CHAPTER 3

EXPOSURE ASSESSMENT

The exposure assessment evaluates the type and magnitude of exposures to chemicals of potential concern at a site. The exposure assessment considers the source from which a chemical is released to the environment, the pathways by which chemicals are transported through the environmental medium, and the routes by which individuals are exposed. Parameters necessary to quantitatively evaluate dermal exposures, such as permeability coefficients, soil absorption factors, body surface area exposed, and soil adherence factors are developed in the exposure assessment. In this chapter, the dermal assessment is evaluated for two exposure media: water (Section 3.1) and soil (Section 3.2).

EPA's *Policy for Risk Characterization* (U.S. EPA, 1995a) states that each Agency risk assessment should present information on a range of exposures (e.g., provide a description of risks to individuals in average and high end portions of the exposure distribution). Generally, within the Superfund program, to estimate exposure to an average individual (i.e., a central tendency), the 95% upper confidence limit (UCL) on the arithmetic mean is chosen for the exposure point concentration, and central estimates (i.e., arithmetic average, 50^{th} percentile, median) are chosen for all other exposure parameters. This guidance document provides recommended central tendency values for dermal exposure parameters, using updated information from the *Exposure Factors Handbook* (EFH) (U.S. EPA, 1997a).

In comparison with the average exposure, the "high end" exposure estimate is defined as the highest exposure that is reasonably expected to occur at a site but that is still within the range of possible exposures, referred to as the reasonable maximum exposure (RME) (U.S. EPA, 1989). According to the *Guidance on Risk Characterization for Risk Managers and Risk Assessors* (U.S. EPA, 1992b), risk assessors should approach the estimation of the RME by identifying the most sensitive exposure parameters. The sensitivity of a parameter generally refers to its impact on the exposure estimates, which correlates with the degree of variability of the parameter values. Parameters with a high degree of variability in the distribution of parameter values are likely to have a greater impact on the range of risk estimates than those with low variability. For one or a few of the sensitive parameters, the maximum or near-maximum values should be used, with central tendency or average values used for all other parameters. The high-end estimates are based, in some cases, on statistically based criteria (95^{th} or 90^{th} percentiles), and in others, on best professional judgment. In general, exposure duration, exposure frequency, and contact rate are likely to be the most sensitive parameters in an exposure assessment (U.S. EPA, 1989). In addition, for the dermal exposure route, the soil adherence factor term is also a very sensitive parameter. This guidance provides recommended upper end estimates for individual exposure parameters and a recommended RME exposure scenario for residential and industrial settings, using updated information from the EFH and other literature sources.

3.1 ESTIMATION OF DERMAL EXPOSURES TO CHEMICALS IN WATER

3.1.1 STANDARD EQUATION FOR DERMAL CONTACT WITH CHEMICALS IN WATER

The same mathematical model for dermal absorption recommended in DEA is used here. The skin is assumed to be composed of two main layers, the stratum corneum and the viable epidermis, with the stratum corneum as the main barrier. A two-compartment distributed model was developed to describe the absorption of chemicals from water through the skin as a function of both the thickness of the stratum corneum (l_{sc}) and the event duration (t_{event}). The mathematical representation of the mass balance equation follows Fick's second law and is a partial differential equation with concentration as a function of both time and distance. The exact solution of this model is approximated by two algebraic equations: (1) to describe the absorption process when the chemical is only in the stratum corneum, i.e., non-steady state, where absorption is a function of $t_{event}^{1/2}$; and (2) to describe the absorption process as a function of t_{event}, once steady state is reached. One fundamental assumption of this model is that absorption continues long after the exposure has ended, i.e., the final absorbed dose (DA_{event}) is estimated to be the total dose dissolved in the skin at the end of the exposure. For highly lipophilic chemicals or for chemicals that are not highly lipophilic but exhibit a long lag time (t_{event}), some of the chemical dissolved into skin may be lost due to desquamation during that absorption period. A fraction absorbed term (FA) is included in the evaluation of DA_{event} to account for this loss of chemical due to desquamation. As shown in Appendix A, for normal desquamation rates to completely replace the stratum corneum in about 14 days, only chemicals with log K_{ow} > 3.5 or chemicals with t_{event} > 10 hours (at any log K_{ow}) would be affected by this loss.

