

Arizona Department of Health Services

Deterministic Risk Assessment Guidance



Prepared by the ADHS Office of Environmental Health

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PREFACE

This document provides guidance for parties using deterministic risk assessment to evaluate the potential health threat that may be posed by any property or site. The guidance essentially summarizes and streamlines risk assessment guidance developed by the United States Environmental Protection Agency (USEPA).

The risk assessment approach recommended here is modeled after USEPA guidance issued by the agency in 1989 in a document entitled *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A)*. This document also incorporates recent studies from the scientific risk assessment literature and supplemental USEPA guidance.

This document has not been sanctioned for use by the USEPA or the Arizona Department of Environmental Quality (ADEQ). However, the concepts, equations, assumptions and narrative are consistent with USEPA risk assessment guidance, and are generally accepted in the scientific community as a reasonable approach in evaluating environmental health risks.

The Arizona Department of Health Services (ADHS) recognizes that alternative risk assessment methods that use Monte Carlo and other analytical methods may be used to more accurately quantify and evaluate health risks. The deterministic approach used in this guidance document is not intended to imply that the deterministic approach is the only acceptable method for evaluate human health risks from environmental contamination. Rather, it is intended to provide guidance for those who wish to use a deterministic approach to evaluate health risks.

PART A

SITE-SPECIFIC REMEDIATION LEVELS

1.0 INTRODUCTION

This document provides guidance for parties using risk assessment to develop site-specific health-based cleanup levels. The approach outlined in Part A uses simplified default equations while still allowing the flexibility to consider site-specific conditions at the site. The approach uses a summary document that describes the methodology used to calculate the standards, but does not require the development of a complete human health risk assessment.

1.1 Overview

Site-specific remediation levels may be developed using the equations in this document by substituting site soil properties for the default soil parameters in the standardized SRL equations (ADHS, 1997) and/or by using more complex equations that consider mass limits and finite sources. Site-specific remediation levels may also be developed by eliminating incomplete exposure pathways if the Conceptual Site Model (CSM) supports such a decision.

1.2 Requirements

A party developing site-specific remediation levels should develop a backup document that presents the methodology used to develop the alternative standards. The document should include the following elements:

- **A CSM that identifies the sources of contamination, the types and concentrations of chemicals detected in various media, chemicals of concern, potential exposure pathways and exposure points;**
- **An exposure component that quantifies the magnitude of exposure from each complete pathway and route;**

- A toxicity component that discusses the dose-response values for carcinogenicity and systemic toxicity, and discusses the USEPA Weight of Evidence (WoE) classification for carcinogens; and
- A summary that displays the formulas, assumptions, calculations, and final proposed site-specific remediation levels.

2.0 CONCEPTUAL SITE MODEL DEVELOPMENT

A CSM should be completed before developing site-specific remediation levels. The CSM is a representation of the connections between contaminant sources, release mechanisms, exposure pathways, and receptors. The complexity of the CSM should be consistent with the complexity of the specific site and available information.

A CSM is developed by conducting an extensive record search and site visit, and by compiling all of the existing data including site sampling data, historical records, aerial photographs, hydrogeologic information and population locations. Once this information is organized, the risk assessment team identifies the sources of contamination, the types and concentrations of chemicals detected in various media, potential exposure pathways and exposure points. The CSM links contaminant sources, release mechanisms, exposure pathways and routes, and receptors.

The development of a CSM is usually interactive. Model development should begin as early in the site investigation process as possible. It is developed to identify data gaps and determine data needs. The preliminary model should be revised following additional data collection efforts to refine the potential sources, transport media, exposure pathways, and receptors identified. The ASTM Standard E 1689-95: *Guide for Developing Conceptual Site Models for Contaminated Sites* (ASTM 1995) provides additional information to develop a CSM.

3.0 EXPOSURE ASSESSMENT

Site-specific remediation levels may be developed using a combination of site-specific factors and standard default exposure assumptions and equations. In addition, more complex models for estimating inhalation exposure may be used. When applicable, incomplete exposure pathways may be eliminated from the exposure equations.

3.1 Site Specific Factors

Site-specific remediation levels may be developed using the equations in this document by substituting soil properties at the site for the default parameters and/or by using alternative models for evaluating inhalation. Site-specific remediation levels may also eliminate incomplete exposure pathways if the CSM supports such a decision. However, engineering controls may not be used to eliminate exposure pathways for sites that have potential future residential uses. The options that may be considered when evaluating exposure include:

- Modifying the default exposure equations to eliminate incomplete exposure pathways;
- Substituting site-specific soil properties in the default Arizona SRL equations to obtain alternative exposure estimates;
- Using a mass-limit equation and site-specific characteristics to calculate alternative exposure estimates;
- Using more complicated finite source models to develop site-specific exposure estimates.

3.1.1 Incomplete Exposure Pathways

If the results of the CSM suggest that an exposure pathway is not complete (ie. ingestion, inhalation, dermal contact), then the default equations may be modified by eliminating the applicable exposure component in the denominator of Equations 1 through 4. The report should provide documentation that supports the conclusion to eliminate any exposure pathway.

3.1.2 Alternatives for Quantifying Inhalation Exposure Concentrations

Alternative approaches for evaluating inhalation exposure will include the development of site-specific volatilization factors (VFs) for volatiles and particulate emission factors (PEFs) for nonvolatiles. Volatile constituents are defined as chemicals that meet all of the following volatility criteria: 1) a Henry's Law constant greater than 10^{-5} (atm-m³/mol), 2) a molecular weight of less than 200 g/mole, and 3) a melting point of less than 25°C.

There is a range of acceptable methods for quantifying inhalation exposure. The first is to substitute site-specific soil characteristics for the default parameters using the default equations (Equations 5 and 7). The second approach for volatiles uses Equation 8 to account for mass-limits of contaminants at the site. The third approach for volatiles applies a more complicated finite source model (Equation 9). All of the VF models are applicable when the contaminant concentration in soil is at or below saturation (i.e., there is no NAPL present). Equation 6 displays the formula for determining site-specific saturation limits.

Default Equations

Site-specific remediation levels may be developed by substituting measured soil and physical properties at the site for default assumptions in the standard VF and PEF equations. Equation 5 displays the default equation for volatiles. Site soil properties for porosity, bulk density, and organic carbon content may be substituted for the default assumptions. The resulting site-specific VF may then be substituted for the default VF in Equations 1 through 4.

Equation 7 displays the default equation for non-volatiles. Site-specific properties for vegetative cover and average windspeed may be substituted for the default assumptions. The resulting site-specific PEF may then be substituted for the default PEF in Equations 1 through 4.

Mass-limit Equation for Volatiles

The USEPA has identified Equation 8 as a suitable method for determining minimum values for VF under site-specific conditions (USEPA 1996a,b). The formula used in the default model (Equation 5) assumes that contamination at the site extends from the surface to an infinite depth. Equation 8 provides a method for testing whether this assumption violates mass-limitations at the site. The mass-limit equation is applicable when contamination extends from the surface for a known fixed thickness in the soil column. Thus, application of the model requires site-specific information about the thickness of the contamination and contaminant concentrations.

If the VF calculated using Equation 5 for a contaminant is less than the VF calculated using Equation 8, then the assumption that the contamination extends from the surface to an infinite depth may be too conservative, and the site-specific VF from Equation 8 may be substituted for the default VF in Equations 1 through 4.

Finite Source Models for Volatiles

The USEPA has identified Equation 9 as a suitable model for addressing finite contaminant sources (USEPA 1996a). The model is based on a flux model developed by Jury (Jury et al.1990) that estimates flux of a contaminant from a finite source. The model is applicable when contamination extends from the surface for a known fixed thickness in the soil column. The model requires site-specific information about the thickness of the contamination and contaminant concentrations.

Application of the model to determine a VF value requires an average flux over the exposure period. To estimate the average contaminant flux over 30 years, the time-dependent contaminant flux must be solved for various times and the results averaged. A simple computer program or spreadsheet can be used to calculate the instantaneous flux of contaminants at set intervals and numerically integrate the results to estimate the average contaminant flux. The time-step interval must be small enough (e.g., 1-day intervals) to ensure that the cumulative loss through volatilization is less than the total initial mass. Inadequate time steps can lead to mass-balance violations (USEPA 1996a).

Alternatively, the EMSOFT computer program developed by the USEPA Office of Research and Development National Center for Environmental Assessment (NCEA) may be used to estimate average flux. The computer program provides an average emission flux over time by using an analytical solution to the integral, thereby eliminating the problem of establishing adequate time steps for numerical integration. EMSOFT is available through the NCEA in Washington, D.C.

When using the finite source model, the risk assessor should recognize the uncertainties inherent in site-specific estimates of subsurface contaminant distributions and use conservative estimates of source size and concentrations to allow for such uncertainties.

3.2 Default Exposure Assumptions

Default values for exposure frequency, exposure duration, ingestion or inhalation rates, skin surface area, and bodyweight should be used for any complete exposure pathway.

3.2.1 Residential Default Exposure Assumptions

Exposure Frequency, Exposure Duration, and Body Weight

Site-specific remediation levels should assume an exposure frequency of 350 days/year. The exposure duration for carcinogens should be assumed to be 30 years, with 6 of those years as a child and 24 years as an adult. Since exposure to contaminants in soil may be different for children and adults, carcinogenic risks during the first 30 years of life should be calculated using age-adjusted exposure factors. These factors integrate exposure from birth until age 30, combining contact rates,

body weights, and exposure durations for small children and adults. Default age-adjusted factors are included in Table 1. Exposure doses are averaged over a lifetime (70 years) for carcinogens (USEPA 1991b).

