhalation exposure to solid powder is presented in Appendix B.

Dermal Exposure:

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

$$EXP_{dermal} = \text{up to } 3{,}100 \text{ mg additive/incident} \times N_{exp\_incident} \times F_{chem} \qquad \text{(Eqn. 4-3)}$$

This exposure will occur over $TIME_{operating\_days}$.

Where:

EXP_{dermal}	=	Potential dermal exposure to chemical of interest per day (mg chemical/day)
$N_{exp\_incident}$	=	Number of exposure incidents per day (Default: 1 incident/day)
F_{chem}	=	Mass fraction of chemical of interest within the brake dust (See Section 3.9)

4.4 Exposure during New Brake Pad Installation and Reassembly (Exposure B)

Workers will manually install new brake pads and reassemble the system to finish the job. This task is not expected to contribute additional inhalation or dermal exposures because the new brake is a solid block with insignificant amount of dust.

5.0 SAMPLE CALCULATIONS

This section presents an example of how the equations introduced in Sections 3.0 through 4.0 can be used to estimate exposures to additive chemicals during automotive brake pad replacement. The default values used in these calculations, as presented in Sections 3.0 through 4.0, should be used only in the absence of site-specific information.

The sample calculations are based on the following data:

1. The production volume for the chemical of interest (Q_{chem_yr}) is *10,000* kg chemical/yr

2. The chemical of interest is a used as an unknown type of brake pad additive.

3. The brake pads to be replaced are done so at an unknown number of servicing sites.

The chemical assessment concerns are for occupational exposures.

5.1 General Facility Estimates

5.1.1 Days of Operation ($TIME_{operating\_days}$)

If specific information is not available, assume 260 operating days per year as discussed in Section 3.2.

5.1.2 Number of Brake Pad Replacements per Job (N_{pads_job})

Aside from the annual production volume, no other site-specific information or data are known; therefore, it is necessary to use default assumptions. This first step is to assume the total number of brake pads replaced per brake job. annual number of batches, which it's the number of brake pads that are replaced in a year at one site. Per Section 3.3, the default number of brake pad replacements per job is 4 pads/job.

5.1.3 Hours per Job (H_{job_worker})

Since the length of time spent by a worker on a brake job is unknown, assume a default value. The type of brake pad being replaced is unknown, therefore assume a default value of 1.3 hours/job.

5.1.4 Number of Brake Jobs per Worker per Day ($N_{jobs\_worker\_day}$)

Assuming an average working day of 8 hours, the number of brake jobs conducted by a worker per day can be calculated as:

$$N_{jobs\_worker\_day} = \frac{8\,\frac{hrs}{day}}{1.3\,\frac{hrs}{job}} \qquad \text{(Eqn. 5-1)}$$

$$N_{jobs\_worker\_day} = 6.15\ jobs/day$$

In this case, it is necessary to round to the nearest whole number, as jobs are discrete values.

5.1.5 Weight of Brake Pad (W_{pad})

Since the weight of brake pads is unknown, assume default value of 176 grams/pad.

5.1.6 Mass Fraction of Chemical of Interest within the Additive ($F_{chem\_additive}$)

Since the mass fraction of chemical of interest within the additive is unknown, assume the additive contains no other chemicals besides the chemical of interest (i.e., 1 kg chemical/kg additive).

5.1.7 Mass Fraction of Additive within the Brake Dust ($F_{additive\_dust}$)

Since the mass fraction of additive within the brake dust is unknown, it is necessary to assume a default weight fraction of 0.7 kg additive/kg dust.

5.1.8 Mass Fraction of Chemical of Interest within the Brake Dust (F_{chem})

This value represents the mass fraction of the chemical of interest in the brake pad, calculated using the following equation:

$$F_{chem} = F_{chem\_additive} \times F_{additive\_dust} \qquad \text{(Eqn. 5-2)}$$

$$F_{chem} = \left(1\,\frac{kg\ chemical}{kg\ additive}\right)\left(0.7\,\frac{kg\ additive}{kg\ dust}\right)$$

$$F_{chem} = 0.7\ kg\ chemical/kg\ dust$$

5.1.9 Fraction of Brake Dust Generated from Brake Pad Wear ($F_{dust\_generated}$)

Since the amount of pad that has been worn off is unknown, assume 25% of the pad is remaining, therefore, assume a default fraction for dust generated to be 0.75 kg dust generated/kg pad.