The following procedures represent updates from the DEA and are recommended for the estimation of the dermal absorbed dose (DAD):

For Organics:

- The equation for DA_{event} is updated to include the net fraction available for absorption in the stratum corneum after exposure has ended (FA).
- The equation for the permeability coefficient (K_p) is updated by excluding three data points from the Flynn data base (Flynn, 1990) in the development of the correlation equation for K_p. The 95% confidence intervals are also provided for the estimation of K_p using this correlation equation.
- The screening procedures are updated to include the new values for K_p and FA in order to provide guidance when the dermal route would pose more than 10% of the ingested dose.
- A statistical analysis of the correlation equation for K_p provides the ranges of the octanol-water partition coefficient (log K_{ow}) and molecular weight (MW) where the extrapolation of the K_p correlation equation would be valid.
- A discussion of the model validation and uncertainties related to the dermal absorption model for chemicals in water is included.
- Appendix A gives a detailed discussion of the above changes.
- The spreadsheet ORG04_01.XLS and Exhibits B-1 through B-3 of Appendix B provide the calculations of the dermal absorbed dose for over 200 organic chemicals, using a default exposure scenario.

For Inorganics:

- The measured values of the permeability coefficients for available chemicals are updated based on the latest literature.
- Screening procedures for determining when the dermal route would pose more than 10% of the ingested dose are updated to include the relative fraction absorbed by accounting for the actual gastrointestinal absorption (ABS_{GI}) of inorganics.
- Appendix A gives a detailed discussion of the above changes.
- The spreadsheet INORG04_01.XLS and Exhibit B-4 of Appendix B provide the calculations for the inorganics with available measured K_p or ABS_{GI}.

For chemicals in water, Equations 3.1, 3.2, 3.3 and 3.4 are used to evaluate the dermal absorbed dose. The following discussion summarizes the key steps in the procedure detailed in Appendix A.

For short exposure durations to organic chemicals in water (Equation 3.2), DA_{event} is not a function of the parameter B, which measures the ratio of the permeability coefficient of the chemical in the stratum corneum to its permeability coefficient in the viable epidermis, because neither the viable epidermis nor the cutaneous blood flow will limit dermal absorption during such short exposure durations.

For long exposure times, Equation 3.3 should be used to estimate DA_{event} for organic chemicals. The lag time is decreased because the skin has a limited capacity to reduce the transport rate of inorganic and/or highly ionized organic chemicals. In addition, the viable epidermis will contribute insignificantly as a barrier to these chemicals. Consequently, for inorganic and highly ionized organic chemicals, it is appropriate

Dermal Absorbed Dose – Water Contact

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT} \quad (3.1)$$

where:

Parameter		Definition (units)	Default Value
DAD	=	Dermally Absorbed Dose (mg/kg-day)	–
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	Chemical-specific, see Eq. 3.2, 3.3 and 3.4
SA	=	Skin surface area availablefor contact (cm^2)	See Exhibit 3-2
EV	=	Event frequency (events/day)	See Exhibit 3-2
EF	=	Exposure frequency (days/year)	See Exhibit 3-2
ED	=	Exposure duration (years)	See Exhibit 3-2
BW	=	Body weight (kg)	70 kg (adult) 15 kg (child)
AT	=	Averaging time (days)	noncarcinogenic effects AT = ED x 365 d/yr carcinogenic effects AT = 70 yr x 365 d/yr

to assume that τ_{event} and B are both near zero, which simplifies Equation 3.3 to Equation 3.4.

Discussions of the permeability coefficient (K_p) and all other parameters for water media are found in Section 3.1.2, with more details and data in Appendix A. Descriptions of the dermal absorption model and equations for calculating all the parameters to evaluate the dermal absorbed dose for organics (DA_{event} in Equations 3.3 and 3.4) are provided in Appendix A.1, and for inorganics (DA_{event} in Equation 3.4) in Appendix A.2. Appendix B (Exhibits B-3 and B-4) contains chemical-specific DA_{event} and DAD values per unit concentration, using default assumptions. Instructions for calculating DA_{event} and DAD values with site-specific exposure assumptions are provided (see Appendix A.5), and the spreadsheets (ORG04_01.XLS and INORG04_01.XLS), including all the calculations, will be available at http://www.epa.gov/oswer/riskassessment/ or http://www.epa.gov/superfund/programs/risk/ ragse/index.htm.

3.1.2 EXPOSURE PARAMETERS

3.1.2.1 Permeability Coefficient for Compounds in Water (K_p in cm/hr)

Some discussion of criteria for selecting an experimental K_p was presented in DEA, Chapter 5. The procedure recommended by RAGS Part E to estimate the permeability coefficient (K_p) of a compound is obtained from updating the correlation presented in DEA. Three data points which came from in vivo studies (ethyl benzene, styrene and toluene) from the Flynn database are now excluded in the development of the new K_p correlation, limiting its representation to in vitro studies using human skin. Updated K_p values for over two hundred common organic compounds in water are provided, in Appendix B, as estimated using procedures described below. It is recommended that these K_p values be used in Equations 3.2 and 3.3. K_p values for several inorganic compounds are given, and default permeability constants for all other inorganic compounds are provided in Exhibit 3-1, to be used in Equation 3.4.