Site-specific remediation levels should be specifically protective of childhood exposure for systemic toxicity. Age-adjustment factors should not be used in evaluating systemic toxicity. Exposure assumptions should reflect childhood contact rates and body weight. The focus on children is protective of the higher daily intake rates by children and their lower body weight. For systemic toxicity, the exposure duration should be assumed to be 350 days/year for 6 years. Exposure doses are averaged over the period of exposure (6 years) for systemic toxicity (USEPA 1996c).

For carcinogens, site-specific remediation levels should be the lesser of the soil concentration based upon carcinogenicity using the age-adjusted factors and the concentration based upon systemic toxicity assuming childhood contact rates and body weight.

Ingestion Exposure

For carcinogens, residential site-specific remediation levels should use an age-adjusted soil ingestion factor that integrates ingestion rates, body weights, and exposure duration for small children and adults of 114 mg•yr/kg•day (USEPA 1996c).

An age-adjustment factor does not need to be used to evaluate systemic toxicity for site-specific remediation levels. Ingestion exposure should reflect a default childhood soil ingestion rate of 200 mg/day (USEPA 1991b).

Inhalation Exposure

Residential inhalation rates for carcinogens should use an age-adjusted inhalation factor that integrates inhalation rates, body weight, and exposure duration for small children and adults of 11 m³•yr/kg•day (USEPA 1996c).

An age-adjustment factor does not need to be used to evaluate systemic toxicity for site-specific remediation levels. Inhalation exposure should reflect the default childhood inhalation rate of 10 m³/day and default body weight of 15 kg (USEPA 1989,1991a,b).

Dermal Contact

Site-specific remediation levels may assume standard default absorption values of 1% for inorganics and 10% for all other contaminants (Cal-EPA 1994). All exposure scenarios should assume a standard default skin adherence factor of 0.2 mg/cm² (USEPA 1992a).

For site-specific residential remediation levels, estimates of dermal contact with carcinogens should be quantified using an age-adjusted skin contact factor that integrates skin surface area, body weight, and exposure duration for small children and adults of 503 mg•yr/kg•day (USEPA 1996c).

Dermal contact with soils should be evaluated using a default childhood skin surface area of 2000 cm²/day and a default body weight of 15 kg (USEPA 1989,1992a).

3.2.2 Non-residential Default Exposure Assumptions

Exposure Frequency, Exposure Duration, and Body Weight

Non-residential site-specific remediation levels should assume an exposure frequency of 250 days/year, which represents the typical number of workdays in a year. The exposure duration should be assumed to be 25 years, which corresponds with the standard default number of years in the workplace. Exposure doses should be averaged over a lifetime (70 years) for carcinogens. Exposure should be averaged over the period of exposure (25 years) for systemic toxicity (USEPA 1991b).

Ingestion Rates

Site-specific non-residential remediation levels should assume a standard default occupational soil ingestion rate of 50 mg/day (USEPA 1991b).

Inhalation Rates

Site-specific non-residential remediation levels should assume a standard default occupational inhalation rate of 20 m³/workday (USEPA 1991b).

Dermal Contact

Site-specific remediation levels may assume standard default absorption values of 1% for inorganics and 10% for all other contaminants (Cal-EPA 1994). All exposure scenarios should assume a standard default skin adherence factor of 0.2 mg/cm² (USEPA 1992).

Site-specific non-residential remediation levels should assume a standard default occupational adult skin surface area of 5000 cm²/day (USEPA 1992).

4.0 TOXICITY ASSESSMENT

Most site-specific remediation levels protect against toxic doses of systemic toxicants (a Hazard Quotient 1), and limit excess lifetime cancer risk to one-in-one million (10^{-6}) for known human carcinogens, and to one-in-one-hundred-thousand (10^{-5}) for possible and probable human carcinogens.

4.1 Toxicity Values

Site-specific remediation levels should use USEPA noncarcinogenic reference doses (RfD) and carcinogenic slope factors (SF) from the USEPA Integrated Risk Information System (IRIS), USEPA Health Effects Assessment Summary Tables (HEAST), and the USEPA National Center for Environmental Assessment (NCEA). The priority among sources of toxicological constants is as follows: (1) IRIS, (2) HEAST, (3) NCEA, and (4) withdrawn values from IRIS or HEAST and values under review.

Route-to-route extrapolations should be used when no toxicity values are available for a given route of exposure. For example, oral cancer slope factors and reference doses may be used for oral and inhalation exposure when organic compounds lack inhalation values. Inhalation slope factors and inhalation reference doses may be used for oral exposure for organic compounds that lack oral values. In addition, oral toxicity values may be used to calculate risk and hazard from dermal exposures (USEPA 1996c).

4.2 Weight of Evidence Classifications

The USEPA Carcinogen Advisory Group has grouped chemicals by weight-of-evidence (WoE) into classes from A to E, which designate their potential as a cancer-causing agent. The WoE represents the carcinogenicity evidence from human and animal studies and indicates the strength of the data. The A classification signifies that the chemical is a proven human carcinogen. Probable human carcinogens are designated either B1, showing that studies in humans are strongly suggestive but not conclusive, or B2 if the chemical has been conclusively carcinogenic in repeated animal studies but not conclusive in human studies. A chemical may be classified C, a possible human carcinogen,

if a single high-quality animal study or several low-quality animal studies suggest carcinogenicity. If there is insufficient human and animal evidence to determine the carcinogenicity of the chemical, it is classified as D. A chemical conclusively demonstrated to be non-carcinogenic to humans is in group E.

Site-specific remediation levels usually limit excess lifetime cancer risk to one-in-one million (10^{-6}) for known human carcinogens (WoE = A), and to one-in-one-hundred-thousand (10^{-5}) for possible and probable human carcinogens (WoE = B, C).

5.0 SUMMARY

Site-specific remediation levels may be developed using the equations in this document by substituting soil properties at the site for the default parameters and/or by using alternative models for evaluating inhalation. Site-specific remediation levels may also eliminate incomplete exposure pathways if the CSM supports such a decision. The options that may be considered when evaluating exposure include:

- Modifying the default exposure equations to eliminate incomplete exposure pathways;**
- Substituting site-specific soil properties in the default Arizona SRL equations to obtain alternative exposure estimates;**
- Using a mass-limit equation and site-specific characteristics to calculate alternative exposure estimates; and**
- Using more complicated finite source models to develop site-specific exposure estimates.**

Equations 1 through 9 may be used to calculate site-specific cleanup standards by applying exposure and toxicity criteria, and a target risk for carcinogenicity and a hazard quotient for systemic toxicity. For carcinogens, site-specific remediation levels should be the lesser of the concentration in soil based upon carcinogenicity or systemic toxicity.

Equation 1 displays the formula for calculating site-specific residential remediation levels based upon carcinogenicity. Equation 2 displays the formula for calculating site-specific residential remediation levels based upon systemic toxicity. Equation 3 displays the formula for calculating site-specific non-residential remediation levels based upon carcinogenicity. Equation 4 displays the

formula for calculating non-residential site-specific remediation levels based upon systemic toxicity. Table 1 displays the acceptable exposure factors for each equation.

Equation 5 may be used to calculate site-specific VFs for volatile contaminants by substituting site-specific physical properties for the default parameters. Equations 8 and 9 provide methods for calculating VFs that consider mass-limits and finite sources.

Inhalation of chemicals adsorbed to respirable particles (PM_{10}) may be assessed using a default PEF equal to 1.316×10^9 m³/kg that relates the contaminant concentration in soil with the concentration of respirable particles in the air from fugitive dust emissions. Alternatively, Equation 7 may be used to set site-specific PEFs.

Site-specific remediation levels should develop a backup document that presents the methodology used to develop the alternative standards. The document normally includes the following elements:

- A CSM that identifies the sources of contamination, the types and concentrations of chemicals detected in various media, chemicals of concern, potential exposure pathways and exposure points;
- An exposure component that quantifies the magnitude of exposure from each complete pathway and route;
- A toxicity component that discusses the dose-response values for carcinogenicity and systemic toxicity, and discusses the USEPA WoE classification for carcinogens; and
- A summary that displays the formulas, assumptions, calculations, and final proposed site-specific remediation levels.

Table 1: STANDARD DEFAULT FACTORS

Symbol Definition (units) Default Reference

CSFo Cancer slope factor oral (mg/kg-d)⁻¹ -- IRIS, HEAST, or NCEA

CSFi Cancer slope factor inhaled (mg/kg-d)⁻¹ -- IRIS, HEAST, or NCEA

RfDo Reference dose oral (mg/kg-d) -- IRIS, HEAST, or NCEA

RfDi Reference dose inhaled (mg/kg-d) -- IRIS, HEAST, or NCEA

TR_A Target cancer risk (WoE = A)^a 10⁻⁶ --

TR_{B,C} Target cancer risk (WoE = B1, B2, C)^b 10⁻⁵ -- —

THQ Target hazard quotient 1 --

BW_a Body weight, adult (kg) 70 RAGS (Part A), USEPA 1989 (EPA/540/1-89/002)

BW_c Body weight, child (kg) 15 Exposure Factors USEPA 1991b (OSWER No. 9285.6-03)

AT_c Averaging time - carcinogens (days) 25550 RAGS(Part A), USEPA 1989 (EPA/540/1-89/002)

AT_n Averaging time - noncarcinogens (days) ED*365

SA_a 25% Surface area, adult (cm²/day) 5000 Dermal Assessment, USEPA 1992(EPA/600/8-91/011B)

SA_c 25% Surface area, child (cm²/day) 2000 Dermal Assessment, USEPA 1992a (EPA/600/8-9/011B)

AF Adherence factor (mg/cm²) 0.2 Dermal Assessment, USEPA 1992a (EPA/600/8-9/011B)

ABS Skin absorption (unitless):

-- organics 0.1 Cal-EPA 1994

--Inorganics 0.01 Cal-EPA 1994

IRA_a Inhalation rate - adult (m³/day) 20 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