5.1.10 Fraction of Brake Pad Dust in Brake System ($F_{dust\_in\_brake}$)

Since the amount of pad that has become dust and been captured by the brake system is unknown, as is the type of brake pad being replaced, assume default fraction of 0.5 kg dust in brake/kg brake dust.

5.1.11 Amount of Additive in Dust Form Handled per Worker per Brake Job (Q_{dust_job})

The amount of brake dust containing additive that is handled by a worker during one brake job is estimated using the following equation:

$$Q_{dust\_job} = N_{pads\_job} \times W_{pad} \times \frac{1\,kg}{1000\,g} \times F_{dust\_generated} \times F_{dust\_in\_brake}$$

(Eqn. 5-3)

$$Q_{dust\_job} = \left(4\,\frac{pads}{job}\right)\left(176\,\frac{grams}{pad}\right)\left(\frac{1\,kg}{1000\,grams}\right)\left(0.75\,\frac{kg\ dust\ generated}{kg\ pad}\right)\left(0.5\,\frac{kg\ dust\ in\ brake}{kg\ dust\ generated}\right)$$

$$Q_{dust\_job} = 0.264\ kg\ dust/job$$

5.1.12 Number of Total Brake Jobs per Year (N_{jobs_year})

Use the following equation to estimate the total annual number of brake jobs:

$$N_{jobs\_year} = Q_{chem\_yr} \Big/ \left(W_{pad} \times \frac{1\,kg}{1000\,g} \times F_{chem} \times N_{pads\_job}\right) \quad \text{(Eqn. 5-4)}$$

$$N_{jobs\_year} = 10{,}000\,\frac{kg}{yr} \Big/ \left(176\,\frac{grams}{pad} \times \frac{1\,kg}{1000\,g} \times 0.7\,\frac{kg\ chemical\ in\ dust}{kg\ dust} \times 4\,\frac{pads}{job}\right)$$

$$N_{jobs\_year} = 20{,}292\ jobs/year$$

5.1.13 Number of Servicing Sites ($N_{service\_sites}$)

Assuming there is one worker conducting brake pad replacements per site (see Section 4.2), the number of sites replacing brake pads containing the chemical of interest is estimated using the following equation:

$$N_{service\_sites} = N_{jobs\_year} \Big/ \left(N_{jobs\_worker\_day} \times 1\,\frac{worker}{site} \times TIME_{operating\_days}\right)$$

(Eqn. 5-5)

$$N_{service\_sites} = \frac{20{,}292\ \frac{jobs}{year}}{\left(6\ \frac{jobs}{worker - day}\right)\left(1\ \frac{worker}{site}\right)\left(260\ \frac{days}{year}\right)}$$

$$N_{service\_sites} = 13.008 \text{ sites}$$

In this case, division did not yield an integer value. $N_{service\_sites}$ must be rounded to the nearest non-zero integer, 13 sites.

5.2 Occupational Exposures

5.2.1 Number of Workers Exposed per Site

Per section 4.2, assume 1 worker per site conducting brake pad replacements. Calculate the total number of workers as:

$$1\,\frac{workers}{site} \times N_{service\_sites} = \left(1\,\frac{workers}{site}\right)(13\ sites) = 13\ workers \qquad \text{(Eqn. 5-6)}$$

Assume all 13 workers are exposed to the chemical of interest during each of the exposure activities assessed below.