Organics. The permeability coefficient is a function of the path length of chemical diffusion (defined here as stratum corneum thickness, l_{sc}), the membrane/vehicle partition coefficient of the chemical (here as octanol/water partition coefficient K_{ow} of the chemical), and the effective diffusion coefficient (D_{sc}) of the chemical in the stratum corneum, and can be written for a simple isotropic membrane as presented in Equations 3.5 and 3.6.

In this approach, K_p from Equation 3.7 is estimated via an empirical correlation as a function of K_{ow} and

Dermal Absorbed Dose per event for Organic Compounds – Water Contact

DA_{event} (mg/cm^2-event) is calculated for organic compounds as follows :

$$If\ t_{event} \le t^*,\ then:\ DA_{event} = 2\ FA \times K_p \times C_w \sqrt{\frac{6\ \tau_{event} \times t_{event}}{\pi}} \tag{3.2}$$

$$If\ t_{event} > t^*,\ then:\ DA_{event} = FA \times K_p \times C_w \left[\frac{t_{event}}{1 + B} + 2\ \tau_{event}\left(\frac{1 + 3\ B + 3\ B^2}{(1 + B)^2}\right)\right] \tag{3.3}$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
FA	=	Fraction absorbed water (dimensionless)	Chemical-specific, See Appendix B
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, See Appendix B
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific, non-ionized fraction, See Appendix A for more discussion
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific, See Appendix B
t_{event}	=	Event duration (hr/event)	See Exhibit 3-2
t^*	=	Time to reach steady-state (hr) = 2.4 τ_{event}	Chemical-specific, See Eq. A.5 to A.8
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve) (dimensionless)	Chemical-specific, See Eq. A.1

MW (Potts and Guy, 1992) obtained from an experimental data base (the Flynn data base composed of about 90 chemicals, see DEA, Chapter 4, and Appendix B of this document) of absorption of chemicals from water through human skin in vitro.

For ionized organic compounds, Equation 3.8 can be used to estimate K_p with the appropriate K_{ow} value. Note that for ionizable organic chemicals, the K_{ow} value used in Equation 3.8 should be the K_{ow} of only species that are non-ionized. Similarly, for these chemicals, the concentration C_w used in Equations 3.2 and 3.3 should be that of the non-ionized fraction. (See Appendices A and B for more discussion on this topic.) Organic chemicals which are always ionized (including ionized but uncharged zwitterions) and ionized species of ionizable organic chemicals at the conditions of interest should be treated the same as inorganic chemicals.

For halogenated chemicals, Equation 3.8 could underestimate K_p. The Flynn data set from which Equation 3.8 was derived consists almost entirely of hydrocarbons with a relatively constant ratio of molar volume to MW. Because halogenated chemicals have a lower ratio of molar volume relative to their MW than hydrocarbons (due to the relatively weighty halogen atom), the K_p correlation based on MW of hydrocarbons will tend to underestimate permeability coefficients for halogenated organic chemicals. To address this problem, a new K_p correlation based on molar volume and log K_{ow} will be explored.

Based on the Flynn data set, Equation 3.8 can be used to predict the permeability coefficient of

EXHIBIT 3-1

PERMEABILITY COEFFICIENTS FOR INORGANICS

Compound	Permeability Coefficient K_p (cm/hr)
Cadmium	1×10^{-3}
Chromium (+6)	2×10^{-3}
Chromium (+3)	1×10^{-3}
Cobalt	4×10^{-4}
Lead	1×10^{-4}
Mercury (+2)	1×10^{-3}
Methyl mercury	1×10^{-3}
Mercury vapor	0.24
Nickel	2×10^{-4}
Potassium	2×10^{-3}
Silver	6×10^{-4}
Zinc	6×10^{-4}
All other inorganics	1×10^{-3}

chemicals with K_{ow} and MW within the following "Effective Prediction Domain" (EPD), determined via a statistical analysis (see Appendix A, Section A.1) as presented in Equations 3.9 and 3.10. Contaminants outside the EPD are identified with an asterisk (*) in Appendix B2 and B3. Note that as additional data are received, the contaminants within the EPD may change. Therefore, users of this guidance should review EPA's website at (http://www.epa.gov/oswer/riskassessment/ or http://www.epa.gov/superfund/programs/risk/ragse/index.htm) to determine what contaminants are currently inside (or outside) the EPD.

