



Chemical Additives Used in Mineral and
Metal Ore Flotation –
Generic Scenario for Estimating Environmental
Releases and Occupational Inhalation
Exposure During Flotation
-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 Quick-Strike Generic Scenario for estimating environmental releases of chemical additives used in mineral and metal ore flotation processes, as well as the occupational inhalation exposure to these chemical additives during the flotation process. This scenario is a quick-strike generic scenario as opposed to a regular generic scenario, meaning its scope is designed to serve the needs of EPA programs on a real-time basis. A quick-strike generic scenario differs from a regular generic scenario in that it has a limited scope that serves the needs of an ongoing evaluation and can be completed in a shorter timeframe than a regular generic scenario.

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 environmental releases of chemical additives during their use in mineral and metal ore flotation processes, as well as the occupational inhalation exposure to these chemical additives during the flotation process.

This draft quick-strike generic scenario (QSGS) 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 environmental releases to and occupational inhalation exposure from chemical additives used in mineral and metal ore flotation processes, as well as subsequent tailings disposal. The reader should note that the estimation methods provided in this document may result in release and exposures 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 QSGS makes conservative assumptions about facility operations and workplace practices. For example, the QSGS defaults to the most conservative facility throughput values if the chemical additive function is unknown.

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

Coverage and methodology

EPA developed this draft QSGS using relevant data¹ supplemented with standard occupational exposure models². The primary sources of information cited in this draft QSGS include information published by the Mine Safety and Health Administration and various EPA and other government sources (e.g., EPA, OECD, and regional/state pollution prevention organizations).

The draft QSGS includes methods for estimating environmental releases of chemical additives used in mineral and metal ore flotation processes, as well as the occupational inhalation exposure during the flotation process. 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 QSGS covers any chemical additive used in mineral and metal ore flotation processes. These chemicals can be classified into one of several types of additives such as flotation aids, surfactants, and frothers. Table 1-1 provides additional examples of the types of additives applicable to the QSGS.

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

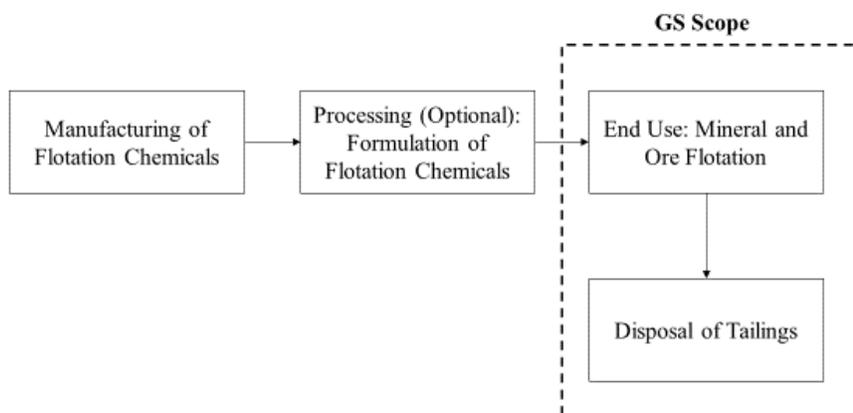


Figure 0-1. QSGS Scope on Use of Chemical Reagents in Mineral and Metal Ore Flotation Processes

The scope of the QSGS applies only to additives in chemicals used at industrial sites for mineral and metal ore flotation processes. Processes for mineral and metal ore flotation

¹ Please refer to Section 8.0 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.

can vary at industrial sites, but generally involve mixing additives with the ore, flotation with air bubbles, separated ore filtration and cleaning, and tailings collection, dewatering, and disposal.

Methods for estimating the following facility operating parameters and environmental releases of additive chemicals used in mineral and metal ore flotation are discussed in the draft QSGS:

- Number of sites in the United States that conduct mineral and metal ore flotation processes;
- Days of operation at flotation sites;
- Annual ore processing rate;
- Annual and daily use rate for chemical reagents;
- Number of chemical reagent transport containers unloaded;
- Release to uncertain media from chemical reagent container cleaning;
- Release to air during mineral/ore flotation;
- Release to uncertain media from cleaning process vessels;
- Release to incineration from thermal processing of collected ore;
- Release to water or land from tailings disposal;
- Number of workers that may come into contact with the chemical during mineral and metal ore flotation processes;
- Occupational inhalation exposure during flotation.

The estimation methods in this draft scenario apply to any chemical additives used in the mineral and metal ore flotation process, regardless of their function.

How this document was developed

The U.S. Environmental Protection Agency (EPA), with support from Eastern Research Group, Inc. (ERG), has developed this Quick-Strike Generic Scenario on environmental releases from mineral and metal ore flotation.

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1.0 INDUSTRY SUMMARY AND BACKGROUND

Mineral and metal ore flotation is a process used to extract desired commodities from milled ores by separating hydrophobic materials from hydrophilic materials (Kawatra, 2009). Mined and milled ores are mixed with water and collector chemicals, which render the surface of the desired mineral or metal hydrophobic. Additional modifying chemical reagents are added to the bulk mixture, or slurry, which is subsequently aerated with bubbles. The bubbles attract the hydrophobic ores, collecting them in a froth at the surface of the slurry. The froth containing the ores is then separated and further processed to clean and isolate the ores. The remaining compounds in the slurry, the tailings, are generally dewatered and stored in ponds, storage facilities, or backfilled into mines no longer being quarried.

Flotation is typical for mineral and metal ores such as gold, silver, copper, lead, zinc, molybdenum, iron, potash, and phosphate (Chevron Phillips, 2017). This process occurs at industrial sites, usually at the sites where the actual mineral and metal ore mining and quarrying occurs, to minimize the need to transport ores for processing and tails for mine backfilling and storage.

1.1 Chemical Additives in Mineral and Metal Ore Flotation

Additives in mineral and metal ore flotation are added to impart specific properties to bulk flotation slurry. The flotation slurry typically contains between 25 and 40% solids, with the remaining slurry comprised of water, used at a rate of about 2.5 tons of water per ton of dry ore processed, and smaller amounts of chemical additives (Bleiwas, 2012). Table 1-1 presents types of chemical additives, their functions, and typical use rates in the flotation slurry. The presented concentrations are ranges typically expected in flotation processing (Yarar, 2000; Michaud, 2016a). These concentrations are expected to vary between different industrial sites.

Table 1-1. Overview of Mineral and Metal Ore Flotation Additives, including Typical Compounds, Functions, and Use Rates ^a

| Additive Types | Functions | Typical Compounds | Use Rate of Additive per Dry Ore (kg additive/ton dry ore) ^b |
|---------------------------|---|---|---|
| Flotation Aids/Collectors | Impart hydrophobicity to the solid to be floated | Alkyl morpholines, alkyl thiocarbonates (xanthates), dialkyl dithiophosphates, dixanthogens, naphthenic acids, sodium alkyl hydroxamates, thiocarbanilide | 0.0045 to 0.91 |
| Flotation Sulfidizers | Precipitate a film of sulfide on the surface of minerals/ores to make them more responsive to collector chemicals | Sodium sulfide | 0.23 to 2.27 |

| Additive Types | Functions | Typical Compounds | Use Rate of Additive per Dry Ore (kg additive/ton dry ore) ^b |
|--------------------|--|--|---|
| Activator | Aids in flotation of previously depressed minerals or those that do not respond to collector chemicals | Cupric sulfate, lead acetate, other metallic salts, lime | 0.23 to 0.91 |
| Frother/Surfactant | Lowers surface tension of slurry to allow air bubbles to accumulate at the surface | Pine oil, eucalyptus oil, cresol, glycol, higher alcohols | 0.023 to 0.18 |
| Depressant | Inhibits the flotation of undesired minerals to prevent interference with flotation of the desired mineral/ore | Lime, sodium sulphate, sodium dichromate, sodium cyanide, sodium sulfide, sulfur dioxide | 0.45 to 4.54 |
| pH regulator | Modify pH of the slurry to optimize flotation | Lime, sodium hydroxide, sodium carbonate, sulfuric acid | 0.023 to 2.27 ^c |

a – Sources: Yarar, 2000; Michaud, 2016a

b – These rates were converted from pounds to kilograms of additive using the conversion factor 1 kg/2.2046 pound, and rounding to two decimal points.

c – The required dosage of pH regulator is highly dependent on the source water and the type of flotation process.

1.2 Market Profile

Mineral and metal ore flotation occurs at the sites from which the ores are mined. These sites fall under the North American Industrial Classification System (NAICS) industry groups 2123 (Nonmetallic mineral mining and quarrying) and 2122 (Metal ore mining). These industry groups consist of establishments that are primarily involved in mineral and metal ore mining, quarrying, and beneficiating. These industry groups are further divided by the type of mineral and metal ore being mined and beneficiated, but not by sites that specifically conduct beneficiating (which includes flotation).

The Mine Safety and Health Administration (MSHA) collects data on the number of sites categorized by type of mine (i.e., coal, metal, nonmetal, stone, or sand and gravel). The scope of this scenario is for ore commodities. Thus, based on the MSHA classifications, the types of sites that are expected to conduct flotation processes include both metal mines and mineral mines. Data for the year 2015 on the number of metal and mineral mining sites is summarized in Table 1-2. Note that this data cannot be further broken down by the types of processes (e.g., crushing, milling, flotation) conducted at each site. Thus, this data likely presents an overestimation of the number of sites conducting mineral and metal ore flotation processes.

Table 1-2. Number of Metal and Mineral Mining Sites in 2015^a

| Ore Type | Number of Establishments |
|--------------|--------------------------|
| Metal Ore | 315 |
| Mineral Ore | 924 |
| <i>Total</i> | <i>1,239</i> |

a – (NIOSH, 2015)

2.0 PROCESS DESCRIPTION

The proposed scenario will include the releases and inhalation exposure specified in Figure 2-1. Once chemical reagent containers are received and emptied into the conditioning tank, the containers are expected to be cleaned on-site or returned to the chemical supplier for cleaning, resulting in release to uncertain media. Cleaning of various process vessels is another potential source of environmental release of chemical additives that may remain in residual amounts in the equipment at the time of cleaning. However, research indicates that many sites do not frequently, if ever, clean out process equipment (Michaud, 2016c).

2.1 Dry Ore Diminution

Prior to flotation, excavated ores first undergo physical diminution processes, such as crushing and milling, to reduce the size of the ores. Any environmental releases or occupational exposures from diminution processes are not covered in the scope of this QSGS, as they do not involve the use of flotation chemical additives that are the focus of this QSGS.

2.2 Conditioning Tank

The crushed ore is then mixed with water and collector chemicals, which render the surface of the desired commodity (mineral or metal) hydrophobic (Kawatra, 2009). Additional modifying chemical reagents, such as frothers, activators, and depressants, are also added to the bulk mixture, or slurry, in a conditioning tank. The cleaning of conditioning tanks is a potential source of environmental release of chemical additives that may remain in residual amounts in the conditioning tanks at the time of cleaning.

2.3 Bulk Flotation

The slurry is then sent to flotation tanks that are aerated with bubbles. As the bubbles float to the surface of the slurry, they attract the hydrophobic mineral or metal, thus collecting them in a froth at the surface of the slurry. Depending on the extent of commodity extraction, the slurry is usually sent to an additional froth flotation tank, known as the scavenging tank. The aeration of the mixture during flotation is expected to produce a release of chemical reagent to air, and potential occupational inhalation exposure. Additionally, the cleaning of these flotation tanks is a potential source of environmental release of chemical additives that may remain in residual amounts in the flotation tanks at the time of cleaning.

