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HAZARDOUS AND RADIOACTIVE MATERIALS BUREAU

New Mexico Environment Department

Position Paper ***Position Paper***

Assessing Human Health Risks Posed by Chemicals: Screening-level Risk Assessment[1]

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1. Introduction

This document discusses the method for deriving human health risk-based contaminant- and medium-specific screening levels[2] (**MSLs**) and performing a screening-level human health risk assessment (the "screen"). The method discussed addresses common human health exposure pathways for soil/sediment, ground water and surface water: ingestion, inhalation, and dermal contact. The exposure pathways which should be included in the screen are indicated in boldface italics in Table 1 *Typical Exposure Pathways by Medium for Residential and Industrial Land Uses.*

The method does **not** consider impacts to ground water resources or ecological receptors; therefore, a separate evaluation of potential impacts to ground water[3] and

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[1]This document is intended as guidance for employees of the Hazardous and Radioactive Materials Bureau (HRMB) and RCRA-regulated facilities within the State of New Mexico. This guidance does not constitute rule-making and may not be relied upon to create a right or benefit, substantive or procedural, enforceable at law or in equity, by any person. HRMB may take action at variance to this guidance and reserves the right to modify this guidance at any time without public notice.

[2]A *MSL* is defined here as a contaminant concentration in environmental medium (i.e., soil/sediment, water, or air) that is considered protective of human health, including sensitive groups of human population, over a lifetime.

[3]The *Soil Screening Guidance: Technical Background Document* (US EPA 1996a) provides a detailed methodology for calculating generic soil screening levels for contaminant migration to ground water and lists chemical concentrations in soil that are considered protective of ground water.

ecological receptors[4] is necessary. Furthermore, it may **not** consider all relevant exposure pathways to humans at a given site (see Section 3.a *Conceptual Site Exposure Model*).

This document does not address specific methods for evaluating human exposure and risk for the following constituents or their groups: lead, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, polychlorinated dibenzo-dioxins and dibenzo-furans, and radionuclides. Human health risk assessments specific to these constituents are or will be addressed by separate guidance documents.

a. Objective and Purpose

This document adopts standard human health risk assessment methods excerpted from various United States Environmental Protection Agency (**EPA**) sources, both national and regional. The goal of issuing this document is to provide a tool for conducting a consistent screening-level human health risk assessment by the Resources Conservation and Recovery Act (**RCRA**) hazardous waste permitted facilities and corrective action/remediation projects under the Hazardous and Solid Waste Amendments. The document is advisory only and is intended to assist the Hazardous and Radioactive Materials Bureau, RCRA-regulated facilities, consultants, and others implementing environmental remediation projects.

This guidance is intended as an initial risk-screening tool, and as such, covers only residential and industrial land use and exposure scenarios. This document addresses only a limited number of potential exposure pathways for contaminated ground water, surface water and soil/sediment (Table 1). It is recommended that residential land use and exposure scenarios be used for screening sites. Residential exposure scenario is used for maximum beneficial uses of a site property. However, if industrial land use can be demonstrated as the only possible current and projected land use scenario, industrial risk values may be applicable for screening the sites. If other land uses and exposure scenarios are more appropriate for a site (e.g., Native American land use scenario, etc.) the exposure pathways covered by the screen should be modified to reflect these other land uses (see Section 3.a *Conceptual Site Exposure Model*) or a site-specific risk assessment should be conducted.

Once a human health risk-based MSL is calculated using assumptions, algorithms, and exposure factors described in the following sections, it can be compared with

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[4]Suggested references for evaluating ecological risk include US EPA (1997b) and NMED HRMB (2000).

the maximum contaminant medium concentration[5] at a given site. The comparison will provide for an initial evaluation of the relative human health concern for a site or set of environmental data.

The decision to conduct the screen at a site will be driven by the potential benefits of developing generic risk-based concentrations in the absence of site-specific risk assessments. The following are some of the benefits of performing a screen:

- Screening sites to determine whether further investigation and evaluation are needed,
- Prioritizing multiple sites within a facility, and
- Focusing future site-specific risk assessment efforts, such as reducing the number of contaminants to be evaluated in a site-specific risk assessment.

b. Prerequisites

The following activities should be completed prior to implementing the screen:

- Develop data quality objectives and conduct site sampling,
- Develop a preliminary conceptual site model,
- Delineate the nature and horizontal and vertical extent of contamination,
- Select contaminants of potential concern (**COPCs**) for the site, and
- Evaluate migration potential of the COPCs.

[5]If adequate data exist for a given site, a 95% upper confidence limit of the mean contaminant concentration (95% UCL) can be substituted for the maximum contaminant concentration. Important considerations of data adequacy include, but are not limited to having (1) the spatial contaminant distribution defined at a site and (2) environmental sampling results derived from a single statistical distribution or population.

TABLE 1 Typical Exposure Pathways by Medium for Residential and Industrial Land Uses		
MEDIUM	**LAND USE**	
	RESIDENTIAL	**INDUSTRIAL**
Ground Water	***Ingestion from drinking***[6]	Ingestion from drinking
	Inhalation of volatile chemicals	Inhalation of volatile chemicals
	Dermal absorption from bathing	Dermal absorption
Surface Water	***Ingestion from drinking***	Ingestion from drinking
	Inhalation of volatile chemicals	Inhalation of volatile chemicals
	Dermal absorption from bathing	Dermal absorption
	Ingestion during swimming	NA
	Ingestion of contaminated fish	NA
Soil/Sediment	***Ingestion***	***Ingestion***
	Inhalation of particulates	***Inhalation of particulates***
	Inhalation of volatile chemicals	***Inhalation of volatile chemicals***
	Exposure to indoor air from soil gas	Exposure to indoor air from soil gas
	Exposure to ground water contaminated by soil leachate	Exposure to ground water contaminated by soil leachate
	Ingestion via plant, meat, or dairy products	Inhalation of particulates from trucks and heavy equipment
	Dermal absorption	***Dermal absorption***

[6]***Boldface italics*** indicate exposure pathways considered in the screening-level human health risk assessment. These exposure pathways should be included in the screen if human exposure to contaminated media (i.e., ground water, surface water and/or sediment/soil) potentially exists.

3. General Considerations

a. Conceptual Site Exposure Model

The primary condition for use of the screen guidance is that land use pattern, exposure pathways of concern, and other conditions at the site match those taken into account by the screen. To determine this, it is necessary to refine the conceptual site model (see Section 1.b *Prerequisites*) and develop a conceptual site exposure model that identifies current and likely future land use scenarios, known and likely contaminant source areas, potential exposure pathways and the media and potential receptors associated with each. This information will be used to determine the applicability of the screening approach to the site and the need for additional information.