Strictly, chemicals with very large and very small K_{ow} values are outside of the EPD. Although large variances in some data points contributed to the definition of the EPD, it is defined primarily by the properties of the data used to develop Equation 3.8. With no other data presently available for chemicals with very large and very small K_{ow}, it is appropriate to use Equation 3.8 as a preliminary estimate of K_p.

For many chemicals with log K_{ow} and MW outside of the prediction domain, a fraction absorbed (FA) is estimated to account for the loss of chemicals due to

Dermal Absorbed Dose Per Event for Inorganic Compounds – Water Contact

DA_{event} (mg/cm^2-event) is calculated for inorganics or highly ionized organic chemicals as follows:

$$DA_{event} = K_p \times C_w \times t_{event} \qquad (3.4)$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Exhibit A-6 and Appendix B
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific, non-ionized fraction, see Appendix A for more discussion
t_{event}	=	Event duration (hr/event)	See Exhibit 3-2

Theoretical Derivation of Permeability Coefficient for Organic Chemicals

$$K_p = \frac{K_{sc/w} \times D_{sc}}{l_{sc}} \qquad (3.5)$$

or:

$$\log K_p = \log K_{sc/w} + \log \frac{D_{sc}}{l_{sc}} \qquad (3.6)$$

Empirically it has been shown that (Kasting, et al., 1987):

$$\log K_{sc/w} = a \log K_{ow} + b$$

and $D_{sc}=D_o \exp(-\beta\ MV)$

where:
D_o and β are constants, characteristic of the medium through which diffusion is occurring. For hydrocarbons, MV will be related directly to molecular weight (MW). Combining these two relationships with Equation 3.6 leads to the general form:

$$\log K_p = b + a \log K_{ow} - c\ MW \qquad (3.7)$$

where:

Parameter		Definition (units)	Default Value
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Appendix B
K_{ow}	=	Octanol/water partition coefficient (dimensionless)	Chemical-specific, see Appendix B
$K_{sc/w}$	=	equilibrium partition coefficient between the stratum corneum and water (dimensionless)	Chemical-specific
D_o	=	Diffusivity of a hypothetical molecule with a molecular volume (MV) = 0 (cm^2/hr)	Chemical-specific
β	=	Constant specific for the medium through which diffusion is occurring	Medium specific
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific, see Spreadsheet ORG04_01.XLS (on website given in Section 3.1.1)
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3} cm
a,b,c	=	correlation coefficients which have been fitted to the Flynn's data to give Equation 3.8.	–
MV	=	Molar volume (cm^3/mol)	Chemical-specific
MW	=	Molecular weight (g/mole)	Chemical-specific

the desquamation of the skin, which would decrease the net amount of chemicals available for absorption after the exposure event (t_{event}) has ended. Predictions of chemical-specific K_p and their use in the estimation of DA_{event}, are included in Exhibit B-3 for about two hundred chemicals.

Empirical Predictive Correlation for Permeability Coefficient of Organics

$$\log K_p = -2.80 + 0.66 \log K_{ow} - 0.0056\ MW \qquad (r^2 = 0.66) \tag{3.8}$$

where:

Parameter		Definition (units)	Default Value
K_p	=	Dermal permeability coefficient of compounds in water (cm/hr)	Chemical-specific, see Appendix B
K_{ow}	=	Octanol/water partition coefficient of the non-ionized species (dimensionless)	Chemical-specific, see Appendix B
MW	=	Molecular weight (g/mole)	Chemical-specific, see Appendix B

Inorganics. Exhibit 3-1 summarizes permeability coefficients for inorganic compounds, obtained from specific chemical experimental data, as modified and updated from DEA, Table 5-3 and from Hostynek, et al. (1998). Permeability coefficients from these references are condensed for each metal and for individual valence states of specific metals. To be most protective of human health, the value listed in this exhibit represents the highest reported permeability coefficient. More detailed information is presented in Appendix A (Exhibit A-6).

3.1.2.2 Chemical Concentration in Water

One of the issues regarding the bioavailability of chemicals in water is the state of ionization, with the non-ionized form being much more readily absorbed than the ionized form. The fraction of the chemical in the non-ionized state is dependent on the pH of the water and the specific ionization constant for that chemical (pK_a). Further information on the formulas for calculating these fractions is provided in the DEA and in Appendix A. However, given the complexities of calculating the non-ionized fraction across multiple samples and multiple chemicals, it is recommended that a standard risk assessment should make the health-protective assumption that the chemical is entirely in the non-ionized state. Therefore, the total concentration of a chemical in water samples (C_w) should be equal to the total concentration of the chemical in water.