IRA_c Inhalation rate - child (m³/day) 10 RAGS (Part A), USEPA 1989 (EPA/540/1-89/002)

IRS_a Soil ingestion - adult (mg/day) 100 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

IRS_c Soil ingestion - child (mg/day), 200 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

IRS_o Soil ingestion - occupational (mg/day) 50 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

EFr Exposure frequency - residential (d/y) 350 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

EFo Exposure frequency - occupational (d/y) 250 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

EDr Exposure duration - residential (years) 30^c Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

EDc Exposure duration - child (years) 6 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

EDo Exposure duration - occupational (years) 25 Exposure Factors , USEPA 1991b (OSWER No. 9285.6-03)

Age-adjusted factors for carcinogens:

IFSadj Ingestion factor, soils ([mg_y]/[kg_d]) 114 RAGS(Part B) , USEPA 1991a (OSWER No. 9285.7-01B)

SFSadj Skin contact factor, soils ([mg_y]/[kg_d]) 503 By analogy to RAGS (Part B)

InhFadj Inhalation factor ([m³_y]/[kg_d]) 11 By analogy to RAGS (Part B)

PEF Particulate emission factor (m³/kg) 1.396 x 10⁺⁹ Soil Screening Guidance (USEPA 1996a,b)

VFs Volatilization factor for soil (m³/kg) Chem. Specific Soil Screening Guidance (USEPA 1996a,b)

sat Soil saturation concentration (mg/kg) Chem. Specific Soil Screening Guidance (USEPA 1996a,b)

Footnotes:

^a USEPA Carcinogenic Weight of Evidence (WoE) Classification for Known Human Carcinogens

^b USEPA Carcinogenic Weight of Evidence (WoE) Classification for Probable Human Carcinogens (WoE = B1 or B2) and Possible Human Carcinogens (WoE = C)

^c Exposure duration for lifetime residents is assumed to be 30 years. For carcinogens, exposures are integrated for childhood (6 years) and adulthood (24 years).

Equations

Equation 1: Combined Exposures to Carcinogenic Contaminants in Residential Soil (USEPA 1996c)



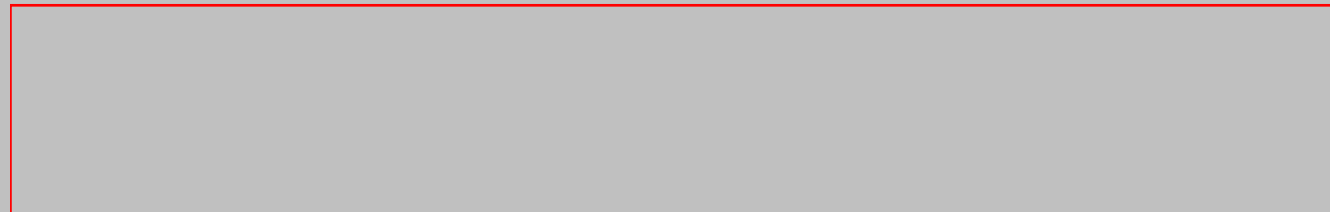
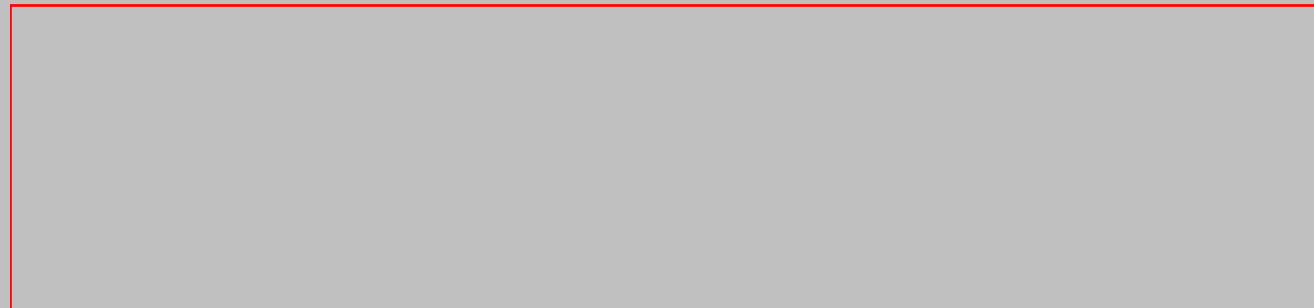
**Equation 2:
Combined
Exposures to
Noncarcinogenic
Contaminants in**

Residential Soil (USEPA 1996c)

**Equation 3:
Combined
Exposures to
Carcinogenic
Contaminants in
Non-residential
Soil (USEPA 1996c)**



**Equation 4:
Combined
Exposures to
Noncarcinogenic
Contaminants in
Non-residential
Soil (USEPA
1996c)**



Footnote:

^a Volatilization Factor (VF_s) is used for VOCs. Particulate Emission Factor (PEF) is used for semi-volatile and non-volatile constituents.

Equation 5: Derivation of the Volatilization Factor (USEPA 1996c)

where:

Parameter Definition (units) Default

VF_s Volatilization factor (m^3/kg) --

D_A Apparent diffusivity (cm^2/s) --

**Q/C Inverse of the mean conc. at the center of a
0.5-acre square source ($g/m^2\cdot s$ per kg/m^3) 68.81**

T Exposure interval (s) 9.5×10^8

b Dry soil bulk density (g/cm^3) 1.5 (or site-specific)

a Air filled soil porosity (L_{air}/L_{soil}) 0.28 (or site-specific)

n Total soil porosity (L_{pore}/L_{soil}) 0.43 (or site-specific)

w Water-filled soil porosity (L_{water}/L_{soil}) 0.15 (or site-specific)

s Soil particle density (g/cm^3) 2.65 (or site-specific)

D_i Diffusivity in air (cm^2/s) Chemical-specific

H Henry's Law constant ($atm\cdot m^3/mol$) Chemical-specific

H' Dimensionless Henry's Law constant H x 41 (USEPA 1991a)

D_W Diffusivity in water (cm^2/s) Chemical-specific

K_d Soil-water partition coefficient (cm^3/g) = $K_{oc}f_{oc}$ Chemical-specific

K_{oc} Soil organic carbon-water partition coefficient Chemical-specific (cm^3/g)

f_{oc} Fraction organic carbon in soil (g/g) 0.006 (or site-specific)

Equation 6: Derivation of the Soil Saturation Limit (USEPA 1996c)

Parameter
Definition (units)
Default



sat Soil saturation concentration (mg/kg) --

S Solubility in water (mg/L-water) Chemical-specific

b Dry soil bulk density (kg/L) 1.5 (or site-specific)

n Total soil porosity ($L_{\text{pore}}/L_{\text{soil}}$) 0.43 (or site-specific)

s Soil particle density (kg/L) 2.65 (or site-specific)

K_d Soil-water partition coefficient (L/kg) $K_{\text{oc}} \times f_{\text{oc}}$ (chemical-specific)

k_{oc} Soil organic carbon/water

partition coefficient (L/kg)

f_{oc} Fraction organic carbon content of soil (g/g) 0.006 (or site-specific)

w Water-filled soil porosity ($L_{\text{water}}/L_{\text{soil}}$) 0.15 (or site-specific)

a Air filled soil porosity ($L_{\text{air}}/L_{\text{soil}}$) 0.28 (or site-specific)

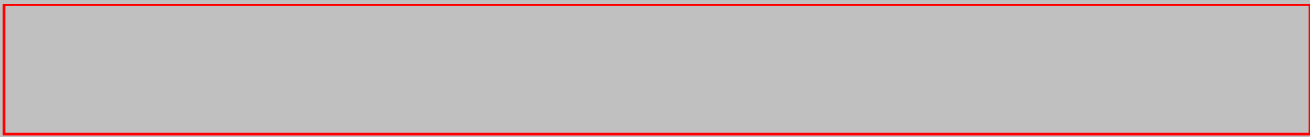
w Average soil moisture content) 0.1 (or site-specific)

($\text{kg}_{\text{water}}/\text{kg}_{\text{soil}}$ or $L_{\text{water}}/\text{kg}_{\text{soil}}$)

H Henry's Law constant ($\text{atm}\cdot\text{m}^3/\text{mol}$) Chemical-specific

H' Dimensionless Henry's Law constant $H \times 41$, where 41 is a units conversion factor

Equation 7: Derivation of the Particulate Emission Factor (USEPA 1996c)



Parameter Definition (units) Default

PEF Particulate emission factor (m³/kg) 1. 316 x 10⁹

Q/C Inverse of the mean concentration at the center of a 0.5-acre-square source (g/m²-s per kg/m³) 90.80

V Fraction of vegetative cover (unitless) 0.5 (or site-specific)

U_m Mean annual windspeed (m/s) 4.69 (or site-specific)

U_t Equivalent threshold value of windspeed at 7 m (m/s) 11.32 (or site-specific)

F(x) Function dependent on U_m/U_t derived using Cowherd (1985) (unitless) 0.194

Cowherd (1985) (unitless)

Equation 8: Mass-Limit Model of the Inhalation of Volatiles (USEPA 1996a)

$$VF = (Q/C) \times [(T \times 3.15E+7 \text{ s/yr}) / (v_b \times d_s \times 1E+6 \text{ g/Mg})]$$

where:

Parameter Definition (units) Default

VF Volatilization factor (m³/kg) --

Q/C Inverse of the mean conc. at the center of a

0.5-acre source (g/m²-s per kg/m³) 68.81

T Exposure interval (yr) 30

b_d Dry soil bulk density (kg/L) 1.5 (or site-specific)

d_s Thickness of the contaminated soil (m) site-specific

Equation 9: Finite Source Model of the Inhalation of Volatiles (USEPA 1996a, Jury et al. 1990)

$$VF = (Q/C) \times (C_o/b) \times (1/J_s^{ave}) \times 10^{-4} \text{ m}^2/\text{cm}^2$$

where:

Parameter Definition (units) Default

VF_s volatilization factor (m³/kg) --

Q/C inverse of the mean conc. at the center of a

0.5-acre square source (g/m²-s per kg/m³) 68.81

C_o uniform contaminant concentration at =0 (g/cm³) site-specific

b_d soil dry bulk density (g/cm³) 1.5 (or site-specific)

J_s^{ave} average contaminant flux at ground surface (g/cm²-s) Equation 12

where:

$$J_s = C(D_A/l)^{1/2} [1 - \exp(-d_s^2/4D_A)]$$

and where:

$$D_A = [(2^{10/3} D_i H + w^{10/3} D_w)/n^2]/(b K_b + w + a H)$$

where:

Parameter Definition (units) Default

J_s^{ave} average contaminant flux over exposure period (g/cm²-s) --

C_o uniform contaminant concentration at =0 (g/cm³) Site-specific

D_A apparent diffusivity (cm²/s) Equation 13

Pi 3.14

time(s) solve daily from =0 to 30 years

d_s depth from the soil surface to the base of site-specific

contamination at = 0 (cm)

n_a air-filled soil porosity (L_{air}/L_{soil}) = $n - w$ 0.28 (or site-specific)

n total soil porosity ($L_{pore}/L_{soil} = 1 - (b/s)$ 0.43 (or site-specific)

w water-filled soil porosity (L_{water}/L_{soil}) = $w_{b/w}$ 0.15 (or site-specific)

b soil dry bulk density (g/cm³) 1.5 (or site-specific)

s soil particle density (g/cm³) 2.65 (or site-specific)

D_i diffusivity in air (cm²/s) chemical-specific

H dimensionless Henry's law constant = 41 x H chemical-specific

H Henry's law constant (atm-m³/mol) chemical-specific

D_W diffusivity in water (cm²/s) chemical-specific

K_d soil-water partition coefficient (cm³/g) = $K_{oc} f_{oc}$ chemical-specific

K_{oc} soil organic carbon partition coefficient (cm³/g) chemical-specific

f_{oc} organic carbon content of soil (g/g) 0.006 (or site-specific)

PART B

DETERMINISTIC RISK ASSESSMENT GUIDANCE

1.0 INTRODUCTION

This section provides guidance for parties using a complete risk assessment to develop site-specific cleanup standards. The approach outlined in Part B provides more flexibility in characterizing risks and setting site-specific remediation levels than the options available in Part A.

1.1 Organization

Risk assessments should use the standard USEPA approach (USEPA 1989). The organizational format should be as follows:

Chapter 1 *Introduction*- overview of the site, objectives of the risk assessment, site background, scope, conceptual site model, and study design;

Chapter 2 *Site Assessment*- sample design, sample locations, number, and media, analytical methods, quality assurance methods, contaminant boundaries;

Chapter 3 *Identification of Chemicals of Concern (COCs)*- data evaluation and presentation, selection methodology, identification of COCs, data uncertainties;

Chapter 4 *Exposure Assessment*- Identification of complete exposure pathways and quantification of current and potential future intakes;

Chapter 5 *Toxicity Assessment*- Identification of hazard and dose response data for the constituents selected as COCs;

Chapter 6 *Risk Characterization*- Presentation and discussion of actual and potential human health risks and discussion of uncertainties.

1.2 Overview and Objectives

1.2.1 Overview of the Site

Present an overview of the site including a summary of the investigations and remedial activity that has been conducted at the site. The discussion should include a description of the general problem at the site.

1.2.2 Risk Assessment Objectives

The risk assessment objectives should be clearly stated and should indicate the specific areas, media, and contaminants that will be addressed.

The objective of most risk assessments is to determine whether residual chemical levels are protective of human health, and to provide a basis for comparing the potential health impacts of various remedial alternatives.

1.3 Site Background

Present information on the known or potential source areas, and concentrations of hazardous substances involved in the release. Discuss other relevant records such as inspection data, photographs, and any removal actions conducted at the site. Describe the basic characteristics of the contamination in air, soil, soil gas and water at the site. The document should establish potential exposure pathways.

1.3.1 Site Description

The site should be described in detail. The general location of the site, the proximity to populated areas, and the possible routes of contaminant migration should be stated. Land uses in the surrounding area should be discussed.

1.3.2 Maps

A map that shows the site boundaries and surface topography with features such as fences, ponds, and structures should be included. The map should display the current layout of the site including the geographical relationship between potential receptors and the site.

1.3.3 History

Discuss the history of specific chemical use at the site including the methods by which chemicals were used and disposed. This section should include a chronology of land use, including the types of chemicals used at the site and operations at the site that may have resulted in the presence of residual contamination. The nature of the past uses of the site should help determine the types of contamination and impacted areas.

The nature of the contamination should be documented and linked to prior ownership and use, and specific site areas, where known. This section should also discuss the magnitude of the scoping activities undertaken to identify all potential site-related contaminants and how the results influenced the sampling plan.

1.4 Conceptual Site Model

A conceptual site model (CSM) is developed by conducting an extensive records search and site visit, and by compiling all of the existing data including site sampling data, historical records, aerial photographs, hydrogeologic information and population locations. Once this information is organized, the risk assessment team develops a CSM that identifies the sources of contamination, the types and concentrations of chemicals detected in various media, potential exposure pathways and exposure points. The CSM links contaminant sources, release mechanisms, exposure pathways and routes, and receptors.

The development of a CSM is usually interactive. Model development should begin as early in the site investigation process as possible. It is developed to identify data gaps and determine data needs. The preliminary model should be revised following additional data collection efforts to refine the potential sources, transport media, exposure pathways, and receptors identified. The pathways and receptors in the final model will be those evaluated throughout the remainder of the risk assessment. The ASTM Standard E 1689-95: Guide for Developing Conceptual Site Models for Contaminated Sites provides additional information to develop a CSM (ASTM 1995).

1.5 Scope and Design of the Risk Assessment

Present the scope of the report and a summary of the study design.

1.5.1 Scope

Discuss the scope and complexity of the risk assessment. Include whether the assessment is intended to apply to a small area on site, the entire facility, or the area around the facility including surrounding residential or nonresidential properties. Discuss the complexity of the report. For example, the assessment may use screening level assumptions or may use an approach that is more complex. The rationale for the selection of the approach should be discussed.

1.5.2 Study Design

Present an overview of the risk assessment methodology and study design. The discussion should include the sources of contamination, potentially complete exposure pathways, and potential receptors. Specific elements that influence the study design include:

- **The sample collection and analytical results including the selection of target compounds of concern and an evaluation of the confidence that all potential chemicals of concern have been identified;**
- **The degree of confidence that all locations that may be contaminated have been identified;**
- **An exposure evaluation including physical and chemical characteristics at the site including contaminant fate and transport;**
- **The types and numbers of potential receptors that may potentially be exposed to contaminants at the site.**

2.0 SITE ASSESSMENT

Data collection efforts conducted at the site should be identified in this section. The discussion should include the rationale for the sample design, a description of sample locations and media, the analytical methods used, the quality control procedures used, and a definition of the boundaries of the contamination.

2.1 Detailed Rationale for Sampling Design

State the rationale for the sampling design and include topics such as sample size and location, types of samples, choice of analytical methods, temporal and meteorological factors, and field screening analyses. Discuss how sample sizes and location were chosen, including the number of areas of concern investigated, the statistical methods used, and statistical performance standards (i.e. degree of confidence that the true mean is less than the mean from the sample data set). The sampling strategy should be adequate to characterize the site. The number of samples that need to be analyzed will depend upon site-specific conditions.

2.2 Sample Locations, Number, and Media

Identify the media sampled and provide information regarding sampling locations.

2.3 Definition of Modeling Parameters

Site-specific characteristics that may need to be quantified for use in fate/transport models include air filled and total porosity of the soil, soil bulk density, soil moisture, soil organic carbon content and average wind speed and direction. This section should include a discussion and a determination of the necessary parameters.

2.4 Analytical Methods for Sampling and Analysis

The procedures for sample collection, preservation, handling, and transport, and the laboratory analytical methods used should be discussed. The method detection limits for the contaminants for which analyses are conducted should be lower than the applicable SRL (ie. residential or non-residential) or an alternative site-specific risk-based concentration.

2.5 Quality Assurance/Quality Control (QA/QC) Methods

Discuss the data quality objectives, sampling methods, sampling devices, QC samples, collection procedures, and sample preservation methods. QC samples include field blanks, trip blanks, duplicates, and split samples. Collection procedures should not alter the samples which should be preserved to prevent any change in concentration. An appendix should contain the laboratory results for all QA/QC results including percent recovery of spike samples and results of sample blanks. The QA/QC results should be used to conclude whether the data quality objectives for the site have been satisfied. The USEPA has published a guidance document entitled "*Guidance for Data Useability in Risk Assessment*" (USEPA 1990a) which outlines proper procedures.

2.6 Definition of Contaminant Boundaries

In order to accurately evaluate risks, the horizontal and vertical extent of the contamination should be determined. The boundaries of the contamination should be identified or referenced in this section. The characterization should be adequate to estimate exposure concentrations at the site.

3.0 IDENTIFICATION OF CHEMICALS OF CONCERN

This section identifies the chemicals of concern (COCs) in each media. This section summarizes the criteria recommended for selecting COCs.

3.1 Evaluation of Chemical Data

Summarize the sampling results from each area of concern. The presentation should include both a narrative summary, and tables of the analytical results. Separate tables should be included for each media of concern. Each table should display the range and frequency of detection, and the mean and upper 95% confidence limit (UCL).