The conceptual site exposure model should answer the following questions:

- Is there potential for land uses other than those covered by the screening-level assessment (i.e., residential and industrial)?
- Are there other likely human exposure pathways that are not considered by the screening-level assessment (e.g., impact to ground water, local fish consumption, raising beef, dairy, or other livestock, etc.)?
- Are there unusual site conditions (e.g., large areas of contamination, high fugitive dust emission rates, potential for indoor air contamination, highly sensitive or exposed groups of human population, etc.)?

If any of these three conditions exist at a given site, the exposure scenarios and pathways covered by the screen should be adjusted[7] to reflect these conditions or a site-specific risk assessment should be performed.

b. Target Risk and Target Hazard

Target risk levels (**TRs**) and target hazard levels (**THs**) for human health are risk management-based criteria used for carcinogens and non-carcinogens, respectively, to determine (1) whether site-related contamination poses an unacceptable risk to human health and requires corrective action or (2) whether implemented corrective actions protect human health. If an estimated risk/hazard falls within target risk/hazard values, a regulatory authority may, without further

[7]The Facility should work directly with the Administrative Authority to develop an approach to address these new conditions.

investigation, conclude that a site does not pose an unacceptable risk. An estimated risk that exceeds these targets, however, would not, by itself, indicate that the proposed action is not safe or that it presents an unacceptable risk. Rather, a site risk calculation that exceeds a target value triggers further evaluation and/or investigation. TR/THs are to be used in the calculation of risk-based COPC-specific concentrations for environmental (i.e., abiotic) media.

In the screen, the following TRs and THs should be used to evaluate carcinogenic and non-carcinogenic effects, respectively:

- **Carcinogenic effects**: The excess lifetime cancer risk levels used in the calculation of risk-based COPC-specific MSL values are consistent with the EPA's National Contingency Plan (*Federal Register* Vol. 55, p. 8666). The range of 10^{-6} to 10^{-4} is recommended as "acceptable." A target risk of 10^{-5} is applied for an individual carcinogen exposure. However, when two or more carcinogens are present at a site a target risk level corresponds to 10^{-6}. Setting a 10^{-6} or 10^{-5} target risk level for multiple or individual carcinogens, respectively, generally will result in cumulative excess lifetime cancer risk of 10^{-5} for the combination of COPCs typically found at RCRA sites.

- **Non-carcinogenic effects**: With the exceptions described below, a target hazard level corresponds to one (1) for exposure to one COPC; hence adverse effects are not anticipated below a target hazard of 1 for an individual contaminant exposure. However, when two or more non-carcinogenic COPCs are present at a site, a target hazard level corresponds to 0.1[8]. The purpose of the safety factor of 10 is to address the potential that two or more COPCs may affect the same target organs or organ systems and/or act by similar mechanisms.

For soil/sediment, there is one exception to calculating risk-based MSLs. For some volatile chemicals (see Section 3.d *Exposure Equations and Factors*), MSLs are based on the soil saturation equation (see Equation 10 in Appendix A).

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[8]COPCs which fail the screening using a TH of 0.1 may proceed to a more detailed screen where a target hazard level corresponds to a hazard index (HI) of one (1). HI represents the sum of more than one HQ for multiple chemicals and/or multiple pathways. HI of 1 refers to the level of exposure to all chemicals from all exposure pathways in a given medium below which it is unlikely for even sensitive populations to experience adverse health effects. HI can be calculated separately for different critical effects and mechanisms of action.

If this guidance is to be used to estimate risk-based COPC-specific MSLs for site screening, it is recommended that both cancer and non-cancer-based constituent MSLs be obtained.

c. Toxicity Values

EPA toxicity values[9], known as non-carcinogenic reference doses[10] (RfDs) and reference concentrations[11] (RfCs) and cancer slope factors[12] (CSFs) or unit risk factors[13] (URFs) are used for the screen and for calculating COPC-specific risk-based MSLs. The toxicity values for COPCs can be obtained from the following sources which are listed in order of preference: EPA's Integrated Risk Information System (**IRIS**) and Health Effects Assessment Summary Tables[14] (**HEAST**).

If relevant information is not available from these sources, provisional toxicity values can be obtained for some chemicals and routes of exposure from EPA's National Center for Environmental Assessment (**NCEA**). NCEA develops issue papers forming the basis for the determination of certain chemicals' toxicity values (i.e., provisional toxicity values) for use by EPA regional offices. Although these NCEA provisional toxicity values are not "consensus" values and have not been subjected to rigorous scientific review, they may be used in the absence of IRIS or HEAST toxicity values. However, they should not be used with the same confidence as values published in IRIS or HEAST.

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[9]A *toxicity value* is a numerical expression of a substance's dose-response relationship that is used in risk assessments (US EPA, 1989).

[10]An *RfD* is a daily oral intake that is estimated to pose no appreciable risk of adverse health effects, even to sensitive populations, over a specific exposure duration (US EPA, 1989).

[11]An *RfC* is an estimated daily concentration of a chemical in air, the exposure to which over a specific exposure duration poses no appreciable risk of adverse health effects, even to sensitive populations (US EPA, 1989).

[12]A *cancer slope factor* is a plausible upper-bound estimate of the probability of a response per unit intake or dose of a chemical over a lifetime (US EPA, 1989). The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen.

[13]A *unit risk factor* represents an upper-bound excess lifetime cancer risk estimated to result from continuous exposure to the substance at a concentration of 1 $\mu g/m^3$ in air or 1 $\mu g/L$ in water (US EPA, IRIS).

[14]It should be noted that the HEAST tables are no longer being updated.

If IRIS, HEAST or NCEA toxicity values are not available for a chemical, surrogate toxicity values in Appendix C may be used. Other chemicals without toxicity values should be evaluated qualitatively in the uncertainty analysis or quantitatively in a site-specific risk assessment.