2.4 Concentrate Dewatering

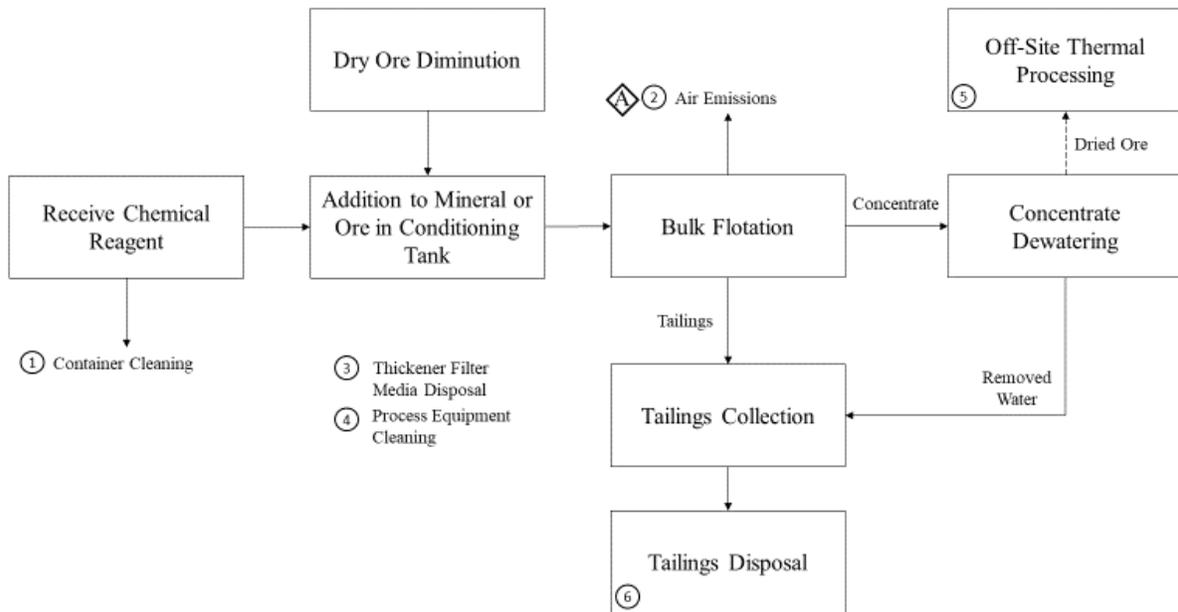
The froth is collected from the top of the flotation tanks, forming the concentrate solution, which is comprised of the commodity of interest, water, and residual chemicals, such as collector chemicals or other additives that are likely to partition to the commodity. The concentrate is further cleaned and filtered to isolate the commodity from excess water. The removed water is generally mixed with the tailings for disposal, where solids may be settled from the water so that the water can be reused. The cleaning of dewatering equipment, such as rotary drum filters, is a potential source of environmental release of chemical additives that may remain in residual amounts in the dewatering equipment or spent filters at the time of cleaning.

2.5 Off-Site Thermal Processing

The dewatered commodity is then sent off-site for thermal or metallurgical processing during which the ores are heated to high temperatures, resulting in release of any chemical reagents to incineration. Figure 2-1 depicts the off-site transfer of the concentrate with a dashed arrow. Thermal processing is expected to involve heating the ore to high temperatures at which any chemical substances adhered to the ore are incinerated. No other potential significant environmental releases of chemical additives are expected during off-site thermal processing.

2.6 Tailings Collection and Disposal

The remaining slurry in the bulk flotation tanks, from which the froth concentrate was extracted, is known as the tailings. The tailings are pumped from the tanks, and may be dewatered and further thickened as necessary. The water removed from the concentrate and tailings solution can be recycled and reused in the flotation process until spent. The dewatered tailings are often used as mine fill or sent to a tailings pond to allow for further sedimentation and eventual pond impoundment (Edraki et al, 2014). Other tailings disposal methods include: valley filling, hillside dams, and raised impoundments. Any water entrained in the tailings pond can be released through evaporation, entrainment in the tailings, seepage into the ground, and discharge to the environment. Thus, chemical reagents that remain in the tailings are expected to be released to land or water.



Occupational Exposures

A. Inhalation exposure during air flotation.

Environmental Releases

1. Release to uncertain media from container cleaning residue.
2. Release to air during flotation.
3. Release to uncertain media from filter media changeout.
4. Release to uncertain media from cleaning process equipment vessels.
5. Off-site release to incineration from thermal processing.
6. Release to land or water from tailings disposal.

Figure 2-1. Typical Releases and Flotation Inhalation Exposure During Mineral and Metal Ore Flotation

3.0 OVERALL APPROACH AND GENERAL FACILITY ESTIMATES

This draft QSGS presents EPA's standard approach for estimating environmental releases to chemical additives during mineral and metal ore flotation.

The estimation methods described in this document utilize available industry-specific information and data to the greatest extent possible. However, EPA acknowledges several areas in which additional industry data would enhance the estimates presented herein. These data needs are summarized in Section 7.0. It should be noted that 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 QSGS presents general facility calculations for mineral and metal ore flotation, including daily chemical additive use rate, number of mineral and metal ore flotation sites, and the number of operating days at these sites.

Section 4.0 of the draft QSGS presents environmental release assessments from mineral and metal ore flotation. Section 5.0 presents the assessment for occupational inhalation exposure during the flotation process. The assessments reference the general facility estimates presented in this section to estimate activity-specific environmental releases during mineral and metal ore flotation.

3.1 Introduction to General Facility Estimates

Throughout the remainder of this section, EPA utilized available industry and MSHA data to estimate the number of potential mineral and metal ore flotation sites in the U.S. This section also describes the methods and assumptions used to estimate typical chemical additive use rates at these sites. Use rates can be estimated using several facility parameters, including the annual facility use rates, days of operation, and number of 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.

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

| Parameter | Parameter Description | Section |
|------------------------------------|--|----------------|
| $TIME_{operating_days}$ | Annual operating days at mining sites (day/yr) | 3.2 |
| $Q_{commodity_site_yr}$ | Annual production rate of mineral and metal commodities (tons commodity recovered/site-yr) | 3.3 |
| $F_{recovery}$ | Fraction of commodity recovered from the mined ore (ton commodity recovered/ton commodity processed) | 3.4 |
| $F_{commodity_ore}$ | Fraction of commodity in the mined ores (ton commodity processed/ton dry ore processed) | 3.5 |
| $Q_{process_site_yr}$ | Amount of commodity – containing ore that is processed to achieve the final mineral or metal commodity (ton dry ore/site-yr) | 3.7 |
| $F_{chem_additive}$ | Mass fraction of chemical of interest within the additive (kg chemical/kg additive) | 3.8 |
| $Q_{additive}$ | Use rate of additive based on the dry weight of the ore being processed (kg additive/ton dry ore) | 3.9 |
| Q_{chem} | Use rate of the chemical of interest based on the dry weight of the ore being processed (kg chemical/ton dry ore) | 3.10 |
| $Q_{chem_site_yr}$ | Annual use rate of the chemical of interest (kg chemical/site-yr) | 3.11 |
| $Q_{chem_site_day}$ | Daily use rate of the chemical of interest (kg chemical/site-day) | 3.12 |
| N_{sites} | Number of sites using the chemical of interest for mineral or metal ore flotation (sites) | 3.13 |
| $N_{containers_unload_site_yr}$ | Number of transport containers unloaded annually per site (containers/site-yr) | 3.13 |

3.2 Days of Operation ($TIME_{operating_days}$)

The number of operating days associated with mining sites can be estimated using MSHA data on the total number of employees and the total number of employee hours reported for the year of 2015. This data is specific to operational employees and does not include office workers. Table 3-2 lists the MSHA data used to estimate the number of operating days for metal and mineral mining sites. Assuming an eight-hour work day, dividing the total employee hours by the number of employees for the year of 2015 yields an estimated average $TIME_{operating_days}$ of 262 days/year for metal mining sites, 243 days/year for mineral mining sites, and 255 days per year if the type of mining site is unknown.

Table 3-2. Estimated Annual Operating Days for Mining Sites in 2015 ^a

| Ore Type | Number of Operation Employees | Total Employee Operation Hours (millions) | Estimated Annual Operating Days ^b |
|-----------------|--------------------------------------|--|---|
| Metal Ore | 41,459 | 86.8 | 262 |
| Mineral Ore | 26,089 | 50.7 | 243 |
| <i>Total</i> | <i>67,548</i> | <i>137.5</i> | <i>255 (Default)</i> |

^a Source: NIOSH, 2015

^b Estimated by dividing employee hours by number of employees and an assumed eight-hour work day.

3.3 Annual Mineral or Metal Commodity Production Rates ($Q_{\text{commodity_site_yr}}$)

This parameter represents the annual production rate of mineral and metal commodities, which are contained within and extracted from the mined ores. Annual production rates for mineral and metal commodities can be estimated using the 2016 U.S. Geological Survey’s (USGS) Mineral Commodity Summaries (USGS, 2016). Table 3-3 summarizes the 2015 production data from the USGS Mineral Commodity Summaries, the number of production sites in 2015 from MSHA data, and the estimated production rate per site per year ($Q_{\text{commodity_site_yr}}$). If the type of commodity being produced is unknown a default production rate of 82,723 tons commodity recovered/site-yr should be assumed.

Table 3-3. Annual Production Rates for Mineral and Metal Ore Commodities

| Ore Type | Annual Production (thousand tons commodity) ^a | Number of Sites ^b | Production Rate per Site $Q_{\text{commodity_site_yr}}$ (tons commodity recovered/site-yr) ^c |
|--------------|--|------------------------------|---|
| Metal Ore | 47,269 | 315 | 150,060 |
| Mineral Ore | 55,225 | 924 | 59,767 |
| <i>Total</i> | <i>102,494</i> | <i>1,239</i> | <i>82,723^d</i> <i>(default)</i> |

a – Source: USGS, 2016

b – Source: NIOSH, 2015

c – Calculated by dividing the annual production rate by the number of sites.

d – This is a midline default value for when both environmental releases and occupational exposures are of concern. If concerns are primarily for environmental releases, the production rate for metal ore can be assumed to increase the throughput per site and, thereby, decrease the number of sites. If concerns are primarily for occupational exposures, the production rate for mineral ore can be assumed to decrease throughput per site and, thereby, increase the number of sites.

3.4 Fraction of Commodity in Mineral or Ore ($F_{\text{commodity_ore}}$)

The fraction of commodity within the mined mineral or metal ore (also referred to as grade) can be determined from the values in Table 3-4. If specific industry information is unavailable, the low-end fraction for the appropriate commodity type (i.e., mineral or metal) should be assumed as a default value. If the commodity type is unknown, a realistic default value should be assumed to be 0.1 tons commodity/ton dry ore.

Table 3-4. Fraction of Mineral or Metal Commodity Within Ore^a

| Ore Type | Low-End Fraction (Default values) | High-End Fraction |
|--------------------------------------|--|-------------------|
| Metal Ore | 0.002 | 0.1 |
| Mineral Ore | 0.1 | 0.3 |
| <i>Default for Unknown Commodity</i> | <i>0.1 ton commodity/ton dry ore^b</i> | |

a – Source: (Nagaraj, 2005)

b – This is a midline default value for when both environmental releases and occupational exposures are of concern. If concerns are primarily for environmental releases, the low-end fraction for metal ore can be assumed to increase the throughput per site and, thereby, decrease the number of sites. If concerns are primarily for occupational exposures, the high-end fraction for mineral ore can be assumed to decrease throughput per site and, thereby, increase the number of sites.

3.5 Fraction of Commodity Recovered from Ore (F_{recovery})

The amount of commodity that is recovered from the mined ore is dependent on the grade and quality of the mined ores, but tends to range from 75 to 90% of the commodity contained in the ore (Bulatovic, 2007). EPA recommends assuming a default recovery rate of 80%, as a mid-line estimate when concerns are for both environmental releases and occupational exposures. Note that if concerns are only for environmental releases, a default of 75% can be assumed to increase the throughput per site and, thereby, decrease the number of sites. If concerns are only for occupational exposures, a default of 90% can be assumed to decrease throughput per site and, thereby, increase number of sites.