Estimates of C_w, and therefore potential impacts of dermal exposure, may be strongly influenced by the presence of particulates in the sample. Although filtra-

Boundaries of Effective Prediction Domain

$$-0.06831 \le 0.5103 \times 10^{-4}\ MW + 0.05616 \log K_{ow} \le 0.5577 \tag{3.9}$$

$$-0.3010 \le -0.5103 \times 10^{-4}\ MW + 0.05616 \log K_{ow} \le 0.1758 \tag{3.10}$$

where:

Parameter		Definition (units)	Default Value
K_{ow}	=	Octanol/water partition coefficient of the non-ionized species (dimensionless)	Chemical-specific, see Appendix B
MW	=	Molecular weight (g/mole)	Chemical-specific, see Appendix B

EXHIBIT 3-2

RECOMMENDED DERMAL EXPOSURE VALUES FOR CENTRAL TENDENCY AND RME RESIDENTIAL SCENARIOS – WATER CONTACT

Exposure Parameters	Central Tendency Scenario				RME Scenario			
	Showering/ Bathing		Swimming		Showering/ Bathing		Swimming	
Concentration- C_w (mg/cm^3)	Site-specific		Site-specific		Site-specific		Site-specific	
Event frequency- EV (events/day)	1		Site-specific		1		Site-specific	
Exposure frequency- EF (days/yr)	350		Site-specific		350		Site-specific	
Event duration- t_{event} (hr/event)	**Adult**[1]	**Child**[2]	**Adult**	**Child**	**Adult**[1]	**Child**[2]	**Adult**	**Child**
	0.25	0.33	Site-specific		0.58	1.0	Site-specific	
Exposure duration- ED (yr)	9	6	9	6	30	6	30	6
Skin surface area- SA (cm^2)	18,000	6,600	18,000	6,600	18,000	6,600	18,000	6,600
Dermal permeability coefficient-K_p (cm/hr)	Chemical-specific values Exhibits B-3 and B-4							

[1] Adult showering scenario used as the basis for the chemical screening for the dermal pathway, as shown in Appendix B, Exhibits B-3 and B-4. Event duration for adult exposure is based on showering data from the EFH (U.S. EPA, 1997a).
[2] Event duration for child exposure is based on bathing data from the EFH (U.S. EPA, 1997a).

tion of water samples in the field has been used to reduce turbidity and estimate the soluble fraction of chemicals in water, existing RAGS guidance (U.S. EPA, 1989) recommends that unfiltered samples be used as the basis for estimating the chemical concentration for calculating the *oral* dose. The rationale is that particulate-bound chemicals may still be available for absorption across the gastrointestinal tract. To be consistent with existing EPA guidance, it is recommended that unfiltered samples also be used as the basis for estimating a chemical concentration for calculating the *dermal* dose.

However, it should be noted that particulate-bound chemicals in an aqueous medium (e.g., suspended sediment particles) would be considered to be much less bioavailable for dermal absorption, due to inefficient adsorption of suspended particles onto the skin surface and a slower rate of absorption into the skin. The uncertainty in the estimation of the dermal dose from a water sample with high turbidity is directly proportional to the magnitude of the difference in the concentration between an unfiltered and filtered sample. The actual bioavailable concentration is likely to lie somewhere between the unfiltered and filtered sample concentrations. The impact of this health-protective assumption and relevant field factors (e.g., turbidity) should be discussed in the uncertainty section. To reduce the uncertainty in estimating the bioavailable chemical concentration, water sample collection methods that minimize turbidity should be employed (U.S. EPA, 1995b, 1996), rather than sample filtration.

3.1.2.3 Skin Surface Area

The surface area (SA) parameter describes the amount of skin exposed to the contaminated media.

Dermal Absorbed Dose – Soil Contact

$$DAD = \frac{DA_{event} \times EF \times ED \times EV \times SA}{BW \times AT} \quad (3.11)$$

where:

Parameter		Definition (units)	Default Value
DAD	=	Dermal Absorbed Dose (mg/kg-day)	–
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	Chemical-specific, see Equation 3.12
SA	=	Skin surface area available for contact (cm^2)	See Appendix C and Equations 3.13 to 3.16
EV	=	Event frequency (events/day)	See Exhibit 3-5
EF	=	Exposure frequency (days/year)	See Exhibit 3-5
ED	=	Exposure duration (years)	See Exhibit 3-5
BW	=	Body weight (kg)	70 kg (adult), 15 kg (child)
AT	=	Averaging time (days)	noncarcinogenic effects AT = ED x 365 d/yr carcinogenic effects AT = 70 yr x 365 d/yr