Inhalation Conversion Factors: In January 1991, EPA's IRIS and NCEA replaced RfDs and CSFs with RfCs for non-carcinogenic effects and URFs for carcinogenic effects (US EPA, 1999b). However, inhalation reference doses (RfD_i) and inhalation slope factors (CSF_i) are still preferred toxicity values for the purpose of calculating risk-based concentrations and estimating risks. The following equations and assumptions may be used to calculate RfD_i and CSF_i from an RfC and URF, respectively.

$$RfD_i \text{ (mg/kg-day)} = [RfC \text{ (mg/m}^3\text{)} \times 20 \text{ m}^3\text{/day}] / 70 \text{ kg}$$

$$CSF_i \text{ (kg-day/mg)} = [URF \text{ (}\mu\text{g/m}^3\text{)}^{-1} \times 70 \text{ kg} \times 10^3 \ \mu\text{g/mg}] / 20 \text{ m}^3\text{/day}$$

Route-to-route extrapolations: Route-to-route extrapolations should only be used when there are no toxicity values available for a given route of exposure. Oral cancer slope factors and reference doses should be used for both oral and inhalation exposures for organic compounds lacking inhalation toxicity values. Inhalation slope factors and inhalation reference doses should be used for both inhalation and oral exposures for organic compounds lacking oral toxicity values. However, extrapolation of toxicity values between ingestion and inhalation exposure routes should not be performed for metals due to known differences in absorption efficiency, metabolism, and toxicity for the two routes of exposure (US EPA, 1994a). An additional route-to-route extrapolation is the use of oral toxicity values for evaluating dermal exposures (see also Section 4. a. iii *Dermal Contact with Contaminants in Soil/Sediment*). A scientifically defensible database does not exist for adjusting an oral slope factor or oral reference dose to estimate a dermal toxicity value with the exception of cadmium (US EPA, 1999c, as cited in US EPA, 1999b). An oral absorption efficiency of 5% is assumed for cadmium which results in an estimated dermal reference dose of 2.5E-05 (US EPA, 1999b). **Although route-to-route extrapolation methods are a useful screening procedure, the appropriateness of these default assumptions for specific contaminants should be verified.**

d. Exposure Equations and Factors

Equations for calculating risk-based COPC-specific MSLs have been derived to reflect the potential risk and/or hazard from exposure to a chemical, given a specific pathway, medium, and land-use combination (e.g., ingestion of ground water, surface water, and soil/sediment for residential land use, and soil/sediment for industrial land use, etc.). Both carcinogenic and non-carcinogenic effects are addressed here.

By setting the risk for carcinogenic effects at a TR of 10^{-6} (for multiple carcinogens) or 10^{-5} (for individual carcinogens), it is possible to solve for the concentration term (i.e., COPC-specific MSL). The TH for non-carcinogenic effects is set at 0.1 for individual chemicals in a given medium, assuming exposure to chemical mixtures. For a single COPC in a single medium, the TH for non-carcinogenic effects is set at one (1).

All equations presented here incorporate pathway-specific default factors that generally reflect reasonable maximum exposure (**RME**) conditions, as detailed in Chapter 8 of RAGS/HHEM Part A (US EPA, 1989). Full human health risk-based screening-level equations and pathway-specific default exposure factors are presented in Appendices A and B, respectively.

The equations used to calculate the MSLs for carcinogenic and non-carcinogenic effects of COPCs are presented in Equations 1 through 8. The MSL equations have been obtained from RAGS/HHEM Part B (US EPA, 1991a) equations and more recent *Soil Screening Guidance* (US EPA, 1996a). The methodology back-calculates a soil/sediment, air or tap water concentration level from a target risk level (carcinogenic effects) or target hazard level (non-carcinogenic effects). For completeness, the soil/sediment equations combine risks/hazards from ingestion, skin contact, and inhalation, simultaneously. The tap water equations combine risks/hazards from ingestion and inhalation.

To calculate MSLs for volatile chemicals in soil, a chemical-specific volatilization factor (**VF_s**) is estimated according to Equation 10 (Appendix A). Because of its reliance on Henry's law, Equation 10 is applicable only when the COPC concentration in soil is at or below saturation limit (i.e., there is no free-phase contaminant present). The soil saturation concentration limit corresponds to the COPC concentration in soil at which the adsorptive limits of the soil particles are the solubility limits of the available soil moisture and saturation of soil pores air have been reached. Above this point, pure liquid-phase contaminant is expected in the soil. If the MSL calculated using VF_s is greater than the calculated soil

saturation limit, the MSL can be set equal to the saturation limit (see US EPA, 1996a). The equation for deriving soil saturation concentration is presented in Equation 10 (Appendix A).

Default exposure factors (Appendix B) have been obtained primarily from RAGS/HHEM *Supplemental Guidance*[15] (US EPA, 1991b) and more recent information from EPA's Office of Solid Waste and Emergency Response and Office of Research and Development.

Carcinogenic risks during the first 30 years of life are calculated using age-adjusted factors because contact rates may differ for children and adults. Use of age-adjusted factors is especially important for soil/sediment ingestion exposures, which are higher during childhood and decrease with age. Additionally, for purposes of combining exposures across pathways, age-adjusted factors are used for inhalation and dermal exposures. The age-adjusted factors approximate the integrated exposure from birth until age 30 combining contact rates, body weights, and exposure durations for two age groups - small children and adults. Age-adjusted factors are obtained from RAGS/HHEM Part B (US EPA, 1991a) or developed by analogy.

Age-adjusted factors for carcinogens in soil/sediment are derived for ingestion, dermal and inhalation exposure routes in accordance with the following equations.

(1) Ingestion:

$$IFS_{adj} = \frac{ED_c \times IRS_c}{BW_c} + \frac{(ED_r - ED_c) \times IRS_a}{BW_a}$$

where:

IFS_{adj}	=	Age-adjusted ingestion factor for soil/sediment ([mg-yr]/[kg-d])
ED_c	=	Exposure duration, child (years)
ED_r	=	Exposure duration, residential (years)
IRS_a	=	Soil/sediment ingestion rate, adult (mg/day)
IRS_c	=	Soil/sediment ingestion rate, child (mg/day)
BW_a	=	Body weight, adult (kg)
BW_c	=	Body weight, child (kg)

[15]Default values from US EPA (1991b) are recommended for some exposure factors (i.e., body weights, inhalation and ingestion rates, exposure duration, and exposure frequency) in the derivation of MSLs in the screen. Generally, these standard default values approximate those reported in the *Exposure Factors Handbook* (1997c) and have been utilized to develop toxicity values.