F_{recovery} = Fraction of commodity recovered from the mined ore
(Default: 0.8 tons commodity recovered/ton commodity processed)

3.6 Annual Commodity Processing Rates ($Q_{\text{process_site_yr}}$)

The amount of commodity – containing ore that is processed to achieve the final mineral or metal commodity is dependent on the fraction of the commodity of interest within the mined mineral or metal ore ($F_{\text{commodity_ore}}$). It is also dependent on the recovery rate of the commodity during the flotation process (F_{recovery}). The annual commodity processing rate can be calculated with the following equation:

$$Q_{\text{process_site_yr}} = \frac{Q_{\text{commodity_site_yr}}}{F_{\text{commodity_ore}} \times F_{\text{recovery}}} \quad (\text{Eqn. 3-1})$$

Where:

$Q_{\text{process_site_yr}}$ = Annual process rate of minerals and ore commodity (ton dry ore/site-yr)
 $Q_{\text{commodity_site_yr}}$ = Annual production rate of mineral or metal ore commodity (ton commodity recovered/site-yr)
 $F_{\text{commodity_ore}}$ = Fraction of commodity within the mined ore (Default: 0.1 tons commodity processed/ton dry ore)
 F_{recovery} = Fraction of commodity recovered from the mined ore (Default: 0.8 tons commodity recovered/ton commodity processed)

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

The chemical of interest may constitute only a fraction of the additive that is blended into the mineral or ore slurry. $F_{\text{chem_additive}}$ 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 Use Rate of Additive per Ton of Dry Ore ($Q_{additive}$)

This value represents the use rate of additive based on the dry weight of the ore being processed. If $Q_{additive}$ 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 the function of the chemical is unknown, and assessment concerns are for both environmental releases and occupational exposures, assume a default mid-line value of 0.91 kg additive/ton dry ore. If assessment concerns are primarily for environmental releases, assume a higher use rate of 4.54 kg additive/ton dry ore, to maximize throughput and minimize number of sites. If assessment concerns are primarily for occupational exposures, assume a lower use rate of 0.0045 kg additive/ton dry ore, to minimize throughput and maximize number of sites and, therefore, the number of workers potentially exposed.

$Q_{additive}$ = Use rate of additive based on the dry weight of ore being processed (Default: 0.91 kg additive/ton dry ore)

3.9 Use Rate of Chemical of Interest per Ton Dry Ore (Q_{chem})

The use rate of the chemical of interest based on the dry weight of the ore being processed can be calculated with the following equation:

$$Q_{chem} = F_{chem_additive} \times Q_{additive} \quad (\text{Eqn. 3-2})$$

Where:

Q_{chem} = Use rate of chemical of interest based on the dry weight of the ore being processed (kg chemical/ton dry ore)
 $F_{chem_additive}$ = Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive)
 $Q_{additive}$ = Use rate of additive based on the dry weight of ore being processed (Default: 0.91 kg additive/ton dry ore)

3.10 Annual Use Rate of Chemical of Interest ($Q_{chem_site_yr}$)

The annual use rate of the chemical of interest can be calculated with the following equation:

$$Q_{chem_site_yr} = Q_{process_site_yr} \times Q_{chem_slurry} \quad (\text{Eqn. 3-3})$$

Where:

$Q_{chem_site_yr}$ = Annual use rate of chemical of interest (kg chemical of interest/site-yr)

| | | |
|-------------------------|---|---|
| $Q_{process_site_yr}$ | = | Annual process rate of minerals and ore commodity (ton dry ore processed/site-yr) |
| Q_{chem} | = | Use rate of chemical of interest based on the dry weight of the ore being processed (kg chemical/ton dry ore) |

3.11 Daily Use Rate of Chemical of Interest ($Q_{chem_site_day}$)

The daily use rate of the chemical of interest can be calculated with the following equation:

$$Q_{chem_site_day} = \frac{Q_{chem_site_yr}}{TIME_{operating_days}} \quad (\text{Eqn. 3-4})$$

Where:

| | | |
|--------------------------|---|---|
| $Q_{chem_site_day}$ | = | Daily use rate of chemical of interest (kg chemical/site-day) |
| $Q_{chem_site_yr}$ | = | Annual use rate of chemical of interest (kg chemical/site-yr) |
| $TIME_{operating_days}$ | = | Number of operating days (Default: 255 days/yr) |

3.12 Number of Sites (N_{sites})

The number of sites using the chemical of interest (N_{sites}) depends on the total annual production of the chemical of interest (Q_{chem_yr}), the daily use rate of the chemical of interest ($Q_{chem_site_day}$), and the annual operating days ($TIME_{operating_days}$). The following equation can be used to calculate the number of sites using the chemical of interest:

$$N_{sites} = \frac{Q_{chem_yr}}{Q_{chem_site_day} \times TIME_{operating_days}} \quad (\text{Eqn. 3-5})$$

Where:

| | | |
|---------------|---|--|
| N_{sites}^3 | = | Number of sites using the chemical of interest in mineral or metal ore flotation processes (sites) |
|---------------|---|--|

³ The value for N_{sites} , calculated using Equation 3-4 should be rounded up to the nearest integer value. $Q_{chem_site_day}$ should then be adjusted for the N_{sites} integer value (to avoid errors due to rounding):

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

$Q_{process_site_yr}$ should then be adjusted for the $Q_{chem_site_day}$ (to avoid errors due to rounding):

$$Q_{process_site_yr} = \frac{Q_{chem_site_day} \times TIME_{operating_days}}{Q_{chem_slurry}}$$

| | | |
|--------------------------|---|---|
| Q_{chem_yr} | = | Annual production volume of chemical of interest (kg chemical/yr) |
| $Q_{chem_site_day}$ | = | Daily use rate of chemical of interest (kg chemical/site-day) |
| $TIME_{operating_days}$ | = | Number of operating days (Default: 255 days/yr) |

The calculated value of N_{sites} should not exceed the total number of mineral and metal ore mining sites known to operate in the U.S. (i.e., 1,239 sites, per Table 1-2).

Note that certain default values that affect this calculation can be changed based on assessment concerns, to either increase or decrease the number of sites. Specifically, the parameters with default values that affect the number of sites calculation are: $Q_{commodity_site_yr}$, $F_{commodity_ore}$, $F_{recovery}$, and $Q_{additive}$.

For assessment concerns primarily for environmental releases, the number of sites should be *minimized*, so as to increase the daily throughput and subsequent release of the chemical of interest at each site. To do this, the assessor should maximize both $Q_{commodity_site_yr}$ and $Q_{additive}$, and minimize both $F_{commodity_ore}$ and $F_{recovery}$.

For assessment concerns primarily for occupational exposures, the number of sites should be *maximized*, so as to maximize the number of workers potentially exposed. To do this, the assessor should minimize both $Q_{commodity_site_yr}$ and $Q_{additive}$, and maximize both $F_{commodity_ore}$ and $F_{recovery}$.

3.13 Number of Transport Containers Unloaded per Site ($N_{containers_unload_site_yr}$)

Mineral and metal ore flotation chemicals can be supplied in a variety of container sizes, typically ranging from 55-gallon drums to 900 kg IBC totes (Moly-Cop, 2017). The distribution of container type and sizes is not known, but EPA recommends assuming chemicals are supplied in 55-gallon drums where information is not available. The number of transport containers unloaded annually per site can be estimated based on the daily use rate, container size, and the fraction of chemical in the formulation.

$$N_{containers_unload_site_yr} = \frac{Q_{chem_site_day} \times TIME_{operating_days}}{F_{chem_additive} \times V_{container} \times \rho_{additive} \times 3.785 \frac{L}{gal}}$$

(Eqn. 3-6)

Where:

Note: If the number of sites is known, the previous equation may also be used to estimate the resulting average annual production rate for use in subsequent calculations.

| | | |
|---|---|--|
| $N_{\text{containers_unload_site_yr}}$ | = | Number of transport containers unloaded at each site per year (containers/site-yr) |
| $Q_{\text{chem_site_day}}$ | = | Daily use rate of chemical of interest (kg chemical/site-day) |
| $TIME_{\text{operating_days}}$ | = | Number of operating days (Default: 255 days/yr) |
| $F_{\text{chem_additive}}$ | = | Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive) |
| $V_{\text{container}}$ | = | Volume of transport container (Default: 55-gallons) |
| P_{additive} | = | Density of additive (kg/L additive; Default: 1 kg/L) |

4.0 ENVIRONMENTAL RELEASE ASSESSMENT

This section presents approaches for estimating environmental releases of chemical additives during mineral and metal ore flotation processes. The release sources are discussed in the order that they occur in the process (see Figure 2-1). The most likely media of release (i.e., air, water, landfill, or incineration) are also identified.

This quick-strike generic scenario conservatively assumes the entirety of flotation chemicals is released from ore processing and tailings disposal. In reality, certain chemicals (e.g. frothers, collectors, activators) may react or be altered in some form as they perform their intended functions. Therefore, actual releases of these chemical reagents are likely to be less than those estimated in this QSGS. Figure 4-1 depicts the areas of release and the associated release fractions that are discussed in Section 4.0.

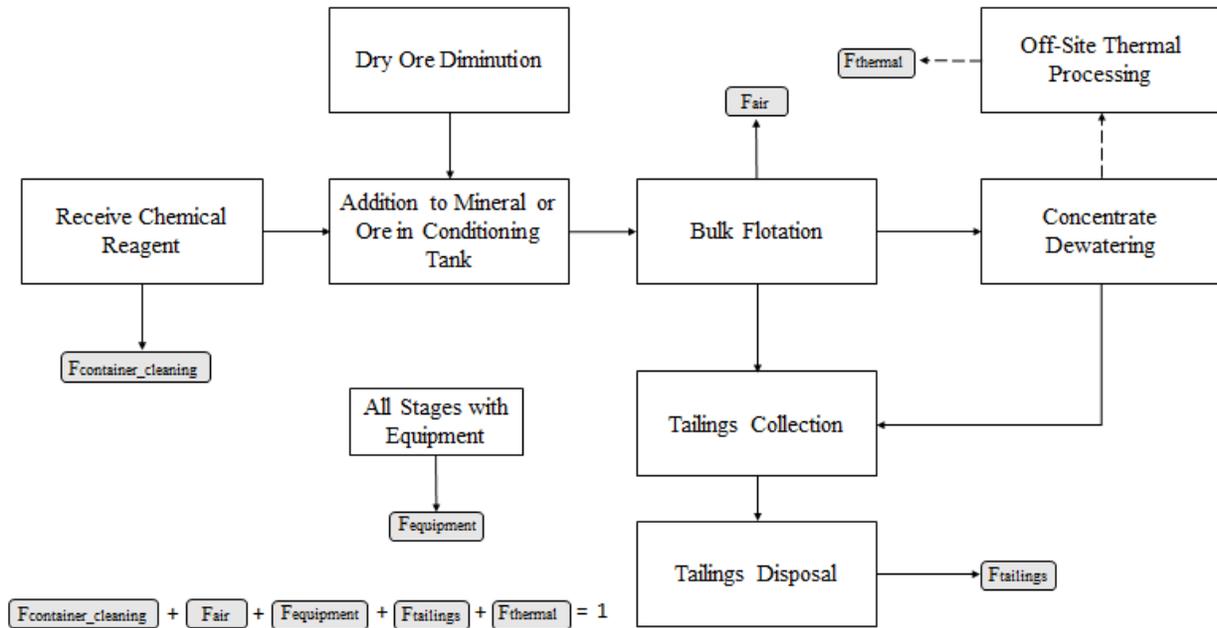


Figure 4-1. Releases Points During Mineral and Metal Ore Flotation

4.1 Introduction to Environmental Release Assessment

EPA generally assumes sites actively implement practices to minimize chemical losses during use; however, upstream releases may still occur. Because losses are assumed to be minimized, the release estimation methodologies presented herein do not include adjustments to account for upstream releases. For example, while it is reasonably expected that some residue remains in transport containers, equipment cleaning calculations are based on the entire container volume; they are not adjusted to account for residual losses from upstream container handling.

Such omissions, however, should not result in negative chemical throughputs. In other words, the amount of chemical released from the process should not exceed the amount that entered it.

Table 4-1 presents the release sources, the likely media of release, and the models used to estimate the release. Note that the standard model 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.

EPA has developed a software package, the Chemical Screening Tool for Exposures and Environmental Release (ChemSTEER), containing the standard models as well as all current EPA defaults.