The distribution of the data with respect to the layout of the site should be included. The text should also mention whether the concentrations of chemicals were close to the detection limits, or whether there are areas that contain hotspots. Any areas that contain hotspots should be identified. Hotspots are areas that have one or more samples that contain concentrations of contaminants that exceed the relevant SRL by a factor of ten or more.

3.2 Identification of Chemicals of Potential Concern

The methodology used to select COCs in each media should be presented in this section. The recommend the approach presented in this section.

3.2.1 Soil

All chemicals detected in at least one soil sample should be considered COCs unless one of the following criteria are met:

- if the highest detected concentration in soil is less than the applicable SRL (i.e. residential or nonresidential);**
- if the compound was detected in less than 5% of the soil samples and no hotspots exist;**

- if the compound is present at similar levels under natural ambient conditions in the area (ie. background), and the contaminant concentration has not been increased by anthropogenic sources.

The USEPA document entitled *Establishing Background Levels* (USEPA 1995a) may be used to determine background levels of naturally occurring contaminants.

3.2.2 Soil Gas

All chemicals detected in at least one soil gas sample should be considered COCs unless one of the following criteria are met:

- if the highest detected concentration is less than the current USEPA Reference Concentration (RfC) or the Unit Risk at the one-in-one-million risk level (1E-6) for carcinogens with a WoE classification of "A" or at the one-in-one-hundred-thousand risk level (1E-5) for carcinogens with a WoE classification of "B or C". Details regarding these criteria are included in Chapter 4.
- if the compound was detected in less than 5% of the soil gas samples collected and no hotspots exist.

3.2.3 Surface Water/Sediment

All chemicals detected in at least one surface water/sediment sample should be considered COCs unless one of the following criteria are met:

- if the highest detected value downstream of the site is less than the highest detected value upstream of the site;
- if the highest detected concentration is less than the Aquifer Water Quality Standard.

3.2.4 Air

All chemicals detected in at least one sample should be considered COCs unless one of the following criteria are met:

- **if the highest detected value upwind of the site is less than the highest detected value downwind of the site;**
- **if the highest detected concentration is less than the current USEPA Reference Concentration (RfC) or the Unit Risk at the one-in-one-million risk level (1E-6) for carcinogens known human carcinogens (WoE classification of "A") or at the one-in-one-hundred-thousand risk level (1E-5) for probable and possible carcinogens (WoE classification of "B or C").**

3.2.5 Groundwater

All chemicals detected in at least one groundwater sample should be considered COCs unless if the highest detected concentration is less than the Aquifer Water Quality Standard (AWQS). In some cases, COCs should remain in the risk assessment even if their maximum concentration is present at less than the AWQS. For example, arsenic can significantly contribute to overall site risk even if it is present at less than the AWQS. A risk assessor should carefully evaluate site conditions before eliminating COCs in groundwater.

3.3 Data Uncertainties

Uncertainties in the sampling and laboratory procedures should be summarized and discussed in a qualitative and quantitative manner for each media. The discussion should include the uncertainties that may exist if data from multiple investigations were used. The QA/QC procedures used should be discussed including the results of sample blanks and spikes.

4.0 EXPOSURE ASSESSMENT

The exposure assessment expands upon and quantifies exposures discussed in the CSM. The CSM initially identifies the sources of contamination, the concentrations of chemicals detected in various media, potential exposure pathways and exposure points. The exposure assessment quantifies exposures identified in the CSM.

The exposure assessment integrates information on chemical releases, environmental measurements, and human activity to estimate the type and magnitude of exposure to COCs received. This is done by characterizing the exposure setting, exposure pathways, exposed populations (receptors), and by quantifying exposure concentrations and intakes.

4.1 Characterization of Exposure Setting

4.1.1 Physical Setting

The risk assessment should describe site-specific surface features that may influence human exposure such as geologic setting, vegetation, and types and locations of structures at the site. The following physical characteristics may influence exposure:

***Geology and Soils-*vegetation, underlying strata, air-filled and total porosity of the soil, soil moisture, soil bulk density, organic carbon content, and the depth of the contaminants below the ground surface**

***Meteorology-* temperature, precipitation, and wind speed and direction**

***Hydrology-* distance from the surface to groundwater, the direction of flow, surface hydrologic features and potential surface transport of contaminants**

4.1.2 Characterization of Potentially Exposed Populations

This section should describe the number and location of people who could be exposed to contaminants at the site including those who reside or work at or near the site, and sensitive subgroups such as children and elderly people. These sensitive receptors may be at higher risk due to higher exposures or greater susceptibility to the COCs.

4.1.2.1 Populations Relative to the Site

Using information from a site visit, population surveys, and maps, establish the number of people with potential exposure and their location relative to the site.

4.1.2.2 Current Land Use

Using zoning maps, census information, aerial photographs, and information from a site visit, characterize the activities and activity patterns of potentially exposed populations. Potential current land uses include residential, commercial/industrial, agricultural and recreational. Sites may have more than one land use. Identify any land use controls that may be in effect.

Determine the human activity patterns at the site, estimate the number of hours spent in these activities by the population and identify any site-specific characteristics influencing exposure. Important activity issues include the amount of time spent outdoors versus indoors, seasonal changes in activities, soil excavations, access restrictions, and paths showing activity trends.

4.1.2.3 Future Land Use

The risk assessment should identify any foreseeable future land uses, and should include the likelihood of each alternative future use. If future land uses may be residential, then future land uses should be assumed to be residential. Numerous future land uses may be evaluated in the risk assessment, however, the risk assessment team should keep in mind the objectives of the risk assessment when selecting future use exposure scenarios.

4.2 Exposure Pathways and Routes of Exposure

Summarize the potentially complete exposure pathways at the site. An exposure pathway is the course a contaminant takes from its source to a receptor or to a potential receptor, and consists of four elements:

- a source and mechanism of chemical release;
- a retention or transport medium;
- a point of potential human contact with contaminated medium;
- an exposure route at the point of contact (inhalation, ingestion, dermal contact).

All potential migration pathways including natural pathways such as volatilization of contaminants through soil and man made pathways such as conduits should be identified. All potential exposure routes should be explored including ingestion of soil, dermal absorption, and inhalation of vapors and dust. Engineering and institutional controls may be considered when identifying complete exposure pathways.

4.2.1 Source Identification

This section should identify potential release mechanisms and receiving media at the site. In some instances, the source itself is the exposure point. However, a contaminated medium from a past release can be a contaminant source for other media (e.g., contaminated surface soil contaminated may be a source to surface water or air).

4.2.2 Fate and Transport Evaluation

Exposure may be determined more precisely with a knowledge about the fate (i.e. behavior of a contaminant when released into a specific media) and transport (i.e. bioconcentration, soil adsorption/mobility, and volatilization) of a contaminant. An analysis of the fate and transport is conducted to identify media that may be receiving site-related chemicals. Following release of a chemical to the environment, it may be:

- transported (through soil, water, or air);
- physically transformed (volatilization, etc.);
- chemically transformed (photolysis, hydrolysis, oxidation, reduction);

- **biologically transformed (biodegradation);**
- **accumulated in one or more media.**

The above fate and transport mechanisms may be affected by physical characteristics such as moisture content, organic carbon content, bulk density, and soil porosity. Site-specific characteristics that may influence transport may include vapor barriers or other engineering controls.

Use all available information to evaluate transport within and between media and retention or accumulation within a single media. Monitoring data should be used to identify media that are currently contaminated and the pathways that may lead to future contamination.

4.2.3 Exposure Points and Routes

An exposure point is any location that serves as a potential contact to the contaminated medium. Any contaminated media should be considered a potential exposure point if the area is currently being used, if the site is not restricted, or if future land use suggests potential human contact to the contaminant. In general, most complete exposure points and routes will occur on-site. However, instances of off-site exposure may occur if contamination extends beyond the property boundaries via a transport mechanism. All exposure points at the site should be identified and discussed in this section. In addition, all potential exposure routes should be explored and discussed, including ingestion of soil, dermal absorption, and inhalation of vapors and fugitive dust.

4.2.4 Synthesis into Complete Exposure Pathways

Based on the information identifying the source, fate and transport of the COCs, and the exposure points and routes, a complete exposure pathway may be established. A summary of all complete exposure pathways, including the potentially exposed populations and the exposure media, points, and routes, should be included in the quantitative risk assessment. Complete exposure pathways should be summarized for current and future land uses. Excluding pathways from quantification should be justified and supported by the CSM.

A table that summarizes all current and potential future exposure pathways should be provided.

4.3 Quantification of Exposure Concentrations

Exposure concentrations in the various media for each exposure area should be calculated and presented in this section. The analysis should include parameters and assumptions in the model and backup documentation to defend the results.

The level of effort used to estimate exposure concentrations depends on the kind of data available, the level of detail in the risk assessment, the objectives of the risk assessment, and the resources available for the project. Estimating exposure concentrations will usually include a simple analysis of the data and application of simple methods that assume steady-state conditions. This section presents models consistent with this strategy. Alternative methods to estimate exposure concentrations may be used if the risk assessment team believes they are warranted. However, alternative methods should be well documented and use peer reviewed literature sources.

4.3.1 Estimating Exposure Concentrations Under Current Conditions

Exposure concentrations in soil should be quantified by calculating the 95% UCL of the arithmetic mean of the concentration of contaminants in each exposure area and media where human activity is occurring.

Surface Soils

The area over which human activity occurs and the spacial distribution of soil matrix data is a critical factor in determining exposure concentrations for surface soil. In general, data from random soil sampling programs or samples from evenly spaced grids can be considered representative of human exposure concentrations when contact with soil in all areas of the site is equally probable (USEPA 1989). At some sites, the contamination will not be evenly distributed and the soils will contain hotspots.