(2) Skin contact:

$$SFS_{adj} = \frac{ED_c \times AF \times SA_c}{BW_c} + \frac{(ED_r - ED_c) \times AF \times SA_a}{BW_a}$$

where:

SFS_{adj}	=	Age-adjusted skin contact factor for soil/sediment ([mg-yr]/[kg-d])
ED_c	=	Exposure duration, child (years)
ED_r	=	Exposure duration, residential (years)
AF	=	Skin adherence factor for soil/sediment (mg/cm^2)
SA_a	=	Exposed skin surface area, adult (cm^2/day)
SA_c	=	Exposed skin surface area, child (cm^2/day)
BW_a	=	Body weight, adult (kg)
BW_c	=	Body weight, child (kg)

(3) Inhalation:

$$InhF_{adj} = \frac{ED_c \times IRA_c}{BW_c} + \frac{(ED_r - ED_c) \times IRA_a}{BW_a}$$

where:

$InhF_{adj}$	=	Age-adjusted inhalation factor for soil/sediment ([m^3-yr]/[kg-d])
ED_c	=	Exposure duration, child (years)
ED_r	=	Exposure duration, residential (years)
IRA_a	=	Inhalation rate, adult (m^3/day)
IRA_c	=	Inhalation rate, child (m^3/day)
BW_a	=	Body weight, adult (kg)
BW_c	=	Body weight, child (kg)

4. Derivation of Risk-based and Contaminant-specific Media Screening Levels

The MSLs consider risks/hazards from human exposure to or contact with COPCs present in contaminated soils/sediments, air and water. The Equations 1 through 8 presented in Appendix A are used to calculate the MSLs for carcinogenic and non-carcinogenic COPCs. Appendix B shows standard default assumptions and factors used by the screening level equations. Sections 3.1 and 3.2 below provide a technical basis for the MSL calculations.

The screening level equations have been obtained from RAGS/HHEM Part B (US EPA, 1991a) equations and more recent *Soil Screening Guidance: Technical Background Document* (US EPA, 1996a). The methodology back calculates a soil/sediment, air or tap water concentration level (i.e., MSL) from a target risk (carcinogens) or target hazard (non-carcinogens).

a. Derivation of Risk-based Screening Levels for Soil/sediment

The equations used to calculate the MSLs for soil/sediment simultaneously combine risks/hazards from three exposure routes: ingestion, skin contact, and inhalation of volatiles and particulates. The algorithms for deriving MSLs for soil/sediment are presented in Equations 1 through 4 of Appendix A.

i. Incidental Ingestion of Soil/Sediment

Carcinogenic effects: To evaluate carcinogenic effects of COPCs (see Equations 1 and 3 in Appendix A), the approach uses an age-adjusted soil/sediment ingestion factor that takes into account the difference in daily soil/sediment ingestion rates, body weights, and exposure duration for children from 1 to 6 years old and other from 7 to 30 years old. The higher intake rate of soil/sediment by young children and their lower body weights result in a lower, or more conservative, risk-based concentration compared to an adult-only consumption.

Non-carcinogenic effects: Under a residential exposure scenario, non-carcinogenic effects of COPCs are evaluated in children only (Equation 2 in Appendix A); under an industrial exposure scenario, non-carcinogenic effects are evaluated in adults only (Equation 4 in Appendix A). No age-adjustment factor is necessary for evaluating non-carcinogenic effects for a residential exposure scenario because it assumes the exposure of children, which have higher ingestion rates due to their lower body weight. For maintaining consistency when evaluating soils/sediments, dermal and inhalation exposures are also based on childhood contact rates.

ii. Inhalation of Volatile Chemicals and Particulates (Fugitive Dust)

The models used to calculate MSLs for inhalation of volatiles or particulates are consistent with EPA's *Soil Screening Guidance: User's Guide* and *Technical Background Document* (US EPA, 1996a and b).

To address the soil/sediment-to-air pathways, the screening level calculations incorporate VF_s for volatile COPCs and particulate emission factors (**PEF**) for nonvolatile COPCs. These factors relate soil/sediment COPC concentrations to air COPC concentrations that may be inhaled onsite. The VF_s and PEF equations can be broken into two separate models: an emission model to estimate emissions of the contaminant from the soil and a dispersion model to simulate the dispersion of the contaminant in the atmosphere.

It should be noted that the box model in RAGS/HHEM Part B (US EPA, 1991a) has been replaced with a dispersion term (**Q/C**) derived from a model using one-year meteorological data from 29 locations across the United States. The box model was replaced because it may not be applicable to a broad range of site types and meteorology and does not use state-of-the-art techniques developed for regulatory dispersion modeling. The dispersion model for both volatile chemicals and particulates is the ISCST3, an updated version of the Office of Air Quality Planning and Standards, Industrial Source Complex Model, ISC2. However, different Q/C terms are used in the VF_s and PEF equations (Equations 9 and 11 in Appendix A). Los Angeles was selected as the 90th percentile data set for volatile chemicals and Minneapolis was selected as the 90th percentile data set for fugitive dusts (US EPA, 1996a). For more details regarding this dispersion model, the reader is referred to *Soil Screening Guidance: Technical Background Document* (US EPA, 1996a).

A default source size of 0.5 acres was chosen for the screening-level calculations. This is consistent with the default exposure area over which EPA typically averages contaminant concentrations in soils. If unusual site conditions exist such that the source area is substantially larger than the default source size assumed here, an alternative Q/C could be applied (see US EPA, 1996a).

(1) Inhalation of Volatile Chemicals in Soil

For the purposes of this guidance, inhalation of volatile chemicals is applicable only to chemicals having a Henry's Law constant of 10^{-5} (atm-m^3/mol) or greater **and** a molecular weight less than 200 g/mole (US EPA, 1991a). The emission terms used in the VF_s calculation (Equation 9 in Appendix A) are chemical-specific and can be calculated from physical-chemical information obtained from the *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities*, Volume II, Appendix A (US EPA, 1998). Other sources that can be used if data are unavailable in the latter reference (US EPA, 1998) include *Superfund Exposure*

Assessment Manual (US EPA,1988), *Subsurface Contamination Reference Guide* (US EPA, 1990), *Fate and Exposure Data* (Howard, 1990), and *Superfund Chemical Data Matrix* (US EPA, 1994b). In those cases where diffusivity coefficients are not provided in existing literature, they can be calculated using Fuller's Method described in the *Superfund Exposure Assessment Manual* (US EPA, 1988). For chemicals that lack physico-chemical information, a "proxy chemical" of similar chemical structure may be used; however, it should be noted that this may over- or under-estimate the screening level for soils.

To calculate MSLs for volatile COPCs in soil, a COPC-specific volatilization factor is calculated using Equation 9 (Appendix A). As discussed in Section 2.4, the VF_s model is applicable only when the contaminant concentration in soil is at or below saturation (i.e. there is no free-phase contaminant present). Soil saturation concentration corresponds to the contaminant concentration in soil at which the adsorptive limits of the soil particles and the solubility limits of the soil pore water and saturation of soil pores air have been reached. Above the soil saturation concentration, the soil contaminant may be present in the free phase (i.e., non-aqueous phase liquids) for contaminants that are liquid at ambient soil temperatures and pure solid phases for compounds that are solid at ambient soil temperatures. The model cannot predict an accurate volatilization factor-based MSL above the saturation concentration because at this point, pure liquid-phase contaminant is expected in the soil. How these cases are handled depends on whether the contaminant is liquid or solid at ambient temperatures.