Table 4-1. Summary of Environmental Releases and Models Used in the QSGS

| Release | Description | Model(s) | Standard EPA Model (✓) |
|---------|--|---|------------------------|
| 1 | Container residue losses on-site to uncertain media | Specific model used is based on the type and size of the containers, and on the physical state of the formulation: <ul style="list-style-type: none"> • EPA/OPPT Bulk Transport Residual Model • EPA/OPPT Drum Residual Model | ✓ |
| 2 | Flotation releases on-site to fugitive air | User-defined model | |
| 3 | Filter media disposal | Not quantified | |
| 4 | Equipment cleaning release on-site to uncertain media | EPA/OPPT Multiple Vessel Residual Model | ✓ |
| 5 | Thermal processing release off-site to incineration | User-defined model | |
| 6 | Tailings disposal on-site to surface water or land impoundments (i.e., pond or mine backfilling) | User-defined model | |

EPA – U.S. Environmental Protection Agency
OPPT – Office of Pollution Prevention and Toxics

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

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

Limited release data specific to ore flotation has been identified. Therefore, some of the environmental release estimates presented in this document are based on standard EPA release models.

4.2 Control Technologies

EPA identified limited information on specific control technologies utilized at mineral and metal ore flotation sites. Tailings ponds are frequently lined, to prevent leaching of chemical contaminants from the tailings into groundwater (EPA, 2016). In addition, once the solids in the tailings are settled, the separated water is frequently recycled for reuse at the site.

4.3 Release On-Site to Uncertain Media from Container Residue (Release 1)

The amount of chemical additive remaining in the transport container is dependent on the size of the transport container. Industry data indicates that mineral and metal ore flotation chemicals can be supplied in a variety of container sizes, typically ranging from 55-gallon drums to 900 kg IBC totes (Moly-Cop, 2017). The distribution of container type and sizes is not known, but EPA recommends assuming chemicals are supplied in 55-gallon drums where information is not available.

It is generally expected that industry makes an effort to minimize container residuals prior to container cleaning or disposal. Information from product safety datasheets on flotation reagents indicate that containers should be emptied prior to disposal, and that unused product should not be disposed of in sewers or other mechanisms leading to waterways (Chevron Phillips, 2011). However, no information was found on the extent of these practices within the mining chemicals use industry. In lieu of additional industry-specific information, EPA conservatively assumes that container residue release is to uncertain media, which includes water, incineration, or landfill. This release likely occurs on-site but could potentially occur off-site if the customer sends the empty containers back to the vendor for cleaning and reuse.

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

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

EPA/OPPT Drum Residual Model may be used for drums containing between 20 and 100 gallons of liquid (default).

The release estimates are based on the current version of the models. Standard EPA/OPPT models are subject to change; therefore, the current version of the standard EPA/OPPT model should be used.

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

$$\begin{aligned}
E_{local_container_residue} &= V_{container} \times \rho_{additive} \times F_{chem_additive} \times F_{container_residue} \\
&\times N_{container_unload_site_day} \times 3.785 \frac{L}{gal}
\end{aligned}
\tag{4-1}$$

The release will occur over $[N_{container_unload_site_yr}]$ from $[N_{sites}]$ sites.

Where:

| | | |
|--------------------------------------|---|--|
| $E_{local_container_residue}$ | = | Daily release of chemical of interest from container residue (kg chemical/site-day) |
| $V_{container}$ | = | Volume of transport container (Default: 55-gallons) |
| $\rho_{additive}$ | = | Density of additive (kg/L additive; Default: 1 kg/L) |
| $F_{chem_additive}$ | = | Mass fraction of chemical of interest within the additive (kg chemical/kg additive) (Default: 1 kg chemical/kg additive) |
| $F_{container_residue}$ | = | Fraction remaining in containers as residue (Default: 0.03 kg container residue/kg additive supplied in drums) |
| $N_{container_unload_site_day}^4$ | = | Number of transport containers unloaded daily at each site (container/site-day) |

If the number of containers used per site per year ($N_{container_unload_site_yr}$) is greater than the days of operation, the days of release equal the days of operation, and the average daily release is calculated based on the following equation:

$$E_{local_container_residue} = Q_{chem_site_day} \times F_{container_residue} \tag{4-2}$$

The release will occur over $[TIME_{operating_days}]$ from $[N_{sites}]$ sites.

Where:

| | | |
|---------------------------------|---|---|
| $E_{local_container_residue}$ | = | Daily release of chemical of interest from container residue (kg chemical/site-day) |
|---------------------------------|---|---|

⁴ The daily number of containers unloaded per site may be estimated as:

$$N_{container_unload_site_day} = \frac{N_{container_unload_site_yr}}{TIME_{operating_days}}$$

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

Where:

| | | |
|-----------------------------------|---|---|
| $N_{container_unload_site_yr}$ | = | Number of transport containers unloaded annually at each site (container/site-yr) |
| $TIME_{operating_days}$ | = | Annual operating days at processing sites (day/yr) |

| | | |
|---------------------------------|---|--|
| $Q_{\text{chem_site_day}}$ | = | Daily use rate of chemical of interest (kg chemical/site-day) |
| $F_{\text{container_residue}}$ | = | Fraction remaining in containers as residue (Default: 0.03 kg container residue/kg additive supplied in drums) |

4.4 Release On-Site to Fugitive Air from Flotation Process (Release 2)

Aerosol emissions during flotation may occur due to agitation of the surface of the slurry from bubbles and bubble bursting; however, the emission rate is expected to be low because frothers are used to provide stability to the flotation froths (i.e., prevent excess bubble bursting). Nonetheless, chemical reagents present in the froth are released to fugitive air from the open froth flotation via aerosols in small quantities (SRI, 1983). Among the chemicals in the froth phase that may become airborne are frothers, collector chemicals, sulfidizers, and activators. Depressants, pH regulators, or other additive types used to modify the bulk slurry generally remain in the slurry and do not partition to the froth where they can become airborne.

In lieu of industry information, air emissions from flotation should be estimated using the following emission factors from SRI International's *Profile for Release and Exposure for Chemicals Used in Processing Ores and Minerals* (SRI, 1983). EPA recommends the defaults as the maximum potential airborne emission rates [$E_{\text{chem_air}}$]:

- Frothers:
 $E_{\text{additive_air}} = 3.2 \times 10^{-5}$ kg additive emitted to air/ton of ore processed
- Collectors, Sulfidizers, and Activators (default for unknown chemical additive type):
 $E_{\text{additive_air}} = 1.8 \times 10^{-5}$ kg additive to air/ton of ore processed

Thus, the daily amount of chemical reagent released to air during flotation can be estimated with the following equation:

$$E_{\text{local_air}} = \frac{Q_{\text{process_site_yr}}}{\text{TIME}_{\text{operating_days}}} \times E_{\text{additive_air}} \times F_{\text{chem_additive}} \quad (4-3)$$

The release will occur over [$\text{TIME}_{\text{operating_days}}$] from [N_{sites}] sites.

Where:

| | | |
|--------------------------------|---|--|
| $E_{\text{local_air}}$ | = | Daily release of chemical of interest from airborne emissions (kg chemical/site-day) |
| $Q_{\text{process_site_yr}}$ | = | Annual process rate of minerals and ore commodity (ton dry ore processed/site-yr) |
| $E_{\text{additive_air}}$ | = | Emission rate to air of additive (Default: 1.8×10^{-5} kg additive emitted to air/ton of ore processed) |

$F_{chem_additive}$ = Mass fraction of chemical of interest within the additive
(Default: 1 kg chemical/kg additive; See Section 3.7)

Thus, the fraction of the chemical of interest released to air based on the daily use rate can be calculated as:

$$F_{air} = \frac{E_{local_{air}}}{Q_{chem_site_day}} \quad (4-4)$$

Where:

F_{air} = Fraction of chemical of interest that is released to air during flotation (kg chemical emitted to air/kg chemical used)
 $E_{local_{air}}$ = Daily release of chemical of interest from airborne emissions (kg chemical/site-day)
 $Q_{chem_site_day}$ = Daily use rate of chemical of interest (kg chemical/site-day)

4.5 Release from Concentrate Thickener Filter Media Disposal (Release 3)

The skimmed froth and mineral or ore particles from the top of the flotation cell is called the concentrate. The concentrate typically contains approximately 20 to 30% solids, thus is customarily sent through thickening and filtration processes to remove excess water before being sent off-site for thermal processing (Michaud, 2016b). The thickening process is a physical separation process that results in the recovery of about 70 to 80% of the water in the concentrate solutions. Following thickening, the concentrate is sent through a vacuum filtration process, which further removes water, resulting in a concentration of approximately 10% water.

The filter, which is generally a disc filter or rotary drum filter, is equipped with a cloth filter media through which water passes, thus separating it from the solids containing the mineral or metal ore of interest (Michaud, 2016c). These filter cloths are cleaned and maintained to retain effectiveness. Some practices for cleaning involve rinsing the filter cloth with water at the end of each use, before shutdown, or blowing air through the cloth to dislodge particles after the solid cake is removed. Water from the filter is recycled and the dislodged particles become mixed with the other dewatered concentrate. The cloth is not expected to be replaced frequently, with information indicating that it may be replaced approximately twice per year (Michaud, 2016c). Thus, any release of chemical reagents would come from the disposal of the filter media with particulates that were not dislodged, to which chemical reagents are adsorbed. This release is expected to be minimal and, with lack of specific industry information to quantify this release, RAD assumes release from this source is accounted for in the equipment cleaning release (Release 4).

4.6 Release On-Site to Uncertain Media from Equipment Cleaning (Release 4)

EPA found little information on industry practice for cleaning equipment used in the flotation process. Information regarding thickening and filtering equipment indicate a

semiannual release from cleaning practices (Michaud, 2016c). Based on this information and because flotation equipment is typically dedicated, EPA recommends assuming cleaning occurs twice per year. The *EPA/OPPT Multiple Vessel Residual Model* is recommended. The model assumes that no more than two percent of the batch size or capacity of the process remains in the equipment as residue that is released as equipment cleaning waste. The multiple vessel model is recommended as the default because equipment may include conditioning tanks, flotation cells, and dewatering equipment. No industry-specific information on the likely media of release was found; therefore, EPA conservatively assumes that equipment cleaning release is to uncertain media, which includes water, incineration, or landfill.

The semiannual release of chemical residue in the process equipment is calculated using the following equation:

$$E_{local_equipment_cleaning} = Q_{chem_site_day} \times F_{equipment_cleaning} \quad (4-5)$$

The release will occur over two days per year from [N_{sites}] sites.

Where:

| | | |
|----------------------------------|---|--|
| $E_{local_equipment_cleaning}$ | = | Daily release of chemical of interest from equipment cleaning (kg chemical/site-day) |
| $Q_{chem_site_day}$ | = | Daily use rate of chemical of interest (kg chemical/site-day) |
| $F_{equipment_cleaning}$ | = | Fraction remaining in equipment as residue (Default: 0.02 kg released/kg chemical) |

Note that mineral and metal ore flotation is a continuous process, not a batch process. Due to this, equipment cleaning release is assessed based on the daily use rate as opposed to the batch size, which is highly variable between sites.

Thus, the fraction of the chemical of interest released to air based on the daily use rate can be calculated as:

$$F_{equipment} = F_{equipment_cleaning} \times \frac{2 \frac{release\ days}{year}}{TIME_{operating_days}} \quad (4-6)$$

Where:

| | | |
|---------------------------|---|---|
| $F_{equipment}$ | = | Fraction of chemical of interest that is released from equipment cleaning, on a daily basis (kg chemical released/kg chemical used) |
| $F_{equipment_cleaning}$ | = | Fraction remaining in equipment as residue (Default: 0.02 kg released/kg holding capacity) |
| $TIME_{operating_days}$ | = | Number of operating days (Default: 255 days/yr) |

4.7 Release Off-Site to Incineration from Thermal Processing (Release 5)

During flotation, chemical additives will partition either to the bulk water phase with the tailings or to the froth phase with the higher concentration commodity concentrate, depending on their physical and chemical properties. Those chemical reagents that partition to the froth phase ultimately are removed with concentrate, that is subsequently dewatered and sent off-site for thermal processing as described below. Those chemical reagents that partition to the tailings are ultimately sent to tailings disposal, where undesired solids, or gangue, are settled in tailings ponds. The water from which solids are settled, which may contain a portion of the chemical reagents is typically recycled to the extent possible, entrained in the tailings ponds, or released to surface waters.