Data sets containing hotspots may be averaged if current contact with soil is spatially random. However, averaging contaminant concentrations from hotspots over a large area is inappropriate if human activity at the site is not spatially random. If a hotspot is near an area that is frequently used, exposure concentrations at the hotspot area should be assessed separately.

Subsurface Soils

The dominant exposure pathway when the primary contaminants are VOCs in subsurface soils is usually vapor phase diffusion into indoor and outdoor air and subsequent inhalation of the contaminants. Vapor phase migration of the COCs to the surface may be estimated using diffusion

modeling. Examples of approaches for estimating flux and outdoor air concentrations are presented in the Appendix. A number of acceptable mathematical models are presented in the SEAM (USEPA 1988) and the Air/Superfund National Technical Guidance Study Series Document: *Guideline for Predictive Baseline Emissions Estimation for Superfund Sites* (USEPA 1995b). Other models may be acceptable if the approach has been published in the peer-reviewed literature. Any model that is used should be validated by laboratory, pilot or field studies.

Diffusion models require an estimated or actual concentration of the contaminant in subsurface soil or soil gas. Often, contamination in the subsurface will contain hotspots. The spacial distribution of subsurface contamination may be a factor in evaluating monitoring data to estimate flux over an exposure area. If a hotspot is near an area that currently contains an occupied structure, soil gas or subsurface soil concentrations may be averaged over the area of the current structure to estimate flux when evaluating current exposures. In general, for contamination where no current structure exists, soil concentrations may be averaged over the area of current exposure in order to calculate flux. Acceptable models for calculating flux and air concentrations are provided in the Appendix.

4.3.2 Estimating Exposure Concentrations Under Future Conditions

Surface Soils

Data from random soil sampling programs or samples from evenly spaced grids can be considered representative of future human exposure concentrations if no hotspots were found. Similarly, data from purposive sampling plans may be considered representative of future human exposure concentrations if hotspots do not exist. However, for sites that contain hotspots, averaging hotspot data over a *maximum* area the size of a residential backyard (500 m²) may be the most appropriate way of estimating future residential exposure concentrations for direct exposure pathways (USEPA 1989). In some circumstances, it may be necessary to estimate future exposure concentrations at hotspots, without averaging any of the data, if the area may present a potential future non-cancer hazard to children. If the future use of the property is not residential, it may be appropriate to average surface soil data over the area which human activity currently occurs or over an area such as 2,000m² (0.5 acres).

Subsurface Soils

If a hotspot is near an area that currently contains an occupied structure, soil gas or subsurface soil concentrations may be averaged over the area of the current structure to estimate flux for future exposures if land uses are not anticipated to change. For contaminated areas where no current structure exists, averaging the data to estimate flux from hotspots over an area of a potential future house (200 m²) may be the best approach for estimating future residential exposures. For properties with nonresidential land uses, it may be appropriate to average subsurface data over a larger area (2,000m²) when estimating flux. Acceptable models for calculating flux and air concentrations are

provided in the Appendix.

4.3.3 Statistical Procedures

The contaminant concentration that should be used to exposure concentrations for all media is the 95 percent upper confidence limit (95% UCL) of the *arithmetic* mean concentration in each exposure area. Using the 95% UCL provides reasonable confidence that the true site average will not be underestimated. For data sets with limited sample numbers, the 95% UCL may be higher than the maximum detected level in the data set. If this occurs, the maximum detected concentration may be used as the estimate of the exposure concentration. Specific guidance calculating appropriate exposure concentration is provided in the Appendix.

4.4 Estimation of Chemical Intakes for Each Exposure Pathway

Exposure is the contact of a receptor with a chemical or physical agent. When exposure is standardized for time and body weight, it is designated as intake and expressed as a chronic daily intake (CDI) in mg of chemical per kg of body weight per day (mg/kg•day). The CDI is the quantity of a chemical, which is available for absorption at the exchange boundary (e.g., skin, lungs, gastrointestinal tract). It is different from the absorbed dose, which represents the concentration of the chemical in blood.

The reasonable maximum exposure (RME) is the highest exposure (CDI) that may *reasonably* be expected at a site, and applies to both current and future land use. The objective of an RME estimate is to join the upper-bound and mid-range exposure variables into an equation, resulting in an intake level that is reasonable, protective, and not the worse case. While central tendency exposures may be evaluated in the risk assessment, risk management decisions will usually be made using an RME estimate. Therefore, developing RME estimates will be required for all risk assessments, while developing an estimate of central tendency exposure is optional.

All potentially complete exposures should be quantified in this section. Residential exposure should be evaluated for adult and child receptors separately. The presentation should include worksheets that identify the assumptions and parameters in the evaluation. This section provides guidance for quantifying exposure.

4.4.1 Incidental Ingestion of Soils

The intake equation for incidental ingestion of soil is summarized in Table 4.4.1. Information about the site and professional judgement may be used to determine variable values for current exposure. Potential future residential exposures should incorporate the RME variables identified in Table 4.4.1. Potential future exposures for residential properties should include the residential childhood scenario. The exposure assumptions in the table are recommended for use by the USEPA (USEPA 1989,1991b).

Table 4.4.1 Formula Used to Calculate Intakes from Ingestion of Soils for Residential and Non-Residential (Occupational) Exposure Scenarios.

$$\text{CDI} = \frac{(\text{CS})(\text{CF})(\text{IR})(\text{EF})(\text{ED})}{(\text{BW})(\text{AT})}$$

Where:

CDI = Chronic Daily Intake (mg/kg-day)

CS = Chemical concentration in soil over exposure area (mg/kg)

CF = Conversion Factor (kg/10⁶ mg)

IR = Ingestion rate (mg/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (kg)

AT = Averaging time (period over which exposure is averaged-days)

Variable Values:

Occupational Residential Residential

Adult Child

CS: 95% UCL (mg/kg) 95% UCL (mg/kg) 95% UCL (mg/kg)

IR: 50 (mg/day) 100 (mg/day) 200 (mg/day)

EF: 250 (days/year) 350 (days/year) 350 (days/year)

ED: 25 (years) 30 (years) 6 (years)

BW: 70 (kg) 70 (kg) 15 (kg)

AT: (carc.) 25,550 (days) 25,550 (days) 25,550 (days)

AT: (non-carc.) 9,125 (days) 10,950 (days) 2,190 (days)

4.4.2 Inhalation of Vapors and Particulates

The intake equations for inhalation of vapors and particulates are summarized in Tables 4.4.2.1 and 4.4.2.2, respectively. Information about the site and professional judgement may be used to determine variable values for current exposure. Potential future exposures should incorporate the RME variables identified in the tables. The exposure assumptions in the table are recommended for use by the USEPA (USEPA 1989, 1991b).

Acceptable models for estimating indoor and outdoor air concentrations are presented in the Appendix.

Table 4.4.2.1 - Formula Used to Calculate Intakes from Inhalation of Vapors for Residential and Non-Residential (Occupational) Exposure Scenarios.

**CHRONIC DAILY INTAKE: $CDI = (AC)(IR)(EF)(ED)$
 $(BW)(AT)$**

where:

AC = Chemical concentration in air (indoor or outdoor) (mg/m³)

IR = Inhalation rate (m³/day or workday)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (kilograms)

AT = Averaging time (days)

Variable Values:

Occupational Residential Residential

Adult Child

AC: 95% UCL (mg/m³) 95% UCL (mg/m³) 95% UCL (mg/m³)

IR: 20 (m³/workday) 20 (m³/day) 15 (m³/day)

EF: 250 (workdays/year) 350 (days/year) 350 (days/year)

ED: 25 (years) 30 (years) 6 (years)

BW: 70 (kg) 70 (kg) 15 (kg)

AT: (carc.) 25,550 (days) 25,550 (days) 25,550 (days)

AT: (non-carc.) 9,125 (days) 10,950 (days) 2,190 (days)

Table 4.4.2.2 - Formula Used to Calculate Intakes from Inhalation of Particulates for Residential and Non-Residential (Occupational) Exposure Scenarios

$$\text{CDI} = \frac{(\text{CS})(\text{PEF})(\text{IR})(\text{EF})(\text{ED})}{(\text{BW})(\text{AT})}$$

where:

CDI = Chronic daily intake (mg/kg-day)

CS = Chemical concentration in surface soil (mg/kg)

PEF = Particulate Emission Factor (kg/m³)

IR = Inhalation rate (m³/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (kg)

AT = Averaging time (period over which exposure is averaged-days)

Variable Values:

Occupational Residential Residential

Adult Child

CS: 95% UCL (mg/kg) 95% UCL (mg/kg) 95% UCL (mg/kg)

PEF: 7.16E-10 (kg/m³) 7.16E-10 (kg/m³) 7.16E-10 (kg/m³)

IR: 20 (m³/workday) 20 (m³/day) 15 (m³/day)

EF: 250 (days/year) 350 (days/year) 350 (days/year)

ED: 25 (years) 30 (years) 6 (years)

BW: 70 (kg) 70 (kg) 15 (kg)

AT: (carc.) 25,550 (days) 25,550 (days) 25,550 (days)

AT: (non-carc.) 9,125 (days) 10,950 (days) 2,190 (days)

4.4.3 Dermal Exposure Estimation Methods

Many inorganic chemicals are poorly absorbed through dermal contact and not all risk assessments will require a quantitative evaluation of intake via dermal absorption. However, for compounds such as pesticides, dermal absorption may significantly contribute to total exposure. Therefore, dermal contact and absorption may be evaluated on a case by case basis. All sites should at least qualitatively evaluate the potential for dermal exposure. At sites where dermal contact may significantly contribute to exposure, dermal exposure should be quantitatively evaluated. Table 4.4.3 provides guidance for quantifying dermal exposure at sites where this is appropriate.