5.2.2 Exposure during Brake System Disassembly and Cleaning (Exposure A)

Inhalation Exposure:

The potential worker exposure to the chemical of interest is calculated using the *EPA/OPPT Small Volume Solids Handling Inhalation Model*. Determine the additive containing the chemical of interest per site day with the following equation:

$$Q_{dust\_worker\_day} = Q_{dust\_job} \times N_{jobs\_worker\_day} \qquad \text{(Eqn. 5-7)}$$

$$Q_{dust\_worker\_day} = \left(0.264\ \frac{kg\ dust}{job}\right)\left(6\ \frac{jobs}{day}\right)$$

$$Q_{dust\_worker\_day} = 1.584\ kg\ dust/day$$

Since the daily amount of solid additives containing the chemical of interest ($Q_{additive\_dust\_site\_day}$) is *less than* 54 kg/site-day; use the *EPA/OPPT Small Volume Solids Handling Inhalation Model*:

$$EXP_{inhalation} = Q_{dust\_worker\_day} \times F_{chem} \times F_{exposure} \qquad \text{(Eqn. 5-8)}$$

$$Typical\ EXP_{inhalation} = 1.584\ \frac{kg\ dust}{day} \times 0.7\ \frac{kg\ chemical}{kg\ dust} \times 0.0477\frac{mg\ chemical}{kg\ dust}$$

$$Typical\ EXP_{inhalation} = 0.0529\frac{mg\ chemical}{site - day}$$

$$Worst\ EXP_{inhalation} = 1.584\frac{kg\ dust}{day} \times 0.7\ \frac{kg\ chemical}{kg\ dust} \times 0.161\frac{mg\ chemical}{kg\ dust\ handled}$$

$$Worst\ EXP_{inhalation} = 0.1786\frac{mg\ chemical}{site - day}$$

This exposure will occur over 260 days/year.

Dermal Exposure:

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

$$\mathrm{EXP_{dermal}} = \text{up to } 3{,}100 \text{ mg additive/incident} \times \mathrm{N_{exp\_incident}} \times \mathrm{F_{chem}}$$

$$= \text{up to } 3{,}100 \text{ mg additive/incident} \times \frac{1 \text{ kg additive}}{10^6 \text{ mg additive}} \times 1 \frac{\text{incident}}{\text{day}} \times 0.02 \frac{\text{kg chemical}}{\text{kg } \textit{dust}}$$

$$= 0.000062 \frac{\text{kg chemical}}{\text{day}}$$

This exposure will occur over 260 days/year.

5.2.3 Exposure during New Brake Pad Installation and Reassembly (Exposure B)

Workers will manually install new brake pads and reassemble the system to finish the job. This task is not expected to contribute additional inhalation or dermal exposures because the new brake is a solid block with insignificant amount of dust.

6.0 DATA GAPS/UNCERTAINTIES AND FUTURE WORK

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

EPA is most interested in obtaining information about the automotive brake replacement industry that is characterized as "typical" or "conservative" (i.e., worse case), and is applicable to a generic formulation site. While EPA welcomes site-specific information as valuable to this GS, additional qualifiers of how reflective it is to the industry are needed to ensure its transparency if used in the GS. Reviewers should also feel free to recommend additional resources that may be useful to the development of this GS.

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

1. This GS assumed the fraction of additive in dust is the same as the fraction in the brake pad. Data on the validity of this assumption would enhance facility and exposure estimates.

2. This GS assumes the same brake pad size for all replacements. Data on the various possible sizes of brake pads by type (disc, drum, car) would enhance facility and exposure estimates.

3. This GS assumes all additive types are found in all brake pads. Further research and data on the differences in components of various brake pad types, as well as the market share of each brake pad type, would enhance facility and exposure estimates.

4. Activity-specific data for number of workers exposed were not identified in the literature; therefore, the GS assumes all workers at a given facility perform each activity. Data on the number of workers associated with each activity would further enhance GS exposure estimates.

5. Specific input on the reasonableness of the default values used in the general facility estimates (e.g., job duration, number of operating days per year) would enhance the quality of the calculations.

6. Industry-specific monitoring data for operations involving dusts emissions would enhance estimates for fugitive dust releases and associated worker inhalation exposures.

7. Industry-specific dermal monitoring data for all operations involving workers handling brake pad additives would enhance dermal exposure estimates.