4.7.1 Chemical Reagent Partitioning Estimation

Due to the complex physical and chemisorption processes that occur in froth flotation, little is known definitively about the partitioning of chemical reagents. Additionally, the flotation process is expected to differ somewhat between types of ores being processed. However, the partitioning of chemical reagents is estimated in this section utilizing general knowledge and assumptions applicable to all types of flotation.

Collector chemicals are expected to partition largely to the froth phase, due to their function of imparting hydrophobicity to the solid ores that are captured by bubbles. Activators and sulfidizers serve similar functions as collectors and have a similar fate. Research indicates that collectors do not completely end up with the concentrate, but the exact partitioning is not quantified (Morris et al, 2012). To quantify partitioning, EPA assumes that all of the collector, activator, and sulfidizer chemicals adhere to ores, as is their function. Additionally, EPA recommends utilizing the recovery rate of the commodity from the ore F_{recovery} (see Section 3.5), with a default recovery rate of 80%, as a mid-line estimate when concerns are for both environmental releases and occupational exposures. The remaining 20% of unrecovered ores ends up with the gangue material. Based on these assumptions, 80% of the collectors, activators, and sulfidizers added to the flotation slurry are processed with the concentrate and incinerated, while 20% are sent to tailings disposal where they settle in tailings ponds.

Depressants act in a similar manner, but serve the opposite function, to prevent the flotation of undesired solids. Due to this functionality, EPA conservatively recommends assuming that 100% of the depressant partitions to the slurry and is disposed of with the tailings. This assumption is founded on the principal that the solids are already likely to sink to the bottom of the flotation cells, especially with the addition of depressants to aid in the sinking. Note that EPA conservatively recommends assuming the functionality of a depressant for unknown chemical additive function (See Section 3.8).

The fate of frothers is dependent on the type of frother, as well as the operating conditions of the flotation cell. In general, frothers are expected to largely partition to the froth phase, as their function is to reduce surface tension and stabilize the froth (Zhang et al, 2010). This observation is especially relevant with low dosages of frother in the slurry. However, most flotation cells operate such that the concentration of frother in the flotation cell is maintained to ensure that the frother demand is met and that the developed froth remains stable. Therefore,

frother is not expected to completely partition to the froth phase (Morris et al, 2012). Additionally, frothers do not adhere to the solids in the concentrate, thus their ultimate fate is not incineration with the concentrate ores. Research indicates that, due to these principals, only 5-10% of the added frother is removed with the concentrate (incinerated), while the remainder stays in the tailings and recycled water (Tsatouhas et al, 2006). EPA conservatively recommends assuming 5% of the frother ends up with the concentrate and 95% with the tailings.

A summary of the partitioning fractions that EPA recommends are listed in Table 4-2. The fraction that ends up with the concentrate for thermal processing is denoted as $F_{\text{concentrate}}$ and the fraction that ends up with the tailings is F_{tailings} . Note that pH regulators are expected to be consumed in froth and, therefore do not partition to the concentrate or tailings in significant amounts.

Table 4-2. Overview of Partitioning Fractions for Each Additive Type

| Additive Types | Functions | Fraction with Concentrate ($F_{\text{concentrate}}$) | Fraction with Tailings (F_{tailings}) |
|---------------------------|---|--|--|
| Flotation Aids/Collectors | Impart hydrophobicity to the solid to be floated | F_{recovery} (Default: 0.8) ^a | 1 - F_{recovery} (default: 0.2) |
| Flotation Sulfidizers | Precipitate a film of sulfide on the surface of minerals/ores to make them more responsive to collector chemicals | | |
| Activator | Aids in flotation of previously depressed minerals or those that do not respond to collector chemicals | | |
| Frother | Lowers surface tension of slurry to allow air bubbles to accumulate at the surface | 0.05 ^b | 0.95 |
| Depressant | Inhibits the flotation of undesired minerals to prevent interference with flotation of the desired mineral/ore | 0 (Default) ^c | 1 (Default) |
| pH regulator | Modify pH of the slurry to optimize flotation | <i>N/A – consumed</i> | |

a – See Section 3.5. This default is for assessment concerns for both environmental releases and occupational exposures.

b – Source: Tsatouhas et al, 2006.

c – Based on the assumption that all undesired solids sink to the tailings.

4.7.2 Thermal Processing Description

Once partitioned to the froth phase, chemical reagents in the concentrate, which are adsorbed to ore containing the commodity of interest, undergo further process stages to purify the commodity. The concentrate is first dewatered on-site before it is sent off-site for metallurgical processing for metal ores or, similarly, thermal processing for mineral ores. Metallurgical processing can involve thermal processes, aqueous processes such as leaching, or processes involving electricity (Duby, 2005). Thermal processes, for both mineral and metal ores, involve the use of heat to refine the ore into a purer state.

The dewatered concentrate is generally first thermally dried to evaporate free water and decompose hydrate and carbonate impurities. Most nonferrous metals are mined and extracted from sulfide-containing ores. These sulfide ores, which are the most common type of

ores to undergo flotation processes, are typically burnt in air, or roasted, to transform metals from metal sulfides to metal oxides. The roasting process releases sulfur as sulfur dioxide and occurs at temperatures ranging from 650°C to 1000 °C (Duby, 2005). Alternative to roasting is chlorination, in which oxide ore concentrates are reacted with chlorine gas at temperatures between 800 and 900 °C to produce metal chlorides. The chlorination process is useful in particular for titanium and zirconium. Since most chemical reagents used in the flotation process that may be adsorbed to the ore concentrate are organic, they are expected to be thermally degraded during the drying and roasting or chlorination processes.

Metal commodities with moderate melting points and low vapor pressure are usually further reduced to a liquid state through smelting, in which the molten metal separate from solid residues and other liquified impurities of different densities (Duby, 2005). Smelting of iron slag typically occurs at temperatures around 1300 to 1500 °C. The operating temperature for the reduction of other nonferrous metals is dependent on the melting point of the metal. Smelting for copper reduction occurs at temperatures around 1150-1250 °C, while processes for reduction of other nonferrous metals is typically below that temperature. Reduction of metals to liquid or gaseous form (as is practice for zinc) with higher temperatures is not feasible. Steelmaking generally has the most intensive thermal requirement, with temperatures up to around 1600 °C (Duby, 2005).

4.7.3 Estimate of Thermal Processing Release to Off-Site Incineration

Utilizing the partition fractions in Table 4-2, the daily amount of chemical reagent released to incineration from thermal processing of the concentrate is can be estimated with the following equation:

$$E_{local_{thermal}} = Q_{chem_site_day} \times (1 - F_{container_residue}) \times (1 - F_{air}) \times (1 - F_{equipment}) \times F_{concentrate} \quad (4-7)$$

The release will occur over [TIME_{operating_days}] from [N_{sites}] sites.

Where:

| | | |
|--------------------------|---|---|
| $E_{local_{thermal}}$ | = | Daily release of chemical of interest from thermal processing (kg chemical/site-day) |
| $Q_{chem_site_day}$ | = | Daily use rate of chemical of interest (kg chemical/site-day) |
| $F_{container_residue}$ | = | Fraction remaining in containers as residue (Default: 0.03 kg container residue/kg additive supplied in drums) |
| F_{air} | = | Fraction of chemical of interest that is released to air during flotation (kg chemical emitted to air/kg chemical used) |
| $F_{equipment}$ | = | Fraction of chemical of interest that is released from equipment cleaning, on a daily basis (kg chemical released/kg chemical used) |

$F_{concentrate}$ = Fraction of chemical reagent that partitions to the concentrate (Default for depressants: 0 kg chemical/kg added to slurry)

4.8 Release On-Site from Tailings Disposal to Surface Water or Land Impoundments (i.e., pond or mine backfilling) (Release 6)

Any chemical additives that partition to the pulp will ultimately end up with the tailings and water that is disposed of in tailings ponds. After flotation, the tailings may undergo some form of initial dewatering. The resulting water is likely to be recycled back to the flotation cells for reuse (Bleiwas, 2012). Note that, while not all of the water in the flotation cells that may contain chemical reagents is discharged to tailings ponds with gangue material, some amount of water is entrained in the tailings and released with the tailings disposal. It is expected that this is the ultimate fate of all water, and associated chemical reagents, otherwise these reagents would build up in the flotation cell and render it less effective. It is therefore assumed that the flotation cell is operated at steady-state and that there is no build-up of chemical reagents. This release thus accounts for remaining chemical reagent after Releases 1 through 5.

The water that is sent with the tailings for disposal is recycled to the extent possible, but may be released through evaporation, entrainment in impounded tailings, seepage into the ground, and discharge to surface waters (Bleiwas, 2012). The solid gangue material in the tailings is released to land from impoundment in tailings ponds and potentially mine backfilling. The fate of chemical reagents in the water and tailings is not completely known, however it is expected that the majority of the reagents are either entrained in the tailings (i.e., land disposal) or discharged to surface waters with wastewater. Because the amount released between tailings and discharged water is unknown, EPA recommends assessing this release to land or water.

This release can be estimated with the following equation, utilizing the partition fractions in Table 4-2:

$$E_{local,tailings} = Q_{chem_site_day} \times (1 - F_{container_residue}) \times (1 - F_{air}) \times (1 - F_{equipment}) \times F_{tailings} \tag{4-8}$$

The release will occur over [TIME_{operating_days}] from [N_{sites}] sites.

Where:

$E_{local,tailings}$ = Daily release of chemical of interest from tailings disposal (kg chemical/site-day)
 $Q_{chem_site_day}$ = Daily use rate of chemical of interest (kg chemical/site-day)
 $F_{container_residue}$ = Fraction remaining in containers as residue (Default: 0.03 kg container residue/kg additive supplied in drums)
 F_{air} = Fraction of chemical of interest that is released to air during flotation (kg chemical emitted to air/kg chemical used)

$F_{\text{equipment}}$ = Fraction of chemical of interest that is released from equipment cleaning, on a daily basis (kg chemical released/kg chemical used)

F_{tailings} = Fraction of chemical reagent that partitions to the tailings (Default for depressants: 1 kg chemical/kg added to slurry)

5.0 OCCUPATIONAL EXPOSURES

This section presents approaches for estimating worker exposures to chemical reagents used in the flotation process. This scenario only considers occupational inhalation exposure during flotation of mineral and metal ores and does not consider other potential sources of occupational exposures, such as during chemical transfers. Figure 2-1 illustrates the occupational inhalation exposure during flotation that is discussed in this section.

Table 5-1 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 5-1. Summary of Exposure Models Used in the QSGS

| Exposure Activity | Description | Route of Exposure and Physical Form | Model Name ^a | Standard EPA Model (✓) |
|-------------------|---|-------------------------------------|--------------------------------------|------------------------|
| A | Exposure during mineral and metal ore flotation | Inhalation of aerosols / mists | <i>User-defined inhalation model</i> | |

5.1 Number of Workers Exposed per Site

MSHA collects data on employment for mineral and metal ore mines. MSHA employment statistics are available for the year 2015 for operational employees, which excludes office workers. This data is summarized in Table 5-2. Note that this data cannot be further broken down by the types of processes (e.g., crushing, milling, flotation) conducted at each site.

Table 5-2. Number of Workers at Mining Sites ^a

| Ore Type | Number of Establishments | Number of Operation Employees | Operation Employees per Site ^b |
|--------------|--------------------------|-------------------------------|---|
| Metal Ore | 315 | 41,459 | 132 |
| Mineral Ore | 924 | 26,089 | 28 |
| <i>Total</i> | <i>1,239</i> | <i>67,548</i> | <i>55</i> |

a – (NIOSH, 2015)

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

5.2 Exposure during Mineral and Metal Ore Flotation (Exposure A)

The process of flotation occurs in a flotation cell that is open to the environment (see Figure 5-1). Occupational inhalation exposure is possible from migration of airborne chemical reagents from the bulk slurry into the air in the form of aerosols (SRI, 1983). Workers are not expected to be directly above the flotation cell, where the concentrations of aerosols are the highest. However, workers may be in proximity to the flotation cell where inhalation exposure to aerosols may occur.