If the MSL calculated for liquid COPC using VF_s is greater than the calculated saturation concentration, the MSL should be set equal to the saturation concentration value, in accordance with *Soil Screening Guidance: Technical Background Document* (US EPA, 1996a). For solids, soil/sediment screening decisions should be based on appropriate other pathways of concern at the site (e.g., soil ingestion and dermal contact, etc.). The updated model for deriving soil saturation concentration is presented in Equation 10 (Appendix A). For more details regarding specific parameters used in the VF_s model, the reader is referred to *Soil Screening Guidance: Technical Background Document* (US EPA, 1996a).

(2) Inhalation of Fugitive Dust

Inhalation of COPCs adsorbed to respirable particles (**PM_{10}**) are assessed using a default PEF equal to 1. 316 x 10^9 m^3/kg that relates the contaminant concentration in soil/sediment with the concentration of respirable particles in the air due to fugitive dust emissions from contaminated soils/sediments. It is important to note that the default PEF addresses wind-borne emissions and does **not** consider dust emissions from traffic or other forms of mechanical disturbance that could lead to a greater emissions than assumed here. Therefore, if these additional sources of dust emission exist or are expected to exist at a given site, the PEF should be adjusted to account for these differences or a site-specific risk assessment should be performed.

The default PEF of 1.316 x 10^9 m^3/kg was derived using values presented in Equation 11 (Appendix A) and corresponds to an exposure point concentration of approximately 0.76 $\mu g/m^3$. The relationship was derived by Cowherd, et alia (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g., years, etc.). This represents an annual average emission rate based on wind erosion that should be compared with chronic health criteria (i.e., chronic reference doses and concentrations); it is **not** appropriate for evaluating the potential for short-term exposures.

Equation 11 (Appendix A) forms the basis for deriving a generic PEF for the inhalation pathway. For more details regarding specific parameters used in the PEF model, the reader is referred to *Soil Screening Guidance: Technical Background Document* (US EPA, 1996a).

iii. Dermal Contact with Contaminants in Soil/Sediment

Much uncertainty surrounds the determination of risks/hazards from skin contact with soils/sediment. One important data gap is the lack of EPA-verified toxicity values for the dermal route of exposure. For screening purposes, it is assumed that dermal toxicity values can be extrapolated from oral values, but this may not always be an appropriate assumption and should be checked.

Chemical-specific dermal absorption values for contaminants in soil and dust have been derived for the following chemicals: arsenic; cadmium; chlordane; 2,4-D (2,4-dichlorophenoxyacetic acid); dichloro-diphenyl-trichloro-ethane

(**DDT**); lindane; polycyclic aromatic hydrocarbons; pentachlorophenols; polychlorinated biphenyls ; and tetrachloro-dibenzo-dioxin (**TCDD**) (*RAGS/HHEM* Part E: *Supplemental Guidance for Dermal Risk Assessment Guidance* [US EPA, 1999c, as cited in US EPA, 1999b]). For other nonvolatile organic chemicals without dermal absorption value, the default skin absorption fraction is assumed to be 10 percent. No default dermal absorption values are recommended for inorganic compounds and VOCs; dermal exposure to inorganic chemicals and VOCs without dermal absorption factors should be evaluated qualitatively in the uncertainty analysis. The RAGS/HHEM Part E (US EPA, 1999c, as cited in US EPA, 1999b) also recommends new values for exposed skin surface areas of 5,700, 3,300, and 2,800 cm^2/day for adult residents, adult workers, and children, respectively. EPA-recommended new age-specific soil-to-skin adherence factors are 0.07, 0.2, and 0.2 mg/cm^2 for adult residents, adult workers, and children, respectively. For more details regarding the justification for these new values, the reader is referred to RAGS/HHEM Part E (US EPA, 1999c).

b. Derivation of Risk-based Screening Levels for Ground Water and Surface Water

Under residential land use scenario, risk/hazard from COPCs in ground water or surface water is assumed to be due, primarily, to direct ingestion and inhalation of volatiles from household water (tap water). Although additional exposure pathways (e.g., dermal absorption, etc.) are possible and can result in substantial dose or dose rate for some contaminants, only ingestion and inhalation of COPCs present in tap water are considered for the screen.

The equations used to calculate the MSLs for tap water simultaneously combine risks/hazards from two exposure routes: ingestion and inhalation of volatiles. These models are presented in Equations 5 and 6 in Appendix A.

i. Ingestion and Inhalation of Contaminants in Tap Water

Calculation of MSLs for ingestion and inhalation of COPCs in household water is based on the method presented in RAGS/HHEM Part B (US EPA, 1991a). Ingestion of drinking water is an appropriate pathway for all contaminants; however, inhalation of volatile COPCs from water will be considered only for chemicals with a Henry's Law constant of 1×10^{-5} atm-m^3/mole or greater **and** with a molecular weight of less than 200 g/mole.

For volatile COPCs in tap water, an upper-bound volatilization constant (VF_w) is used. The VF_w is based on all uses of household water (e.g., showering, laundering, dish washing, etc.). It is assumed that the volume of water used in a residence for a family of four is 720 L/day, the air volume in the dwelling is 150,000 L and the air exchange rate is 0.25 air changes/hour (US EPA, 1991a). Furthermore, it is assumed that the average transfer efficiency weighted by water use is 50 percent[16] (i.e., half of the concentration of each chemical in water will be transferred into air by all water uses).

5. Screening Sites for Human Health Risk/Hazard

Screening sites for human health risks or hazards involves the comparison of the maximum COPC concentration in the environmental medium of concern with its respective human health risk-based MSL. Section 3.0 provides a technical discussion of methods for deriving MSLs for individual COPCs in each environmental medium.

In general, the MSLs for soil/sediment are intended for application to surface and near-surface soils/sediments. Note, however, that inhalation risk from fugitive dust results from soil particle entrainment; therefore, COPC concentrations in the surface soil horizon (usually the top 2 centimeters [cm] or deeper if activities at a site could redistribute subsurface soils to the surface) are of primary concern for this pathway. The entire column of contaminated soil[17] can contribute to volatile chemical emissions at a site; however, the top 2 cm of soil are likely to be depleted of volatile COPCs at most sites. Therefore, COPC concentrations in subsurface soils are of primary concern for estimating the risk from volatile COPCs.

It is also important to note that MSLs alone are not synonymous with cleanup levels. Other factors such as odor threshold lower than MSL may impact media cleanup levels.