Variables used in the formula are taken from RAGS (USEPA 1989) and the USEPA Dermal Assessment (USEPA 1992a). Skin surface area (SA) available for contact was usually assumed to be 5,000 cm²/day, which is 25% of the surface area of an average adult (USEPA 1992a). The surface area for childhood exposure here assumes an exposed surface area of 2,000 cm²/day (USEPA 1992a). The soil adherence factor (AF) was assumed to be 0.2 mg/cm² (USEPA 1992a).

Table 4.4.3 - Formula Used to Calculate Transient and Occupational CDI From Dermal Absorption of Contaminants in Soil

$$\text{CDI} = \frac{(\text{CS})(\text{CF})(\text{SA})(\text{AF})(\text{ABS})(\text{EF})(\text{ED})}{(\text{BW})(\text{AT})}$$

where:

CDI = Chronic Daily Intake (mg/kg-day)

CS = Chemical Concentration in Soil (mg/kg)

CF = Conversion Factor (1E-6 kg/mg)

SA = Skin Surface Available for Contact (cm²/day)

AF = Soil to Skin Adherence Factor (mg/cm²)

ABS = Absorption Factor (unitless)

EF = Exposure Frequency (days/year)

ED = Exposure Duration (years)

BW = Body Weight (kg)

AT = Averaging Time (period over which exposure is averaged-days)

Variable Values:

Occupational Residential Residential

Adult Child

CS: 95%UCL (mg/kg) 95% UCL (mg/kg) 95% UCL(mg/kg)

SA: 5,000 (cm²/day) 5,000 (cm²/day) 2,000 (cm²/day)

AF: 0.2 (mg/cm²) 0.2 (mg/cm²) 0.2 (mg/cm²)

ABS: chemical specific chemical specific chemical specific

EF: 250 (days/year) 350 (days/year) 350 (days/year)

ED: 25 (years) 30 (years) 6 (years)

BW: 70 (kg) 70 (kg) 70 (kg)

AT: (carc.) 25,550 (days) 25,550 (days) 25,550 (days)

AT: (non-carc) 9,125 (days) 10,950 (days) 2,190 (days)

4.5 Identification of Uncertainties

This section should discuss the major assumptions of the exposure assessment, the uncertainties associated with each assumption, and how these uncertainties influence the exposure estimates.

4.6 Summary of the Exposure Assessment

A summary of the exposure assessment should be presented in tabular form. The table presents quantitative estimates of exposure from each pathway. The information should be separated into current and potential future exposures. The summary of potential future exposures should include exposures under a "no action alternative" but may also include exposures that may occur following potential remedial alternatives such as installation of a vapor barrier or other engineering controls.

5.0 TOXICITY ASSESSMENT

The toxicity assessment provides information about the potential for contaminants to cause adverse health effects in exposed individuals and an estimate of the relationship between exposure and the increased likelihood of adverse effects.

5.1 Information for Noncarcinogenic Effects

Toxicity information about noncarcinogenic effects for each chemical of concern at the site should be summarized and presented in this section. Information that should be provided includes the

following:

- **Current chronic reference doses (RfDs) and reference concentrations (RfCs) for each chemical of concern. The uncertainty and modifying factors used in the determination of the toxicity value also should be included.**
- **The database from which the toxicity value was taken (IRIS or HEAST)**

In general, it is inappropriate to adjust an RfD to account for absorption (ie. bioavailability) unless it is expressed as an absorbed dose. However, dermal exposures are expressed as the amount of the substance absorbed per day, and it will often be appropriate to derive an absorbed dose RfD from an administered dose value for use in calculating non-cancer hazard. Occasionally, it may be appropriate to adjust for relative absorption efficiencies for other pathways such as ingestion if the RfD is based upon a medium of exposure (i.e., soil matrix vs. water or corn oil) that does not exist at the site. However, any such adjustments should be well referenced, and should only be done by a qualified toxicologist (USEPA 1989).

5.2 Information for Carcinogenic Effects

The USEPA has developed carcinogenicity weight of evidence (WoE) classifications for many chemicals. The WoE represents the carcinogenicity evidence from human and animal studies, and indicates the strength of the data. An A classification signifies that the chemical is a known human carcinogen. Probable human carcinogens are designated either B1, showing that studies in humans are strongly suggestive but not conclusive, or B2 if the chemical has been conclusively carcinogenic in repeated animal studies but not conclusive in human studies. A chemical may be classified C, a possible human carcinogen, if a single high-quality animal study or several low-quality animal studies suggest carcinogenicity. If there is insufficient human and animal evidence to determine the carcinogenicity of the chemical, it is classified as D. A chemical conclusively shown to be non-carcinogenic to humans is in group E.

The WoE classification for each of the COCs should be identified. These designations will be used in the Risk Characterization to separate risks presented by known human carcinogens and the possible and probable human carcinogens.

Toxicity information about carcinogenic effects for each chemical of concern at the site should be summarized and presented in this section. Information that should be provided includes the following:

- **Current slope factors (SF) and WoE for all carcinogens for oral and inhalation exposures**

- **The database from which the slope factor was taken (IRIS or HEAST)**

The chemicals of concern at most sites will generally have toxicity values available. If a site has chemicals of concern without toxicity values, the ADHS should be contacted regarding the use of substitute toxicity values.

In general, it is inappropriate to adjust a SF to account for absorption (i.e., bioavailability) unless the SF is expressed as an absorbed dose. However, dermal exposures are expressed as the amount of the substance absorbed per day, and it will often be appropriate to derive an absorbed dose SF from an administered dose value for use in calculating risk. Occasionally, it may be appropriate to adjust for relative absorption efficiencies for other pathways such as ingestion if the SF is based upon a medium of exposure (i.e., soil matrix vs. water or corn oil) that does not exist at the site. However, any such adjustments should be very well referenced, and should only be done by a qualified toxicologist (USEPA 1989).

5.3 Summary of Toxicity Information

A short description of the toxic effects of each chemical of concern should be included in the text in this section. The summary of toxic effects of a COC should highlight any toxic effect which may be important at the site. For example, if sensitive groups are present, the toxicity for that group should be included in the summary. It should also be noted that most toxicity studies are conducted for acute or subchronic exposure, while chronic exposure is usually being evaluated in risk assessments of this type. If a large number of COCs have been identified, toxicological profiles may be included in an appendix.

5.4 Uncertainties Related to Toxicity Information

The uncertainties inherent in developing RfDs and Slope Factors should be briefly presented in this section. Many of these uncertainties are identified in RAGS.

6.0 RISK CHARACTERIZATION

Current and potential future risks should be characterized in this chapter using the exposure and toxicology information in the risk assessment. The risk characterization should be presented in a quantitative and qualitative format. Calculations should include risks from all chemicals of concern for each identifies exposure route and for all exposure routes combined.

The RME is the highest exposure that may *reasonably* be expected at a site, and applies to both current and future land use. While central tendency exposures and risk may be evaluated in the risk assessment, risk management decisions will usually be made using an RME estimate. Therefore, developing RME estimates is required for all risk assessments, while developing an estimate of central tendency exposure is optional.

In most cases, both excess lifetime carcinogenic risk (ELCR) and non-carcinogenic hazard quotients (HQ) should be assumed to be additive when more than one chemical of concern is present. Values for individual chemical specific values are summed to obtain an estimate of ELCR. Hazard Quotients for most chemicals should be summed to develop the Hazard Index (HI). In some cases, it may be appropriate to develop one or more HIs if the toxic endpoint of the individual constituents differ. Details on this procedure are provided in Section 6.1.2.

6.1 Current Land Use and Exposures

6.1.1 Excess Lifetime Cancer Risk Under Current Conditions

This section of the risk assessment should provide a narrative discussion of the methodology and exposure assumptions used to develop the cancer risk estimates. Following this discussion, the risk assessment should present the quantitative results. The risk assessment should then provide explanatory text that interprets and qualifies the results.

Carcinogenic risk is calculated as the incremental probability of an individual developing cancer over a lifetime (70 years) due to exposure to a carcinogenic compound. This is also called ELCR and represents the increased risk of developing cancer above the background rate, estimated at 30%. Total ELCR is expressed as a probability.

Carcinogenic risks are based on calculations developed in the following order. Information on exposure pathways, exposure concentrations, and toxicology are assembled or calculated. CDIs are then calculated using assumptions from the exposure and toxicity values. Chemical specific carcinogenic slope factors (SF) are used to convert estimated CDI, averaged over a lifetime, to incremental risk. The ELCR for each exposure pathway is then summed to estimate total ELCR.

The dose-response relationship is considered linear under the low dose conditions usually encountered in environmental exposures. In consideration of this assumption, the SF is a constant and risk is directly related to intake. The linear low-dose cancer risk equation is:

$$\text{ELCR} = \text{CDI} \times \text{SF}$$

where:

ELCR = a unitless excess probability of an individual developing cancer;

CDI = Chronic Daily Intake averaged over 70 years (mg/kg-day);

SF = Slope Factor, expressed in (mg/kg-day)⁻¹.

The resulting ELCR estimates for current land uses should be summarized and presented in a table. The following tables should be presented in the text:

- **The ELCR for multiple substances for each currently complete exposure pathway. ELCR estimates for known human carcinogens (WoE = A) should be displayed separately.**
- **The sum of the ELCR estimates for all currently complete exposure pathways. The total ELCR estimates should be expressed using one significant figure. ELCR contributed by known human carcinogens should be specifically discussed.**

6.1.2 Systemic (Noncarcinogenic) Effects Under Current Conditions

This section of the risk assessment should provide a narrative discussion of the methodology and exposure assumptions used to develop the noncarcinogenic health effect results. Following this discussion, the risk assessment should present the quantitative results. The risk assessment should then provide explanatory text that interprets and qualifies the results.