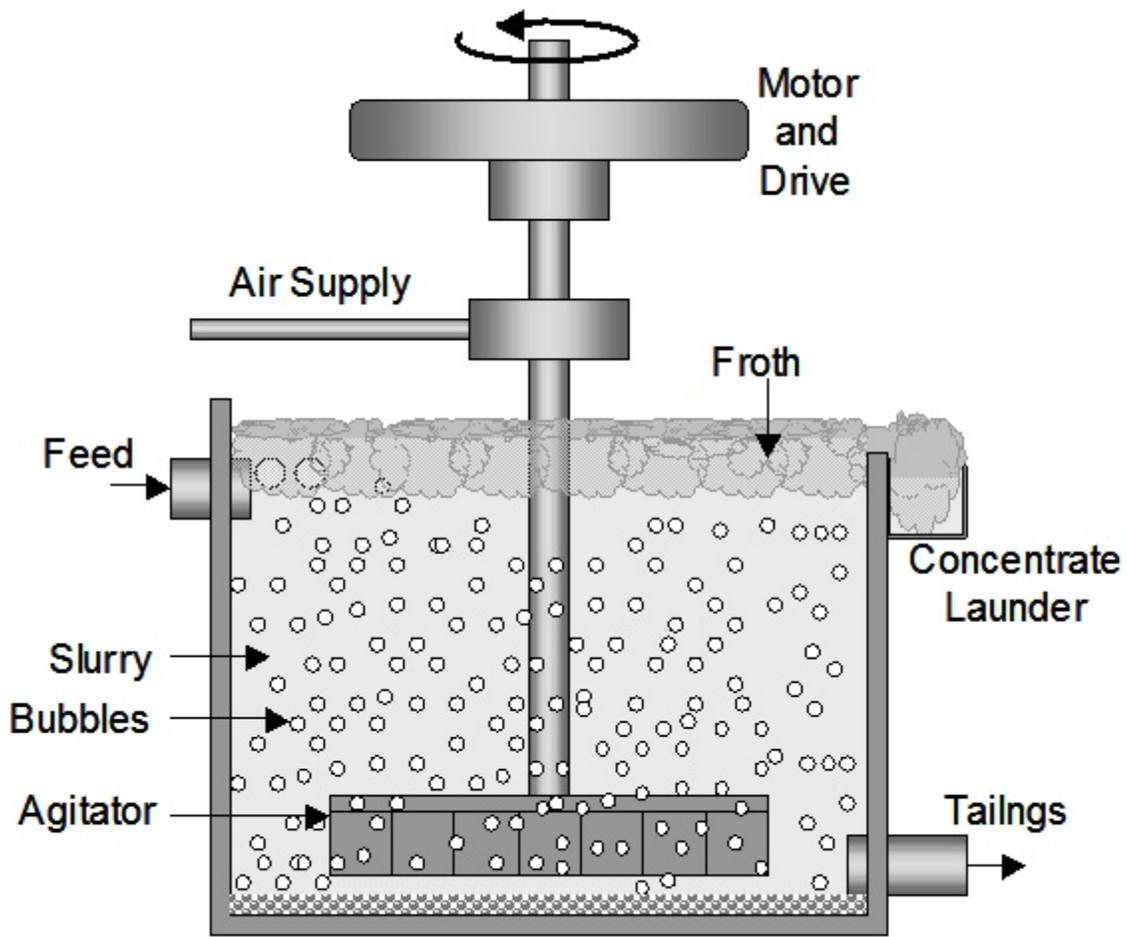


Figure 5-1. Diagram of Flotation Cell (Source: Grewal, 2017)

MSHA collects and houses various data on the mining industry, including personal breathing zone (PBZ) air samples from the year 2000 through 2016 (MSHA, 2016). This dataset is organized both by site location and worker job description. The relevant location and job function for this exposure estimate are classified as “M – Flotation & Reagent Areas” and “Pump, Slurry Mix Operator,” respectively. While these data are for individual chemicals, the functionality of the chemicals with respect to flotation is not classified in the dataset.

In addition to samples for specific chemical substances, the MSHA dataset contains PBZ data for slurry operators for respirable particulates not otherwise regulated (PNOR). In the dataset, these samples are listed as respirable nuisance dust and unlisted particles, which are classified as PNOR per 29 CFR 1900.1000. Respirable dust is quantified as particles that are less than 10 microns in diameter, as opposed to total dust which is not selective based on particle size. These samples are likely to be representative of aerosol exposure; thus, where no data exists for chemicals listed in Table 1-1, the concentrations for PNOR should be used as default.

The PBZ data for slurry mix operators are presented in Table 5-3 below, categorized by chemical function. These samples are all full-shift PBZ samples.

Table 5-3. PBZ Sample Results for Slurry Operators in Flotation Areas, 2000 – 2016 ^a

| Chemical Function | Chemical Additives in Dataset | Concentration ^b (mg/m ³) | Output 1 Concentration [C _{additive}] (mg/m ³) | Output 2 Concentration [C _{additive}] (mg/m ³) |
|--|-------------------------------|---|--|--|
| Frother, surfactant | Oil mist | 0.18 | 0.18 (Low-end) | 0.27 (high-end) |
| | | 0.27 | | |
| Flotation Aids/Collectors, Flotation Sulfidizers, Activators | PNOR, Respirable | 0.13 | 0.47 (central tendency) | 1.57 (90 th percentile) ^c |
| | | 22.79 | | |
| | | 0.52 | | |
| | | 1.6 | | |
| | | 0.5 | | |
| | | 0.36 | | |
| | | 0.44 | | |
| | | 0.16 | | |
| | | 0.55 | | |
| | | 0.2 | | |
| | | 1.33 | | |
| | | 0.42 | | |
| pH regulator | Ammonia | 1 | 0 | 0 |
| Depressant | Sulfur dioxide | 1 | 0 | 0 |

a – Source: MSHA, 2016

b – Samples are listed as full-shift in the dataset; however, sample times are not provided in the dataset.

c – The 90th percentile value was calculated using Excel’s “percentile.inc” function, as opposed to the “percentile.exc” function, because the “percentile.inc” function result is more representative of the dataset.

As evident in Table 5-3, depressants and pH regulators are not expected to present potential inhalation exposure. This is because these chemicals are typically present in the bulk slurry and do not partition in significant amounts to the froth, or surface of the slurry, where they can become airborne in aerosols (SRI, 1983). Thus, worker inhalation exposures to depressants and pH regulators is assumed to be negligible.

Flotation aids/collectors, frothers, sulfidizers, and activators are expected to partition to the froth phase, where they can be released to air in aerosol form (SRI, 1983). The MSHA dataset includes data points for oil mists, which can be classified as frothers according to Table 1-1. Thus, for frothers, EPA recommends assuming the low-end and high-end concentrations [C_{chem}] as presented in Table 5-3 for Equation 5-1.

The MSHA dataset does not specifically list the flotation aids/collectors, sulfidizers, or activator chemicals listed in Table 1-1. However, since these chemicals are largely present in the froth phase, they are expected to present potential worker inhalation exposure. In lieu of chemical-specific data, EPA recommends using the central tendency and 90th percentile concentrations [C_{chem}] for PNOR as the default exposure concentrations in Equation 5-1.

Specific information on the length of time the slurry operator is expected to run the froth flotation cells was not found. EPA recommends assuming workers are exposed for the entire duration of the work shift, or 8 hours per day.

Note that the weight fraction of the chemical of interest in the fluid at the surface of the flotation tank is assumed equal to the weight fraction of the chemical of interest in the mist (particulate). In addition, because little information was found regarding the composition of the fluid at the surface of the flotation tank or the composition of the aerosol, it is assumed that the fluid and aerosol composition are equal to that of the chemical additive; thus, the fraction of the chemical of interest in the samples is assumed to be equal to the fraction of the chemical of interest in the chemical additive ($F_{chem_additive}$).

To estimate the potential worker inhalation exposure to the chemical during flotation, EPA recommends using the following equation:

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

The exposure will occur over $[TIME_{operating_days}]$.

Where:

| | | |
|----------------------|---|---|
| $EXP_{inhalation}$ | = | Inhalation potential dose rate of chemical during flotation (mg chemical/day) |
| $C_{additive}$ | = | Mass concentration of additive in air (mg additive/m ³ of air; Defaults in Table 5-3) |
| $TIME_{exposure}$ | = | Duration of exposure to the chemical during flotation (Default: 8 hours/day) |
| $RATE_{breathing}$ | = | Inhalation rate (CEB default: 1.25 m ³ /hr) (U.S. EPA, 1991) |
| $F_{chem_additive}$ | = | Mass fraction of chemical of interest within the additive (Default: 1 kg chemical/kg additive; See Section 3.7) |

6.0 SAMPLE CALCULATIONS

This section presents an example of how the equations introduced in Sections 3.0 through 5.0 can be used to estimate releases and flotation inhalation exposure chemical reagents used in mineral and metal ore flotation. The default values used in these calculations, as presented in Sections 3.0 through 5.0, 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 ($Q_{\text{chem_yr}}$) is *100,000 kg chemical/yr*,
2. The chemical of interest is used as a collector chemical,
3. The type of ore being processed is unknown,
4. Flotation occurs at an unknown number of mining sites.

The chemical assessment concerns are for both environmental releases and occupational exposures.

6.1 General Facility Estimates

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

If specific information is not available, assume Days of Operation ($\text{TIME}_{\text{operating_days}}$) of 255 days/year, which is the default if the type of ore being processed is unknown.

6.1.2 Annual Commodity Production Rates ($Q_{\text{commodity_site_yr}}$)

The annual production rate of the ore of interest (commodity) produced per site is assumed to be 82,723 tons of commodity recovered/site-yr, which is the value from Table 3-3 for unknown commodities and concerns for both releases and exposures.

6.1.3 Fraction of Commodity in Mineral or Ore ($F_{\text{commodity_ore}}$)

The fraction of commodity within the mined mineral or metal ore can be determined from the values in Table 3-4. Since specific industry information is unavailable, and concerns are for both releases and exposures the mid-line default fraction is assumed to be 0.1 tons commodity processed/ton dry ore processed.

6.1.4 Fraction of Commodity Recovered from Ore (F_{recovery})

Since specific industry information is unavailable, and concerns are for both releases and exposures the mid-line default fraction is assumed to be 80% tons of commodity recovered per ton of commodity that is processed.

6.1.5 Annual Commodity Processing Rates ($Q_{\text{process_site_yr}}$)

The amount of commodity – containing ore that is processed to achieve the final commodity is calculated with the following equation:

$$Q_{\text{process_site_yr}} = \frac{Q_{\text{commodity_site_yr}}}{F_{\text{commodity_ore}} \times F_{\text{recovery}}}$$
$$Q_{\text{process_site_yr}} = \frac{82,723 \frac{\text{tons commodity recovered}}{\text{site - yr}}}{0.1 \frac{\text{ton commodity processed}}{\text{ton dry ore}} \times 0.8 \frac{\text{ton commodity recovered}}{\text{ton commodity processed}}}$$
$$Q_{\text{process_site_yr}} = 1,034,038 \frac{\text{tons dry ore}}{\text{site - yr}}$$

6.1.6 Mass Fraction of Chemical of Interest within the Additive ($F_{\text{chem_additive}}$)

The fraction of the chemical of interest in the additive that is blended into the mineral or ore slurry is assumed to be 1 kg chemical/kg additive.

6.1.7 Use Rate of Additive per Ton of Dry Ore (Q_{additive})

The use rate of additive based on the dry weight of the ore being processed is determined using Table 1-1. For collector chemicals, the use rate is 0.91 kg additive/ton dry ore.