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[16]The average 50 percent of transfer efficiency of volatiles from water to the indoor air is based on the radon data obtained by Prichard and Gesell (Prichard, 1987; Prichard and Gesell, 1981). The radon transfer efficiencies (i.e., percent volatilization) varies from 30 percent for toilets to 90 percent for dishwashers in a typical home (i.e., four occupants per residence using on average of 720 L of water per day; 150,000 L dwelling volume; 0.25 air changes per hour). The authors noted that the most "sensitive" dwellings (small apartments) were small, relatively tight structures in which large amounts of radon-rich water are used in household appliances and baths. The radon transfer efficiencies ranged over a factor of 50 depending on the dwelling type (i.e., from 50 percent for 150,000 L small apartments to 1 percent for 680,000 L larger older structure).

[17]Site-specific conditions (i.e., the vertical extent of contamination) will dictate the depth of contaminated soil which should be evaluated.

The following step-wise approach is required for screening sites for human health risks or hazards:

Step 1: Calculate human health risk-based MSL for individual COPCs in various media for both carcinogenic and non-carcinogenic effects as described in Section 3. **Note that, if multiple carcinogens are present at a site, the MSLs for individual carcinogens should be based on a target risk (TR) of 10^{-6} (see Equations 1, 3, 5, and 7 in Appendix A). If multiple non-carcinogens are present at a site, the MSLs for individual non-carcinogenic COPCs should be calculated by using a target hazard level (TH) of 0.1 in Equations 2, 4, 6, and 8 in Appendix A** (see also Section 3.b *Target Risk and Target Hazard*).

Step 2: Separate COPCs for which carcinogenic and non-carcinogenic MSLs were obtained and exclude, but do not eliminate, those COPCs for which saturation-based MSLs were calculated. These excluded COPCs should be addressed separately and according to the procedure outlined in Section 3.1.2.1.

Step 3: Divide the maximum contaminant medium concentration by the carcinogenic or non-carcinogenic MSL of the COPC. This ratio represents a screening quotient[18] (**SQ**).

$$SQ_i = MC_i / MSL_i$$

where:

SQ_i = Screening quotient of "ith" COPC (unitless)
MC_i = Maximum site-specific medium concentration of "ith" COPC (mg/kg [soil/sediment], µg/L [water], or µg/m^3 [air])
MSL_i = Medium- and contaminant-specific screening level (mg/kg [soil/sediment], µg/L [water], or µg/m^3 [air])

Generally, SQs of 1 or less are considered "safe" or "acceptable." Therefore, at those sites where COPC concentrations fall below their respective MSLs, no further action or evaluation may be warranted. A ratio greater than 1 suggests that further evaluation, investigation, or stabilization, but not necessarily cleanup, may be necessary. Further evaluation may include additional sampling or a refinement of other conservative assumptions inherent in the MSLs (e.g., a modification of exposure factor default values for a specific site, etc.).

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[18]Screening quotient represents the ratio of a single chemical maximum concentration in a given medium to the risk-based chemical-specific screening level for this medium.

6. Analysis of Uncertainties

The analysis of uncertainties for MSLs can serve as an important basis for the following:

- Identifying contaminants that require further evaluation, and/or
- Identifying areas that require further evaluation after remediation has been completed.

Human health risk-based MSLs are associated with varied levels of uncertainty involving many factors (e.g., confidence that anticipated future land use is correct, etc.). To place risk-based MSLs that have been developed for a site in proper perspective, an assessment of the uncertainties associated with the COPC concentrations should be conducted. This assessment should be similar to the uncertainty assessment discussed in RAGS/HHEM Part A (US EPA, 1989) and in the more recent *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (US EPA, 1998). Much of the uncertainty assessment conducted for a site-specific risk assessment is directly applicable to the uncertainty analysis of the risk-based MSLs.

Each component of risk-based MSLs - from media of potential concern to target risk/hazard level - should be examined and the major areas of uncertainty discussed. For example, the uncertainty associated with the selected future land use scenario and the accuracy of the technical models used (e.g., for volatilization of contaminants from soil, etc.) to reflect site-specific conditions (present and future) should be discussed. If site-specific exposure assumptions have been made, it is particularly important to document the data supporting those assumptions and evaluate their relevance for potentially exposed populations at or near the site.

Many assumptions regarding the RME individual(s) are incorporated into the COPC- and medium-specific screening levels. Although MSLs are believed to be fully protective for the RME individual(s), the proximity to other nearby sources of exposure (e.g., other hazardous waste sites, naturally-occurring background contamination, presence of groups of population with high dietary intake of COPCs, etc.) and/or the existence of the same contaminants in multiple media, may lead to a situation where, even after attainment of all MSLs, protectiveness is not clearly achieved (i.e., cumulative risks may fall outside the risk range). Therefore, the likelihood that these factors (naturally occurring background and/dietary contaminants, multiple pathways, other areas of concern or potential release sites, or other sources of contaminants) will affect the RME individual(s) should be addressed when analyzing uncertainties.

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APPENDIX A

HUMAN HEALTH RISK-BASED SCREENING-LEVEL EQUATIONS

HUMAN HEALTH RISK-BASED SCREENING-LEVEL EQUATIONS

The algorithms used to calculate the MSLs for carcinogenic and non-carcinogenic COPCs are presented in Equations 1 through 8. The MSL equations have been obtained from RAGS/HHEM Part B (US EPA, 1991a) and the more recent *Soil Screening Guidance: Technical Background Document* (US EPA, 1996a). The method back-calculates a soil/sediment, water and air concentration level from a target risk (carcinogenic effects) or target hazard (non-carcinogenic effects). For completeness, the soil equations simultaneously combine risks/hazards from ingestion, skin contact, and inhalation; the tap water equations combine risk/hazards from ingestion and inhalation.

Equation 9 calculates a COPC-specific volatilization factor used to derive MSL for volatile COPCs in soil/sediment. The algorithm for deriving soil/sediment saturation concentration is presented in Equation 10. Finally, Equation 11 presents the algorithm for deriving the generic (default) soil-to-air particulate emission factor of 1.316x 10^9 m^3/kg. **Pathway-specific exposure factors and their default values for these equations can be found in Appendix B.**

SOIL/SEDIMENT SCREENING-LEVEL EQUATIONS

The following equations are based on three soil/sediment exposure routes: ingestion, skin contact, and inhalation:

Equation 1: Combined Exposures to Carcinogenic Contaminants

$$MSL = \frac{TR \times AT_c}{EF_r \left[\left(\frac{IFS_{adj} \times CSF_o}{10^6 mg/kg}\right) + \left(\frac{SFS_{adj} \times ABS \times CSF_o}{10^6 mg/kg}\right) + \left(\frac{InhF_{adj} \times CSF_i}{VF_s^*}\right)\right]}$$

in Residential Soil/Sediment

Equation 2: Combined Exposures to Non-carcinogenic Contaminants in Residential Soil/Sediment

$$MSL = \frac{TH \times BW_c \times AT_n}{(EF_r \times ED_c) \times [(\frac{1}{RfD_o}) \times (\frac{IRS_c}{10^6 mg/kg}) + (\frac{1 \times SA_c \times AF \times ABS}{RfD_o \times 10^6 mg/kg}) + (\frac{1}{RfD_i} \times \frac{IRA_c}{VF_s*})]}$$