8. Other models for inhalation exposures may have better applicability and would improve exposure estimates.

9. Market share considerations of the additive may enhance accuracy of estimates.

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Appendix A

ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUE

Summary of Exposure Estimation Equations

Table A-1 summarizes the equations introduced in Section 3.0, which are used to calculate the general facility parameters. Table A-2 summarizes the equations used in evaluating occupational exposures of additives. The default values for the ChemSTEER models are presented in Appendix B.

Table A-1. General Facility Parameter Calculation Summary)

General Facility Estimates
Number of Brake Jobs per Worker per Day ($N_{jobs\_worker\_day}$) $$N_{jobs\_worker\_day} = \frac{8\,\frac{hrs}{day}}{H_{job\_worker}}$$ (Eqn. 3-1)
Mass Fraction of Chemical of Interest within the Brake Dust (F_{chem}): $$F_{chem} = F_{chem\_additive} \times F_{additive\_dust}$$ (Eqn. 3-2)
Amount of Additive in Dust Form Handled per Worker per Brake Job $Q_{additive\_dust\_worker\_job}$) $$Q_{dust\_job} = N_{pads\_job} \times W_{pad} \times \frac{1\,kg}{1000\,g} \times F_{dust\ generated} \times F_{dust\_in\_brake}$$ (Eqn. 3-3)
Number of Total Jobs per Year ($N_{jobs\ \_year}$) $$N_{jobs\_year} = {Q_{chem\_yr}}\Big/{\left(W_{pad} \times \frac{1\,kg}{1000\,g} \times F_{chem} \times N_{pads\_job}\right)}$$ (Eqn. 3-4)
Number of Servicing Sites ($N_{service\_sites}$) $$N_{service\_sites} = {N_{jobs\_year}}\Big/{\left(N_{jobs\_worker\_day} \times 1\,\frac{worker}{site} \times TIME_{operating\_days}\right)}$$ (Eqn. 3-5)

Table A-2. Occupational Exposure Calculation Summary

Occupational Exposure Calculations
Number of Workers Exposed Per Site: See Section 4.2.
Exposures from Disassembly and Cleaning (Exposure A): *Inhalation:* The daily handling of the additive containing the chemical of interest may be estimated using the following equation: $$Q_{dust\_worker\_day} = Q_{dust\_job} \times N_{jobs\_worker\_day}$$ Since $Q_{dust\_worker\_day}$ is less than or equal to 54 kg/site-day: EPA/OPPT Small Volume Handling Inhalation Model (See Section 4.3) *Dermal:* $$EXP_{dermal} = \text{up to } 3{,}100 \text{ mg additive/incident} \times N_{exp\_incident} \times F_{chem} \quad (4\text{-}3)$$ … over the lesser of $N_{pads\_site\_yr}$ or $TIME_{operating\_days}$.
Exposures from New Brake Pad Installation and Reassembly (Exposure B): *Not application, chemicals entrained within solid brake pad. No dust formation.*

Appendix B

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

B.1. CHEMICAL PARTICLE INHALATION EXPOSURE MODELS

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

EPA/OPPT Small Volume Solids Handling Inhalation Model

This model 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 Handing Inhalation Model* is based on exposure monitoring data obtained for workers handling up to 54 kg of powdered material. Beyond this data-supported limit, EPA assumes that exposures within occupational work areas are maintained below the regulation-based exposure limit for “particulates, not otherwise regulated”.

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

B.1.1 <u>EPA/OPPT Small Volume Solids Handling Inhalation Model</u>

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*[3] (i.e., $\leq$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

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

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 ($Q_{facility\_day}$; kg/site-day) is equal to the amount handled per worker ($Q_{shift\_handled}$; kg/worker-shift), if site-specific information is not available.