6.1.8 Use Rate of Chemical of Interest per Ton Dry Ore ($Q_{\text{chem_slurry}}$)

The use rate of the chemical of interest within the mineral or metal ore slurry can be calculated with the following equation:

$$Q_{\text{chem}} = F_{\text{chem_additive}} \times Q_{\text{additive}}$$
$$Q_{\text{chem}} = 1 \frac{\text{kg chemical}}{\text{kg additive}} \times 0.91 \frac{\text{kg additive}}{\text{ton dry ore}}$$

$$Q_{chem} = 0.91 \frac{kg \text{ chemical}}{ton \text{ dry ore}}$$

6.1.9 Annual Use Rate of Chemical of Interest ($Q_{chem_site_yr}$)

The annual use rate of the chemical of interest can be calculated with the following equation:

$$Q_{chem_site_yr} = Q_{process_site_yr} \times Q_{chem_slurry}$$

$$Q_{chem_site_yr} = 1,034,038 \frac{tons \text{ ore}}{site - yr} \times 0.91 \frac{kg \text{ chemical}}{ton \text{ ore}}$$

$$Q_{chem_site_yr} = 940,975 \frac{kg \text{ chemical}}{site - yr}$$

6.1.10 Daily Use Rate of Chemical of Interest ($Q_{chem_site_day}$)

The daily use rate of the chemical of interest can be calculated with the following equation:

$$Q_{chem_site_day} = \frac{Q_{chem_site_yr}}{TIME_{operating_days}}$$

$$Q_{chem_site_day} = \frac{940,975 \frac{kg \text{ chemical}}{site - yr}}{255 \frac{days}{yr}}$$

$$Q_{chem_site_day} = 3,690 \frac{kg \text{ chemical}}{site - day}$$

6.1.11 Number of Sites (N_{sites})

The following equation can be used to calculate the number of sites using the chemical of interest:

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

$$N_{sites} = \frac{100,000 \frac{kg \text{ chemical}}{yr}}{3,690 \frac{kg \text{ chemical}}{site - day} \times 255 \frac{days}{yr}}$$

$$N_{sites} = 0.1 \text{ site}$$

$$N_{sites} = 1 \text{ site}$$

Because it was necessary to round to 1 site, the daily use rate of chemical of interest [$Q_{chem_site_day}$] should be recalculated to avoid rounding errors:

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

$$Q_{chem_site_day} = \frac{100,000 \frac{kg \text{ chemical}}{yr}}{1 \text{ site} \times 255 \frac{days}{yr}}$$

$$Q_{chem_site_day} = 392.15 \frac{kg \text{ chemical}}{site - day}$$

Because it was necessary to round to 1 site, the processing rate of ore [$Q_{process_site_yr}$] should be recalculated to avoid rounding errors:

$$Q_{process_site_yr} = \frac{Q_{chem_site_day} \times TIME_{operating_days}}{Q_{chem_slurry}}$$

$$Q_{process_site_yr} = \frac{392.15 \frac{kg \text{ chemical}}{site - day} \times 255 \frac{days}{yr}}{0.91 \frac{kg \text{ chemical}}{ton \text{ dry ore}}}$$

$$Q_{process_site_yr} = 109,900 \frac{ton \text{ ore}}{site - yr}$$

6.1.12 Number of Transport Containers Unloaded per Site ($N_{containers_unload_site_yr}$)

Assuming the default transport container size of 55-gallon drums, the number of transport containers unloaded annually per site can be estimated based on the daily use rate, container size, and the fraction of chemical in the formulation.

$$N_{\text{containers_unload_site_yr}} = \frac{Q_{\text{chem_site_day}} \times TIME_{\text{operating_days}}}{F_{\text{chem_additive}} \times V_{\text{container}} \times \rho_{\text{additive}} \times 3.785 \frac{L}{gal}}$$

$$N_{\text{containers_unload_site_yr}} = \frac{392.15 \frac{kg \text{ chemical}}{\text{site} - \text{day}} \times 255 \frac{\text{days}}{\text{yr}}}{1 \frac{kg \text{ chemical}}{kg \text{ additive}} \times 55 \text{ gal} \times 1 \frac{kg}{L} \text{ additive} \times 3.785 \frac{L}{gal}}$$

$$N_{\text{containers_unload_site_yr}} = 480 \frac{\text{containers}}{\text{site} - \text{yr}}$$

6.2 Environmental Releases

6.2.1 **Release to Water, Incineration, or Landfill from Container Residue (Release 1)**

Assuming a default container size of 55-gallon drums, this release is estimated using the *EPA/OPPT Drum Residual Model*. Since the number of containers used per site per year ($N_{\text{container_unload_site_yr}}$) is greater than the days of operation, the days of release equal the days of operation, and the average daily release is calculated as follows:

$$E_{\text{local_container_residue}} = Q_{\text{chem_site_day}} \times F_{\text{container_residue}}$$

$$E_{\text{local_container_residue}} = 392.15 \frac{kg \text{ chemical}}{\text{site} - \text{day}} \times 0.03 \frac{kg \text{ container residue}}{kg \text{ additive supplied in drums}}$$

$$E_{\text{local_container_residue}} = 11.76 \frac{kg \text{ chemical}}{\text{site} - \text{day}}$$

The release will occur over 255 days/year from 1 site.

6.2.2 **Release to Air from Flotation Process (Release 2)**

Aerosol emissions during flotation can be estimated using the airborne emission rate [$E_{\text{additive_air}}$] for collector chemicals, $E_{\text{additive_air}} = 1.8 \times 10^{-5}$ kg emitted additive to air/ton of ore processed.

The daily amount of chemical reagent released to air during flotation can be estimated with the following equation:

$$E_{local_air} = \frac{Q_{process_site_yr}}{TIME_{operating_days}} \times E_{chem_air} \times F_{chem_additive}$$

$$E_{local_air} = \frac{109,900 \frac{ton\ dry\ ore}{site - yr}}{255 \frac{days}{yr}} \times 1.8 \times 10^{-5} \frac{kg\ additive\ emitted}{ton\ dry\ ore} \times 1 \frac{kg\ chemical}{kg\ additive}$$

$$E_{local_air} = 7.76 \times 10^{-3} \frac{kg\ chemical\ emitted}{site - day}$$

The release will occur over 255 days/yr from 1 site.

The fraction of the chemical of interest released to air can be calculated as:

$$F_{air} = \frac{E_{local_air}}{Q_{chem_site_day}}$$

$$F_{air} = \frac{7.76 \times 10^{-3} \frac{kg\ chemical\ emitted}{site - day}}{392.15 \frac{kg\ chemical\ used}{site - day}}$$

$$F_{air} = 2 \times 10^{-5} \frac{kg\ chemical\ emitted}{kg\ chemical\ used}$$

6.2.3 Release from Concentrate Thickener Filter Media Disposal (Release 3)

This release is expected to be minimal and, with lack of specific industry information to quantify this release, is accounted for in the equipment cleaning release (Release 4).

6.2.4 Release to Water, Incineration, or Landfill from Equipment Cleaning (Release 4)

The EPA/OPPT *Multiple Vessel Residual Model* is used to estimate this release of chemical residue in the process equipment, calculated using the following equation:

$$E_{local_equipment_cleaning} = Q_{chem_site_day} \times F_{equipment_cleaning}$$

$$Elocal_{equipment_cleaning} = 392.15 \frac{kg\ chemical}{site - day} \times 0.02 \frac{kg\ released}{kg\ chemical}$$

$$Elocal_{equipment_cleaning} = 7.84 \frac{kg\ released}{site - day}$$

The release will occur over two days per year from 1 site.

The fraction of the chemical of interest released to air based on the daily use rate can be calculated as:

$$F_{equipment} = F_{equipment_cleaning} \times \frac{2 \frac{release\ days}{year}}{TIME_{operating_days}}$$

$$F_{equipment} = 0.02 \frac{kg\ released}{kg\ chemical} \times \frac{2 \frac{release\ days}{year}}{255 \frac{days}{yr}}$$

$$F_{equipment} = 1.6 \times 10^{-4} \frac{kg\ chemical\ released}{kg\ chemical\ used}$$

6.2.5 Off-Site Release to Incineration from Thermal Processing (Release 5)

Assume the partition fractions for collector chemicals listed in Table 4-2, which is equal to $F_{recovery}$. The fraction that ends up with the concentrate for thermal processing [$F_{concentrate}$] is 0.8 and the fraction that ends up with the tailings [$F_{tailings}$] is 0.2.

Utilizing [$F_{concentrate}$] of 0.8, the daily amount of chemical reagent released to incineration from thermal processing of the concentrate is can be estimated with the following equation:

$$Elocal_{thermal} = Q_{chem_site_day} \times (1 - F_{container_residue}) \times (1 - F_{air}) \times (1 - F_{equipment}) \times F_{concentrate}$$

$$Elocal_{thermal} = 392.15 \frac{kg\ chemical}{site-day} \times \left(1 - 0.03 \frac{kg\ container\ residue}{kg\ additive\ supplied\ in\ drums}\right) \times \left(1 - 2 \times 10^{-5} \frac{kg\ chemical\ emitted\ to\ air}{kg\ chemical\ used}\right) \times \left(1 - 1.6 \times 10^{-4} \frac{kg\ equipment\ residue}{kg\ chemical\ used}\right) \times 0.8 \frac{kg\ to\ thermal}{kg\ total}$$

$$Elocal_{thermal} = 304.25 \frac{kg\ to\ thermal}{site - day}$$

The release will occur over 255 days/year from 1 site.

6.2.6 Release from Tailings Disposal to Land or Water (Release 6)

This release can be estimated with the following equation, utilizing the partition fraction $F_{tailings}$ of 0.2:

$$E_{local\ tailings} = Q_{chem_site_day} \times (1 - F_{container_residue}) \times (1 - F_{air}) \times (1 - F_{equipment}) \times F_{concentrate}$$

$$\begin{aligned} E_{local\ tailings} &= 392.15 \frac{kg\ chemical}{site - day} \times \left(1 - 0.03 \frac{kg\ container\ residue}{kg\ additive\ supplied\ in\ drums}\right) \\ &\times \left(1 - 2 \times 10^{-5} \frac{kg\ chemical\ emitted\ to\ air}{kg\ chemical\ used}\right) \\ &\times \left(1 - 1.6 \times 10^{-4} \frac{kg\ equipment\ residue}{kg\ chemical\ used}\right) \times 0.2 \frac{kg\ to\ tailings}{kg\ total} \end{aligned}$$

$$E_{local\ tailings} = 76.06 \frac{kg\ to\ tailings}{site - day}$$

The release will occur over 255 days/year from 1 site.

6.3 Occupational Exposure

6.3.1 Number of Workers Exposed per Site

The number of workers is assumed to be 55 workers/site, per Table 5-2.

6.3.2 Exposure during Mineral and Metal Ore Flotation (Exposure A)

The default central tendency and 90th percentile concentrations for PNOR from Table 5-3 are assumed. Central tendency $C_{additive}$ is 0.47 mg/m³ and 90th percentile $C_{additive}$ is 1.57 mg/m³.

Potential worker inhalation exposure to the chemical during flotation is estimated using the following equation:

$$EXP_{inhalation} = C_{additive} \times TIME_{exposure} \times RATE_{breathing} \times F_{chem_additive}$$

$$Central\ Tendency\ EXP_{inhalation} = 0.47 \frac{mg\ additive}{m^3} \times 8 \frac{hr}{day} \times 1.25 \frac{m^3}{hr} \times 1 \frac{kg\ chemical}{kg\ additive}$$

$$\text{Central Tendency } EXP_{\text{inhalation}} = 4.7 \frac{\text{mg}}{\text{day}}$$

$$90\text{th Percentile } EXP_{\text{inhalation}} = 1.57 \frac{\text{mg}}{\text{m}^3} \times 8 \frac{\text{hr}}{\text{day}} \times 1.25 \frac{\text{m}^3}{\text{hr}}$$

$$90\text{th Percentile } EXP_{\text{inhalation}} = 15.7 \frac{\text{mg}}{\text{day}}$$

The exposure will occur over 255 days/yr.