The amount of skin exposed depends upon the exposure scenario. For dermal contact with water, the total body surface area for adults and children is assumed to be exposed for both swimming and bathing. Since body weight and SA are dependent variables, all SA estimates used 50^{th} percentile values in order to correlate with the average body weights. The recommended SA exposed to contaminated water for the adult resident is 18,000 cm^2. This SA value was calculated by incorporating data from Tables 6.2 and 6.3 for the Exposure Factors Handbook (U.S. EPA, 1997a), averaging the 50^{th} percentile values for males and females.

The recommended SA value for exposure to contaminated water for the child resident is 6,600 cm^2. This SA was calculated by incorporating the data from the EFH for the 50^{th} percentile of the total body surface area for male and female children, and calculating a time weighted average surface area for a 0-6 year old child. The lack of data for all ages led to a conservative assumption that a 0-1 year old and 1-2 year old had the same surface area as a 2-3 year old. This recommended child SA was calculated by averaging the male and female surface areas.

Dermal Absorbed Dose Per Event – Soil Contact

DA_{event} (mg/cm^2-event) is calculated as follows:

$$DA_{event} = C_{soil} \times CF \times AF \times ABS_d \quad (3.12)$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
C_{soil}	=	Chemical concentration in soil (mg/kg)	Site-specific
CF	=	Conversion factor (10^{-6} kg/mg)	10^{-6} kg/mg
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	See Section 3.2.2.3 and Appendix C
ABS_d	=	Dermal absorption fraction	See Exhibit 3-4

Surface Area Exposed for Adult Resident – Soil Contact

where:

$$Exposed\ SA\ (Adult\ Resident) = SA_{head} + SA_{forearms} + SA_{hands} + SA_{lower\ legs} \quad (3.13)$$

Parameter		Definition (units)	Default Value
SA	=	Skin surface area available for contact (cm^2)	See Appendix C

Surface Area Exposed for Adult Commercial/Industrial – Soil Contact

$$Exposed\ SA\ (Adult\ Commercial/Industrial) = SA_{head} + SA_{forearms} + SA_{hands} \quad (3.14)$$

where:

Parameter		Definition (units)	Default Value
SA	=	Skin surface area available for contact (cm^2)	See Appendix C

3.1.2.4 Event Time, Frequency, and Duration of Exposure

Exhibit 3-2 summarizes the default exposure values for both surface area and exposure duration, presented as central tendency and RME. All the central tendency values were obtained from the EFH, while the RME values were derived as previously presented. Recommended event duration values are provided for a showering activity. Even though children may be bathing for a longer duration, the showering adult remains the most highly exposed receptor.

3.2 ESTIMATION OF DERMAL EXPOSURE TO CHEMICALS IN SOIL

3.2.1 STANDARD EQUATION FOR DERMAL CONTACT WITH CHEMICALS IN SOIL

The general guidance for evaluating dermal absorption of compounds from soil is presented in *Risk Assessment Guidance for Superfund* (RAGS, U.S. EPA, 1989) and is expanded upon in the DEA. This section briefly discusses the rationale and updates specific parameters. The standard equation for dermal contact with chemicals (Equation 3.11) is the same as that in Section 3.1.1. (Equation 3.1). Equation 3.12 provides DA_{event} for soil contact.

3.2.2 EXPOSURE PARAMETERS

3.2.2.1 Skin Surface Area

The skin surface area parameter (SA) describes the amount of skin exposed to the contaminated media. The amount of skin exposed depends upon the exposure scenario. Clothing is expected to limit the extent of the exposed surface area in cases of soil contact. All SA estimates used 50th percentile values to correlate with average body weights used for all scenarios and pathways. This was done to prevent inconsistent parameter combinations since body weight and SA are dependent variables. Body part-specific SAs were calculated for adult (>18 years old) and child (<1 to <6 years old) residents as described below and documented in Appendix C.