Model Equation:

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

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

Where:

$EXP_{inhalation}$	=	Inhalation exposure to the particulate chemical per day (mg chemical/worker-day)
$Q_{shift\_handled}$	=	Quantity of the solid/particulate material containing the chemical of interest that is handled by workers each shift (kg/worker-shift; see Table B-6 for appropriate EPA default values; must be ≤ 54 kg/worker-shift for this model to be valid)
N_{shifts}[4]	=	Number of shifts worked by each worker per day (EPA default = 1 shift/day)
F_{chem}	=	Weight fraction of the chemical of interest in the particulate material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
$F_{exposure}$	=	Exposure factor; amount of total particulate handled that is expected to be inhaled (EPA defaults: 0.0477 mg/kg (typical) and 0.161 mg/kg (worst case))

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

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

Activity Type	Default $Q_{shift\_handled}$ [5] (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 Division[6]. *Textile Dye Weighing Monitoring Study*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington D.C., EPA 560/5-90-009. April 1990.

B.2. 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

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

[6] Note: This reference is currently available for viewing in the ChemSTEER Help System.

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 hands, immersion in material, contact with surfaces) and are documented in the references listed in this section.

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

Model Equation:

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

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

Where:

EXP_{dermal}	=	Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)
$AREA_{surface}$	=	Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm^2; see Table B-7 for appropriate EPA default values)
Q_{remain_skin}	=	Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm^2-event; see Table B-7 for appropriate EPA default values)
F_{chem}	=	Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)
N_{event}[7]	=	Frequency of events for the activity (EPA default = 1 event/worker-day)

Each model, however, utilizes unique default values within that equation based upon the nature of the contact and the physical form of the chemical material. These default values are summarized in Table B-7. The following models are the standard EPA models for estimating worker dermal exposures:

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

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

For several categories of exposure, EPA uses qualitative assessments to estimate dermal exposure. Table B-8 summarizes these categories and the resulting qualitative dermal exposure assessments.

References:

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

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

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

Default Model	Example Activities	$AREA_{surface}$[a] (cm^2)	Q_{remain_skin}[b] (mg/cm^2-event)	Resulting Contact $AREA_{surface} \times Q_{remain\_skin}$ (mg/event)
Physical Form: Liquids				
EPA/OPPT 1-Hand Dermal Contact with Liquid Model	• Liquid sampling activities • Ladling liquid/bench-scale liquid transfer	535 (1 hand mean)	Low: 0.7 High: 2.1	< 1,100
EPA/OPPT 2-Hand Dermal Contact with Liquid Model	• Maintenance • Manual cleaning of equipment and containers • Filling drum with liquid • Connecting transfer line	1070 (2 hand mean)	Low: 0.7 High: 2.1	< 2,200
EPA/OPPT 2-Hand Dermal Immersion in Liquid Model	• Handling wet surfaces • Spray painting	1070 (2 hand mean)	Low: 1.3 High: 10.3	< 11,000
Physical Form: Solids				
EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model	• Handling bags of solid materials (closed or empty)	No defaults	No defaults	< 1,100[c]
EPA/OPPT 2-Hand Dermal Contact with Solids Model	• Solid sampling activities • Filling/dumping containers of powders, flakes, granules • Weighing powder/scooping/mixing (i.e., dye weighing) • Cleaning solid residues from process equipment • Handling wet or dried material in a filtration and drying process	No defaults	No defaults	< 3,100[23]

a - These default values were adopted in the 2013 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citations of this sources) and are the mean values for men taken from the EPA Exposure Factors Handbook, 2011.
b - These default values were adopted in the 2013 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived the selected ranges of values for liquid handling activities from: U.S. EPA. A Laboratory Method to Determine the Retention of Liquids on the Surface of Hands. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Exposure Evaluation Division. EPA 747-R-92-003. September 1992.
c - These default values were adopted in the 2013 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived values for dermal contact for solids handling activities from: Lansink, C.J.M., M.S.C. Breelen, J. Marquart, and J.J. van Hemmen: Skin Exposure to Calcium Carbonate in the Paint Industry. Preliminary Modeling of Skin Exposure Levels to Powders Based on Field Data (TNO Report V 96.064). Rijswijk, The Netherlands: TNO Nutrition and Food Research Institute, 1996.

Table B-8. EPA Default Qualitative Assessments for Screening-Level Estimates of Dermal Exposure

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

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