Equation 3: Combined Exposures to Carcinogenic Contaminants in Industrial Soil/Sediment

$$MSL = \frac{TR \times BW_a \times AT_c}{EF_o \times ED_o [(\frac{IRS_o \times CSF_o}{10^6 mg/kg}) + (\frac{SA_a \times AF \times ABS \times CSF_o}{10^6 mg/kg}) + (\frac{IRA_a \times CSF_i}{VF_s^*})]}$$

Equation 4: Combined Exposures to Non-carcinogenic Contaminants in Industrial Soil/Sediment

$$MSL = \frac{TH \times BW_a \times AT_n}{EF_o \times ED_o[(\frac{1}{RfD_o} \times \frac{IRS_o}{10^6 mg/kg}) + (\frac{1}{RfD_o} \times \frac{SA_a \times AF \times ABS}{10^6 mg/kg}) + (\frac{1}{RfD_i} \times \frac{IRA_a}{VF_s^*})]}$$

* Use VF_s for volatile chemicals (defined as having a Henry's Law Constant [atm-m^3/mol] greater than 10^{-5} and a molecular weight less than 200 grams/mol) or PEF for non-volatile chemicals.

TAP WATER SCREENING-LEVEL EQUATIONS

The following equations are based on two tap water exposure routes: ingestion and inhalation.

Equation 5: Ingestion and Inhalation Exposures to Carcinogenic Contaminants in Tap Water

$$MSL = \frac{TR \times AT_c \times 1000 ug/mg}{EF_r [(IFW_{adj} \times CSF_o) + (VF_w \times InhF_{adj} \times CSF_i)]}$$

Equation 6: Ingestion and Inhalation Exposures to Non-carcinogenic Contaminants in Tap Water[19]

$$MSL = \frac{TH \times BW_a \times AT_n \times 1000 ug/mg}{EF_r \times ED_r \left[\left(\frac{IRW_a}{RfD_o}\right) + \left(\frac{VF_w \times IRA_a}{RfD_i}\right)\right]}$$

AIR SCREENING-LEVEL EQUATIONS

Equation 7: Inhalation Exposures to Carcinogenic Contaminants in Air

$$MSL = \frac{TR \times AT_c \times 1000 ug/mg}{EF_r \times InhF_{adj} \times CSF_i}$$

Equation 8: Inhalation Exposures to Non-carcinogenic Contaminants in Air

$$MSL = \frac{TH \times RfD_i \times BW_a \times AT_n \times 1000 ug/mg}{EF_r \times ED_r \times IRA_a}$$

SOIL-TO-AIR VOLATILIZATION FACTOR EQUATION

Equation 9: Derivation of the Volatilization Factor[20]

$$VF_s = (Q/C) \times \frac{(3.14 \times D_A \times T)^{1/2}}{(2 \times \rho_b \times D_A)} \times 10^{-4} (m^2/cm^2)$$

where:

$$D_A = \frac{[(\Theta_a^{10/3} D_i H' + \Theta_w^{10/3} D_w)/n^2]}{\rho_b K_d + \Theta_w + \Theta_a H'}$$

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[19]For the residential scenario, a child's exposure factors should be substituted for the adult exposure factors (indicated by the 'a' subscript).

[20]From EPA's *Soil Screening Guidance: Technical Background Document* (US EPA, 1996a).

and where:

Parameter	Definition (units)	Default
VF_s	Volatilization factor (m^3/kg)	Calculated value; Chemical-specific
D_A	Apparent diffusivity (cm^2/s)	Calculated value; Chemical-specific
Q/C	Inverse of the mean concentration at the center of a 0.5-acre square source (g/m^2-s per kg/m^3)	68.81
T	Exposure interval (s)	9.5×10^8
ρ_b	Dry soil bulk density (g/cm^3)	1.5
Θ_a	Air filled soil porosity (L_{air}/L_{soil})	0.28 or n-Θ_w
n	Total soil porosity (L_{pore}/L_{soil})	0.43 or 1 - (ρ_b/ρ_s)
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15
ρ_s	Soil particle density (g/cm^3)	2.65
D_i	Diffusivity in air (cm^2/s)	Chemical-specific
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific
H'	Dimension-less Henry's Law constant	H x 41 (where 41 is a units conversion factor)
D_w	Diffusivity in water (cm^2/s)	Chemical-specific
K_d	Soil-water partition coefficient (cm^3/g)	Chemical-specific or K_{oc} x f_{oc} (organics)
K_{oc}	Soil organic carbon-water partition coefficient (cm^3/g)	Chemical-specific
f_{oc}	Fraction of organic carbon in soil (g/g)	0.006 (0.6%)

SOIL SATURATION EQUATION

Equation 10: Derivation of the Soil Saturation Concentration[14]

$$C_{sat} = \frac{S}{\rho_b}(K_d\rho_b + \Theta_w + H'\Theta_a)$$

Parameter	Definition (units)	Default
C_{sat}	Soil saturation concentration (mg/kg)	Calculated value; chemical specific
S	Solubility in water (mg/L-water)	Chemical-specific
ρ_b	Dry soil bulk density (kg/L)	1.5
ρ_s	Soil particle density (kg/L)	2.65
K_d	Soil-water partition coefficient (L/kg)	Chemical-specific or K_{oc} x f_{oc} (organics)
k_{oc}	Soil organic carbon/water partition coefficient (L/kg)	Chemical-specific
f_{oc}	Fraction organic carbon content of soil (g/g)	0.006 or site-specific
Θ_w	Water-filled soil porosity (L_{water}/L_{soil})	0.15
Θ_a	Air filled soil porosity (L_{air}/L_{soil})	0.28 or n-Θ_w
n	Total soil porosity (L_{pore}/L_{soil})	0.43 or 1 - (ρ_b/ρ_s)
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific

H'	Dimension-less Henry's Law constant	H x 41 (where 41 is a units conversion factor)

SOIL-TO-AIR PARTICULATE EMISSION FACTOR (PEF) EQUATION

Equation 11: Derivation of the Particulate Emission Factor[14]

$$PEF = Q/C \times \frac{3600 s/h}{0.036 \times (1-V) \times (U_m/U_t)^3 \times F(x)}$$

where:

Parameter	Definition (units)	Default
PEF	Particulate emission factor (m^3/kg)	1.316×10^9
Q/C	Inverse of the mean concentration at the center of a 0.5-acre-square source (g/m^2-s per kg/m^3)	90.80
V	Fraction of vegetative cover (unitless)	0.5
U_m	Mean annual wind speed (m/s)	4.69
U_t	Equivalent threshold value of wind speed at 7 m (m/s)	11.32
F(x)	Function dependent on U_m/U_t derived using Cowherd (1985) (unitless)	0.194

APPENDIX B

EXPOSURE FACTORS AND THEIR DEFAULT VALUES

EXPOSURE FACTORS AND THEIR DEFAULT VALUES

Symbol	Definition (units)	Default Value	Reference
CSF_o	Cancer slope factor oral [$(mg/kg\text{-}d)^{-1}$]	NA[21]	US EPA IRIS, HEAST (1997a), or NCEA
CSF_i or URF[22]	Cancer slope factor inhaled [$(mg/kg\text{-}d)]^{-1}$ or unit risk factor ($m^3/\mu g$)	NA	US EPA IRIS, HEAST (1997a), or NCEA
RfD_o	Reference dose oral (mg/kg-d)	NA	US EPA IRIS, HEAST (1997a), or NCEA
RfD_i or RfC[23]	Reference dose inhaled (mg/kg-d) or reference concentration (mg/m^3)	NA	US EPA IRIS, HEAST (1997a), or NCEA
TR	Target cancer risk for multiple carcinogens	10^{-6}	--
	Target cancer risk for a single carcinogen	10^{-5}	--
TH	Target hazard quotient for a single non-carcinogen	1	--
	Target hazard quotient for multiple non-carcinogens	0.1	--
BW_a	Body weight; adult (kg)	70	US EPA, 1989
BW_c	Body weight; child (kg)	15	US EPA, 1991b
AT_c	Averaging time; carcinogens (days)	25,550	US EPA, 1989

[21] *NA* means not applicable.

[22] See Section 3.c *Toxicity Values* for equations used to calculate CSF_i from URF.

[23] See Section 3.c *Toxicity Values* for equations used to calculate RfD_i from RfC.

Symbol	Definition (units)	Default Value	Reference
AT_n	Averaging time; non-carcinogens (days)	ED*365	US EPA, 1989
SA_a	Exposed skin surface area; adult resident (cm^2/day)	5,700	US EPA, 1999c
	Exposed skin surface area; adult worker (cm^2/day)	3,300	US EPA, 1999c
SA_c	Exposed skin surface area; child (cm^2/day)	2,800	US EPA, 1999c
AF_a	Soil-to-skin adherence factor; adult resident (mg/cm^2)	0.07	US EPA, 1999c
	Soil-to-skin adherence factor; adult worker (mg/cm^2)	0.2	US EPA, 1999c
AF_c	Soil-to-skin adherence factor; child (mg/cm^2)	0.2	US EPA, 1999c
	Skin absorption (unitless):		
ABS	-- nonvolatile organics – volatile organics – inorganics	0.1 – –	US EPA, 1999c
IRA_a	Inhalation rate; adult (m^3/day)	20	US EPA, 1991b
IRA_c	Inhalation rate; child (m^3/day)	10	US EPA, 1989; 1997c
IRW_a	Drinking water ingestion; adult (L/day)	2	US EPA, 1989
IRW_c	Drinking water ingestion; child (L/day)	1	California EPA, 1994
IRS_a	Soil ingestion; adult (mg/day)	100	US EPA, 1991b

Symbol	Definition (units)	Default Value	Reference
IRS_c	Soil ingestion; child (mg/day)	200	US EPA, 1991b
IRS_o	Soil ingestion; occupational (mg/day)	50	US EPA, 1991b
EF_r	Exposure frequency; residential (days/year)	350	US EPA, 1991b
EF_o	Exposure frequency; occupational (days/year)	250	US EPA, 1991b
ED_r	Exposure duration; residential (years)	30[24]	US EPA, 1991b
ED_c	Exposure duration; child (years)	6	US EPA, 1991b
ED_o	Exposure duration; occupational (years)	25	US EPA, 1991b
	AGE-ADJUSTED FACTORS FOR CARCINOGENS		
IFS_{adj}	Ingestion factor, soils ([mg•year]/[kg•day])	114	US EPA, 1991a
SFS_{adj}	Skin contact factor, soils ([mg•year]/[kg•day])	361	By analogy to US EPA, 1991a
$InhF_{adj}$	Inhalation factor, air ([m^3•year]/[kg•day])	11	By analogy to US EPA, 1991a
IFW_{adj}	Ingestion factor, water ([l•year]/[kg•day])	1.1	By analogy to US EPA, 1991a
	OTHER FACTORS		
VF_w	Volatilization factor for water (L/m^3)	0.5	US EPA, 1991a

[24]For non-carcinogenic effects, the exposure duration for lifetime residents is assumed to be 30 years total. For carcinogenic effects, exposures are combined for children (6 years) and adults (24 years).

Symbol	Definition (units)	Default Value	Reference
PEF	Particulate emission factor (m^3/kg)	1.316×10^9	US EPA, 1996a
VF_s	Volatilization factor for soil (m^3/kg)	See *Equation 9*	US EPA, 1996a
C_{sat}	Soil saturation concentration (mg/kg)	See *Equation 10*	US EPA, 1996a

APPENDIX C

CHEMICAL NAMES AND THEIR SURROGATES[25]

[25]Modified from US EPA, 1999c.

CHEMICAL NAMES AND THEIR SURROGATES

CHEMICAL NAME	SURROGATE NAME
Bromobenzene	Chlorobenzene
1-Chlorobutane	2-Chloro-1,3-butadiene
1-Chloro-1,1-difluoroethane	Dichlorodifluoromethane
Chlorodifluoromethane	Dichlorodifluoromethane
2-Chloropropane	1,2-Dichloropropane
o-Chlorotoluene	Chlorobenzene
Crotonaldehyde	Methyl methacrylate
Ethyl ether	Bis(2-chloroethyl) ether
Ethyl methacrylate	Methyl methacrylate
Methacrylonitrile	Acetonitrile
Methyl acetate	Acetone
Methyl acrylate	Methyl methacrylate
Methyl styrene (mixture)	Styrene
Methyl styrene (alpha)	Styrene
iso-Propylbenzene	tert-Butylbenzene
n-Propylbenzene	n-Butylbenzene
1,2,3-Trichloropropene	1,2,3-Trichloropropane
Triethylamine	Dimethylamine
Vinyl bromide	Bromoethane