Adult resident. The adult resident was assumed to wear a short-sleeved shirt, shorts and shoes; therefore, the exposed skin surface is limited to the head, hands, forearms and lower legs. The recommended SA exposed to contaminated soil for the adult resident is 5700 cm^2 and is the average of the 50th percentile for males and females greater than 18 years of age. Surface area data were taken from EFH, Tables 6-2 (adult male) and 6-3 (adult female). Exposed SA for the adult

Surface Area Exposed for Child Resident – Soil Contact

$$Fraction\ of\ Total\ SA_{body\ part\ i} = \frac{SA\ fraction_{age\ <1} + SA\ fraction_{age\ 1<2} + \ldots + SA\ fraction_{age\ 5<6}}{6} \tag{3.15}$$

$$Exposed\ SA = (FTSA_{head})(SA_{total}) + (FTSA_{forearms})(SA_{total}) + (FTSA_{hands})(SA_{total}) + (FTSA_{lowerlegs})(SA_{total}) + (FTSA_{feet})(SA_{total}) \tag{3.16}$$

where:

Parameter		Definition (units)	Default Value
FTSA	=	Fraction of total surface area for the specified body part (cm^2)	See Appendix C
SA	=	Skin surface area available for contact (cm^2)	See Appendix C
SA_{total}	=	Total skin surface available for contact	See Appendix C
$(FTSA_i)(SA_{total})$	=	Surface area for body part "i" (cm^2)	–

resident was calculated using Equation 3.13, documented in Appendix C with the assumption that the female adult forearm SA was 45% of the arm SA (based on the adult male forearm-to-arm SA ratio).

Adult commercial/industrial. The adult commercial/industrial receptor was assumed to wear a short-sleeved shirt, long pants, and shoes; therefore, the exposed skin surface is limited to the head, hands, and forearms. The recommended SA exposed to contaminated soil for the adult commercial/industrial receptor is 3300 cm^2 and is the average of the 50^{th} percentile for males and females greater than 18 years of age. Surface area data were taken from EFH, Tables 6-2 (adult male) and 6-3 (adult female). Exposed SA for the adult commercial/industrial receptor was calculated using Equation 3.14 and is documented in Appendix C with the assumption that the female adult forearm SA was 45% of the arm SA (based on the adult male forearm-to-arm SA ratio).

Child. The child resident (<1 to <6 years old) was assumed to wear a short-sleeved shirt and shorts (no shoes); therefore, the exposed skin is limited to the head, hands, forearms, lower legs, and feet. The recommended SA exposed to contaminated soil for the child resident is 2800 cm^2 and is the average of the 50^{th} percentile for males and females (<1 to <6 years old). Body part-specific data for male and female children were taken from EFH, Table 6-8, as a fraction of total body surface area. Total body SAs for male and female children were taken from EFH, Tables 6-6 (male) and 6-7 (female), and used to calculate average male/female total SA (see Appendix C). Exposed SA for the child resident was calculated, using Equations 3.15 and 3.16 and is documented in Appendix C with the following assumptions: (1) because of the lack of data for certain ages, the fraction of total SA was assumed to be equal to the next oldest age group that had data and (2) the forearm-to-arm ratio (0.45) and lower leg-to-leg ratio (0.4) are equivalent to those of an adult. These assumptions introduce some uncertainty into the calculation, but are used in the absence of age-specific data.

While clothing scenarios described above for the adult and child residents may not be appropriate for all regions, the climate in some areas would allow a short-sleeved shirt and/or shorts to be worn throughout a majority of the year. In addition, in some regions of the country, children may remain barefoot throughout a major portion of the year. These clothing scenarios were chosen to ensure adequate protection for those receptors that may be exposed in the warmer climates, with the realization that risks would likely be overestimated for some seasons.

When selecting the surface area, site-specific conditions should be evaluated in coordination with the project's risk assessors. For colder climates, the surface area may be weighted for different seasons. Because some studies have suggested that exposure can occur under clothing (Maddy, et al., 1983), these clothing scenarios are not considered to be overly conservative.

3.2.2.2 Soil-to-Skin Adherence Factors

The adherence factor (AF) describes the amount of soil that adheres to the skin per unit of surface area. Recent data (Kissel et al., 1996; Kissel et al., 1998; and Holmes et al., 1999) provide evidence to demonstrate that 1) soil properties influence adherence, 2) soil adherence varies considerably across different parts of the body; and 3) soil adherence varies with activity.

Given these results, the Workgroup recommends that an activity which best represents all soils, body parts, and activities be selected (U.S. EPA, 1997a). Body part-weighted AFs can then be calculated and used in estimating exposure via dermal contact with soil based on assumed exposed body parts. Given that soil adherence depends upon the body part, an overall body part-weighted AF must be calculated for each activity. The assumed clothing scenario determines which body part-specific AFs are used in calculating the 50th and 95th percentile weighted AFs. The weighted AFs are used with the relative absorption, exposure frequency and duration, exposed surface area, body weight, and averaging time to estimate the dermal absorbed dose. The general equation used to calculate the weighted AF for a particular activity is shown in Equation 3.17.