Noncarcinogenic or systemic health effects may include neurotoxic, hepatotoxic, nephrotoxic, teratogenic, reproductive reactions, and any other non-cancer related systemic toxic responses. The potential for an individual to suffer a noncarcinogenic effect is not expressed as a probability, but as a ratio or quotient. The ratio is determined by comparing the CDI to the chemical specific RfD

which is not expected to produce toxic effects. The HQ is the ratio of an exposure level over a specified period (CDI) to the experimentally determined toxicity of the chemical RfD. The screening Hazard Index (HI) is the sum of all HQs for each pathway and chemical.

The HQ is calculated as follows:

$$\text{Non-cancer Hazard Quotient (HQ)} = \text{CDI/RfD}$$

where:

CDI = Daily Intake (dose) in mg/kg-day;

RfD = Reference Dose in mg/kg-day.

The screening HI is the sum of all HQs for multiple substances and pathways. This approach assumes that simultaneous subthreshold exposures to several chemicals could result in an adverse health effect. A limitation to this approach is that the assumption of dose additivity is most properly applied to compounds that induce the same effect by the same mechanism of action. Therefore, application of the hazard index equation to substances that do not act by the same mechanism could overestimate the potential for health effects. If the initial screening level HI exceeds 1, it may be appropriate to segregate the compounds by effect and mechanism of action to derive separate HIs for each group. However, the process of segregating HIs by mechanism and effect is complex, and such an analysis should only be done by a qualified toxicologist (USEPA 1989).

The resulting HIs for current land uses should be summarized in tables. The following tables should be presented in the text for current land use:

- Chronic Hazard Quotients or Indices for all substances for each current exposure pathway;
- Chronic Hazard Index for all current exposure pathways.

Hazard Quotients and Indices should be expressed using one significant figure.

6.2 Potential Future Land Use and Exposures

6.2.1 Excess Lifetime Cancer Risk Under Potential Future Conditions

This section of the risk assessment should provide a narrative discussion of the methodology and exposure assumptions used to develop the cancer risk estimates. Following this discussion, the risk assessment should present the quantitative results. The risk assessment should then provide explanatory text that interprets and qualifies the results.

The methodology for developing potential future risk estimates are identical to that of developing current risk estimates except that land uses and exposures may change in the future, resulting in different risk estimates. The risk analysis should include potential future risk under a "no action alternative" but may also include exposures that may occur following potential remedial alternatives such as installation of a cap or other actions that reduce potential future exposures.

Future land uses other than residential and commercial/industrial may be evaluated in the risk assessment, however, residential and/or commercial/industrial uses should always be included in the risk assessment.

6.2.2 Systemic (Noncarcinogenic) Effects Under Potential Future Conditions

This section of the risk assessment should provide a narrative discussion of the methodology and exposure assumptions used to develop the noncarcinogenic health effect results. Following this discussion, the risk assessment should present the quantitative results. The risk assessment should then provide explanatory text that interprets and qualifies the results.

The methodology for developing a potential future non-cancer hazard is identical to that of developing current risk estimates except that land uses and exposures may change in the future resulting in different hazard indices. The risk analysis should include potential future non-cancer hazard under a "no action alternative" but may also include exposures that may occur following potential remedial alternatives such as installation of a cap or other actions that reduce potential future exposures.

Future land uses other than residential and commercial/industrial may be evaluated in the risk assessment, however, residential and/or commercial/industrial uses should always be included in the risk assessment.

6.3 Uncertainties

This section addresses the uncertainties in the risk assessment. Possible sources of uncertainty include site-specific uncertainty errors, errors in estimating exposures, and uncertainties in the toxicity evaluation of chemicals.

Risk estimates are based upon a number of assumptions regarding contaminant concentrations, fate and transport, exposures, doses and toxicity information. The uncertainty at each of these stages should be recognized and discussed in a qualitative and quantitative manner. An analysis of risk factors and COCs as they relate to the contribution of total risk can simplify the uncertainty discussion and help identify meaningful risk assessment refinement strategies.

Uncertainties in the exposure assessment include most of the site-specific uncertainties inherent in risk characterization. Elements that need to be addressed are:

- **Definition of the physical setting, including the likelihood of exposure pathways and land uses actually occurring, and the possible presence of chemicals or degradation products that were not included in the risk assessment;**
- **Uncertainties in the diffusion model applicability and assumptions;**
- **Uncertainties in the fate, transport and exposure parameter values.**

Include a summary of the uncertainty in the toxicity values for the durations of exposure assessed for substances that contribute to estimates of cancer risk and non-cancer hazard indices. Refer to Chapter 8 in RAGS for a checklist of uncertainties that apply to toxicity assessments.

6.4 Summary Discussion and Tabulation of the Risk Characterization

Summarize the risk characterization results. The results of the risk assessment should not be taken as a characterization of absolute risk. An important use of the risk and hazard index estimate is to highlight potential sources of risk at a site so that it may be dealt with effectively in the remedial process. The discussion of the risk characterization results is a key component of this chapter. The discussion of risk should include:

- Discussion of confidence in site characterization, identification of all site-related contaminants, and contaminant concentrations and distributions;
- Level of confidence in the quantitative toxicity information used to estimate risks;
- Level of confidence in the exposure estimates, pathways and exposure parameter assumptions;
- The magnitude of the cancer risks and non-cancer hazard indices;
- The major factors driving the site risks such as chemicals, pathways, and pathway combinations;
- The major factors reducing the certainty in the results and their significance.

A tabular summary of the cancer risks and non-cancer hazard indices should be displayed for all identified exposure pathways and current and potential future land uses for all substances carried through the risk assessment. The tables should be accompanied by text, and should not stand alone as the entire risk characterization.

REFERENCES

Arizona Department of Health Services. 1997. *Arizona Soil Remediation Levels*. Office of Environmental Health, Environmental Health Sciences Section. Phoenix, Arizona. January 20, 1997.

ASTM 1995. *Guide for Developing Conceptual Site Models for Contaminated Sites*. Standard E 1689-95. Philadelphia, Pennsylvania.

California Environmental Protection Agency. 1994. *Preliminary Endangerment Assessment Guidance Manual*. Department of Toxic Substances Control, Sacramento, California.

Cowherd, C., Muleski, G., Engelhart, P. and Gillette D. 1985. *Rapid Assessment of Exposure to Particulate Emission from Surface Contamination*. EPA/600/8-85/002. Prepared for Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, D.C. NTIS PB85-192219 7AS.

Johnson, Paul C., and Ettinger, Robert A. 1991. *Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings*. Environmental Science and Technology, 25(8):1445-1452

Jury W.A., Spencer W.F., Farmer W.J. 1983. *Behavior Assessment Model for Trace Organics in Soil: Part I Model Description. Evaluation of Volatilization in Organic Chemicals Residing Below the Soil Surface*. Journal of Environmental Quality 12 (4): 558-564.

Jury W.A., Russo D., Streile G., and Abd H. 1990. *Evaluation of Volatilization in Organic Chemicals Residing Below the Soil Surface*. Water Resources Research 26 (1): 13-20.

Karimi A., Farmer W., Cliath M. 1987. *Vapor Phase Diffusion of Benzene in Soil*. Journal of Environmental Quality. Vol 16:1. p.38-43.

U.S. Department of Health and Human Services. 1989. *Toxicological Profile for Benzene*. Agency for Toxic Substances and Disease Registry. Atlanta, GA.

USEPA 1988. *Superfund Exposure Assessment Manual*. Office of Remedial Response . EPA/540/1-88/001. OSWER Directive 9285.5-1.

USEPA 1989. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A)*. Office of Emergency and Remedial Response, Washington, DC.

USEPA 1990a. *Guidance for Data Useability in Risk Assessment*. Office of Emergency and Remedial Response. Publication 9285.7-05.

USEPA 1990b. *Exposure Factors Handbook*. EPA/600/8089/043. Office of Health and

USEPA 1991a. *Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals)*. Publication 9285.7-01B. Office of Emergency and Remedial Response, Washington, D.C. NTIS PB92-963333.

USEPA 1991b. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*. Publication 9285.6-03. Office of Emergency and Remedial Response, Washington, DC. NTIS PB91-921314.

USEPA 1992a. *Dermal Exposure Assessment: Principles and Applications*. EPA/600/8-91/011B. Office of Health and Environmental Assessment, Washington, DC.

USEPA 1992b. *Supplemental Guidance to RAGS: Calculating the Concentration Term*. Office of Emergency and Remedial Response. Publication 9285.7-081.

USEPA 1992c. *Air/Superfund National Technical Guidance Study Series: Assessing Potential Indoor Air Impacts for Superfund Sites*. Office of Air Quality. EPA-451/R-92-002.

USEPA 1992d. *Supplemental Guidance to RAGS: Calculating the Concentration Term*. Office of Emergency and Remedial Response. Publication 9285.7-081

USEPA 1995a. *Establishing Background Levels*. EPA/540/F-94/030 Office of Solid Waste & ER. NTIS PB94-963313

USE PA 1995b. *Air/Superfund National Technical Guidance Study Series: Guidance for Predictive Baseline Emissions Estimation for Superfund Sites Interim Final*. Office of Air Quality Planning and Standards Research TP, NC 27711. EPA-4511 R-96-001 Nov 95

USEPA 1996a. *Soil Screening Guidance: Technical Background Document*. EPA/540/R-95/128. Office of Emergency and Remedial Response, Washington, D.C. PB96-963502.

. USEPA 1996b. *Soil Screening Guidance: User's Guide*. EPA/540/R-96/018. Office of Emergency and Remedial Response, Washington, DC. PB96-963505.

**USEPA 1996c. *Region IX Preliminary Remediation Goals (PRGs)*. August 1, 1996.
<http://www.epa.gov/region9>**

USEPA 1996d. *Integrated Risk Information System (IRIS)*. Duluth, MN.