7.0 DATA GAPS/UNCERTAINTIES AND FUTURE WORK

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

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

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

1. This QSGS assumed a generic ore processing rate that is based on the mining sector as a whole. Data on ore processing rates for flotation sites, specific to the commodities being processed would enhance these estimates.
2. This QSGS assumes a 100% release scenario, even though in reality, certain chemicals (e.g. frothers, collectors, activators) may react or be altered in some form as they perform their intended functions. Data on releases from flotation sites would enhance this assessment.
3. This QSGS assumes specific partitioning information based on generic assumptions. Data on the partitioning of chemical reagents to froth or the pulp phase would enhance the releases estimates.
4. This QSGS assumes tailings disposal release to water and land. Data on the discharge of water from tailings ponds and the content, or lack therefore, of chemical reagents in this discharge would enhance the release estimates.
5. This QSGS utilizes standard release models to estimate chemical reagent transport container cleaning residue and equipment cleaning residue. Information on industry-specific practices for cleaning of transport containers and flotation process equipment would enhance these estimates.
6. Activity-specific data for number of workers potentially exposed during flotation were not identified in the literature; therefore, the QSGS assumes all workers at a given facility perform each activity. Data on the number of workers associated with each activity would further enhance QSGS exposure estimates.

7. Additional industry-specific monitoring data for flotation operators would enhance estimates for flotation inhalation exposures.

8.0 REFERENCES

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A. APPENDIX: SAMPLE INITIAL REVIEW ENGINEERING REPORT (IRER)

INITIAL REVIEW ENGINEERING REPORT
Example Mineral Flotation IRER

CBI: No

Contractor Draft 9/29/2017

ENGINEER: ERG

PV (kg/yr): 100,000 Import Only NX

SUBMITTER: Mineral Flotation Company

USE: Mineral and metal ore flotation aid. Substance is a collector chemical for unknown ore type.

OTHER USES:

MSDS: No

Label: No

TLV/PEL:

CRSS :

Chemical Name: Flotation aid / Collector Chemical

S-H2O: 1E-06 g/L @

VP: 1.0E-6 torr @ 20.00

MW: 200.00 %<500 %<1000

Physical State and Misc CRSS Info:

Consumer Use:

SAT (concerns) :

Migration to groundwater: Negligible to slow

PBT rating: P3B3T

Health: Dermal, Drinking Water, Inhalation

Eco: Water (All releases to water with a CC =)

OCCUPATIONAL EXPOSURE RATING: 2-3C

NOTES & KEY ASSUMPTIONS:

Generated by the 09/30/2013 version of ChemSTEER. All releases and exposures were assessed per the 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation.

POLLUTION PREVENTION CONSIDERATIONS:

EXPOSURE-BASED REVIEW: No

INITIAL REVIEW ENGINEERING REPORT

CBI: No

Example Mineral Flotation IRER:

Use: Mineral Flotation

Number of Sites/ Location: 1

unknown site(s)

Days/yr: 255

Basis: Per 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation, assume: 255 days of operation/yr (Section 3.2), Fchem additive of 100% NCS in the raw material (Section 3.4), an additive use rate in slurry Qadditive_slurry of 2 lbs additive/ton ore processed, and an ore processing rate Qprocess_site_yr of 1,034,038 tons ore/site-yr (utilizing eqn 3-1, assuming defaults from Section 3.3 and 3.4). Using eqn 3-2, 3-3, and 3-4, the daily use rate of the chemical of interest Qchem site day = (Fchem add x Qadditive_slurry x Qprocess_site_yr) / TIMEoperating_days = (1 kg chem/kg additive x 0.91 kg additive/ton ore x 1,034,038 ton ore/site-yr) / 255 days/yr = 3,690 kg chem/site-yr. With this use rate CS calculates < 1 site. RAD assumes 1 site and CS calculates revised use rate of 392.15 kg chem/site-day.

Process Description: NCS is unloaded from drums (liquid, 100%) --> charged to conditioning tanks with ores --> bulk flotation processes --> froth dewatering --> ore and NCS concentrate sent to off-site metallurgical processing (NCS destroyed at high temperatures) (Per 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation)

ENVIRONMENTAL RELEASES ESTIMATE SUMMARY

IRER Note: The daily releases listed for any source below may coincide with daily releases from the other sources to the same medium. // Note that the revised chemical use rate of 392.15 kg chem/site-day results in a revised ore processing rate of $Q_{process_site_yr} = (Q_{chem\ site\ day} \times TIME_{operating_days}) / (Q_{add\ slurry} \times F_{chem\ add}) = (392.15\ kg\ chem/site\ day \times 255\ days/yr) / (0.91\ kg\ additive/ton\ ore) = 109,900\ ton\ ore/site-yr.$

Water or Incineration or Landfill

High End: 1.2E+1 kg/site-day over 255 days/yr from 1 site
or 3.0E+3 kg/site-yr from 1 site or 3.0E+3 kg/yr-all sites

to: water, incineration, or landfill (GS)

from: Cleaning Liquid Residuals from Drums Used to Transport the
Raw Material

basis: EPA/OPPT Drum Residual Model, CEB standard 3% residual. Per
the 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation,
RAD assumes drums as the default container size and uses the
EPA/OPPT Drum Residual Model to estimate release. Per GS, release
is to water, incineration, or landfill.

Water or Incineration or Landfill

Conservative: 7.8E+0 kg/site-day over 2 days/yr from 1 site
or 1.6E+1 kg/site-yr from 1 site or 1.6E+1 kg/yr-all sites

to: water, incineration, or landfill (GS)

from: Equipment Cleaning Losses of Liquids from Multiple Vessels

basis: EPA/OPPT Multiple Process Vessel Residual Model, CEB
standard 2% residual. Per the 2017 Draft Quick-Strike GS on Mineral
and Metal Ore Flotation, RAD uses the EPA/OPPT Multiple Process
Vessel Residual Model to estimate equipment cleaning release. Per
GS, release occurs twice per year and is to water, incineration, or
landfill. $LF = (0.02 \times 2 \text{ day/yr} / 255 \text{ day/yr}) = 1.6E-4$.

Water or Landfill

Output 2: 7.6E+1 kg/site-day over 255 days/yr from 1 site
or 1.9E+4 kg/site-yr from 1 site or 1.9E+4 kg/yr-all sites

to: Land or Water (GS)

from: Tailings Disposal

basis: User-Defined Loss Rate Model. Per GS, the remaining NCS is
released during tailings disposal, from the amount of NCS that does
not end up in the froth phase. Per Section 4.6.2, this fraction is
0.2 kg to tailings/kg chemical for collector chemicals. Thus, the
loss fraction for this release = $(1 - 0.03 \text{ (container}$
 $\text{cleaning)} - 2E-5 \text{ (air flotation)} - (0.02 \times 2 \text{ day/yr} / 255 \text{ day/yr})$
 $\text{(equipmt cleaning)}) \times 0.2 \text{ kg tailings/kg chem} = 0.194$. Per GS, this
release is to land or water.

Air

Output 2: 7.8E-3 kg/site-day over 255 days/yr from 1 site
or 2.0E+0 kg/site-yr from 1 site or 2.0E+0 kg/yr-all sites

to: Air (GS)

from: Air Flotation

basis: User-Defined Loss Rate Model. Per the 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation, assume an emission rate for collector chemicals of $E_{\text{additive_air}} = 1.8\text{E-}5$ kg emitted additive to air/ton of ore processed. The release is calculated with eqn 4-3 = $(Q_{\text{process_site_yr}} \times E_{\text{additive_air}} \times F_{\text{chem_additive}}) / 255 \text{ days/yr} = (109,900 \text{ ton ore/site-yr} \times 1.8 \text{ kg additive to air/ton ore} \times 1 \text{ kg chem/kg additive}) / 255 \text{ days/yr} = 7.76\text{E-}3 \text{ kg chem/site-day}$. $LF = 7.8\text{E-}3 / 392.15 = 2\text{E-}5$ (equation 4-4).

Incineration

Output 2: $3.0\text{E}+2$ kg/site-day over 255 days/yr from 1 site
or $7.8\text{E}+4$ kg/site-yr from 1 site or $7.8\text{E}+4$ kg/yr-all sites
to: Incineration (GS)

from: Off-Site Thermal Processing

basis: User-Defined Loss Rate Model. Per the 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation, once flotation occurs, the froth is dewatered and sent off-site for thermal processing. Collector chemicals, like the NCS, are expected to partition to the froth at a fraction of 0.8 kg chemical to thermal processing/kg chemical (Section 4.6.2). Utilizing this fraction, eqn 4-7, and the loss fractions from the previous releases, the fraction of chemical that is released to thermal processing is = $(1 - 0.03 \text{ (container cleaning)} - 2\text{E-}5 \text{ (air flotation)} - (0.02 \times 2 \text{ day/yr} / 255 \text{ day/yr}) \text{ (equipmt cleaning)}) \times 0.8 \text{ kg thermal/kg chem} = 0.776$. Per GS, the release is to incineration.

RELEASE TOTAL

$1.0\text{E}+5$ kg/yr - all sites

OCCUPATIONAL EXPOSURES ESTIMATE SUMMARY

Tot. # of workers exposed via assessed routes: 55

Basis: Per the 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation, the number of workers per site is assumed to be 55 workers/site. RAD assumes all workers perform all activities, as conservative.

Inhalation:

Exposure to Mist (non-volatile) (Class I)

Central Tendency:

- > Potential Dose Rate: 4.7E+0 mg/day over 250 days/yr
- > Lifetime Average Daily Dose: 2.1E-2 mg/kg-day over 250 days/yr
- > Average Daily Dose: 4.1E-2 mg/day over 250 days/yr
- > Acute Potential Dose: 6.0E-2 mg/day over 250 days/yr

90th Percentile:

- > Potential Dose Rate: 1.6E+1 mg/day over 250 days/yr
- > Lifetime Average Daily Dose: 6.9E-2 mg/kg-day over 250 days/yr
- > Average Daily Dose: 1.4E-1 mg/day over 250 days/yr
- > Acute Potential Dose: 2.0E-1 mg/day over 250 days/yr

Number of workers (all sites) with inhalation exposure: 55

Basis: Air Flotation; User-defined Inhalation Model. Per the 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation, RAD assesses inhalation exposure during floatation utilizing the central tendency and 90th percentile estimates for collector chemicals. Per November 2016 guidance, Body Weight (BW) was updated from 70 kg to 80 kg and Averaging Time over a Lifetime (ATc) parameter in ChemSTEER from 70 years to 78 years (i.e., BW = 80 kg and ATc = 78 years). Central Tendency Cm = 0.47 mg/m³ over h = 8 hrs/day. 90th Percentile Cm = 1.57 mg/m³ over h = 8 hrs/day.

NOTE: The respirator class is: I. Particulate (including solid or liquid droplets).

INHALATION MONITORING DATA REVIEW

- 1) Uncertainty (estimate based on model, regulatory limit, or data not specific to industry): Yes
 - 2)a) Exposure level > 1 mg/day? Yes
 - OR
 - b) Hazard Rating for health of 2 or greater? No
- => Inhalation Monitoring Data Desired? **No**

Dermal:

Exposure to Liquid at 100.00% concentration

High End:

- > Potential Dose Rate: 2.2E+3 mg/day over 250 days/yr
- > Lifetime Average Daily Dose: 9.9E+0 mg/day over 250 days/yr
- > Average Daily Dose: 1.9E+1 mg/day over 250 days/yr
- > Acute Potential Dose: 2.8E+1 mg/day over 250 days/yr

Number of workers (all sites) with dermal exposure: 55

Basis: Unloading Liquid Raw Material from Drums; EPA/OPPT 2-Hand Dermal Contact with Liquids Model. The 2017 Draft Quick-Strike GS on Mineral and Metal Ore Flotation does not include dermal exposures in the scope of the GS. RAD assesses dermal exposures from unloading raw materials consistent with past cases and standard RAD methodology. Per November 2016 guidance, Body Weight (BW) was updated from 70 kg to 80 kg and Averaging Time over a Lifetime (ATc) parameter in ChemSTEER from 70 years to 78 years (i.e., BW = 80 kg and ATc = 78 years).