Adult resident. The adult resident (>18 years old) was assumed to wear a short-sleeved shirt, shorts and shoes; therefore, the exposed skin surface was limited to the face, hands, forearms and lower legs. The weighted AFs for adult residential activities (e.g., grounds keepers, landscapers, and gardeners) were calculated using Equation 3.18 and are documented in Appendix C. Note: This calculation differs from that presented in Section 3.2.2.1 in the areas used for head and face. In the total surface area calculation presented earlier, the total head area was used. For the soil-to-skin adherence factor, empirical measurements were from the face only and the face surface area was estimated to be ⅓ the total head surface area.

Adult commercial/industrial. The adult commercial/industrial receptor was assumed to wear a short-sleeved shirt, long pants, and shoes. Therefore, the exposed skin surface was limited to the face, hands, and forearms. The weighted AFs for adult commercial/industrial activities (e.g., grounds keepers, landscapers, irrigation installers, gardeners, construction workers, equipment operators, and utility workers) were calculated using Equation 3.19, and documented in Appendix C.

Child resident. The child resident (<1 to <6 years old) was assumed to wear a short-sleeved shirt and shorts (no shoes). Therefore, the exposed skin was limited to face, hands, forearms, lower legs, and feet. Weighted AFs for children in day care and "staged" children playing in dry and wet soil activities were calculated using Equation 3.20, and documented in Appendix C.

As noted in Appendix C, body part-specific AFs for both child and adult receptors were not always available for all body parts assumed to be exposed. Weighted adherence factors for receptors were

Surface Area Weighted Soil Adherence Factor

$$Weighted\ AF = \frac{(AF_1)(SA_1) + (AF_2)(SA_2) + . . . + (AF_i)(SA_i)}{SA_1 + SA_2 + . . . + SA_i} \qquad (3.17)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

Surface Area Weighted Soil Adherence Factor for Adult Resident

$$Weighted\ AF_{adult\ resident} = \frac{(AF_{face})\ (SA_{face}) + (AF_{forearms})\ (SA_{forearms}) + (AF_{hands})\ (SA_{hands}) + (AF_{lowerlegs})\ (SA_{lowerlegs})}{SA_{face} + SA_{forearms} + SA_{hands} + SA_{lowerlegs}} \qquad (3.18)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

Surface Area Weighted Soil Adherence – Adult/Commercial

$$Weighted\ AF_{adult\ commercial} = \frac{(AF_{face})(SA_{face}) + (AF_{forearms})(SA_{forearms}) + (AF_{hands})(SA_{hands})}{SA_{face} + SA_{forearms} + SA_{hands}} \qquad (3.19)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

Surface Area Weighted Soil Adherence Factor – Child

$$Weighted\ AF_{child} = \frac{(AF_{face})(SA_{face}) + (AF_{forearms})(SA_{forearms}) + (AF_{hands})(SA_{hands}) + (AF_{lowerlegs})(SA_{lowerlegs}) + (AF_{feet})(SA_{feet})}{SA_{face} + SA_{forearms} + SA_{hands} + SA_{lowerlegs} + SA_{feet}} \qquad (3.20)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

calculated using only those body parts for which AFs were available because of the difficulty in trying to assign an AF for one body part to another body part. For example, the weighted AF for the children in day care was based on the forearms, hands, lower legs, and feet (AFs for the face were not available). However, the surface area for all exposed body parts was used in calculating the dermal absorbed dose. For the day care child example, the surface area used in estimating the DAD included the whole head, forearms, hands, lower legs and feet. Therefore, the body part that may not have had AF data available was assumed, by default, to have the same amount of soil adhered as the weighted AF.

3.2.2.3 Recommended Soil Adherence Factors

This section recommends default soil AFs for the child resident, the adult resident, and the adult commercial/industrial worker, and provides the basis for the recommendations. EPA suggests selecting an activity from AF data which best represents the exposure scenario of concern and using the corresponding weighted AF in the dermal exposure calculations (U.S. EPA, 1997a). To make this selection, activities with available AFs were categorized as those in which a typical residential child, residential adult, and commercial/industrial adult worker would be likely to engage (see Appendix C). Within each receptor category, activities were ranked in order from the activity with the lowest to highest weighted AF (50^{th} percentile) (Exhibit 3-3). The 50^{th} percentile weighted AF was used in ranking the activities from those with the lowest to highest weighted AFs, because the 50^{th} percentile is a more stable estimation of the true AF (i.e., it is not affected as significantly by outliers as the 95^{th} percentile).

As with other contact rates (e.g., soil ingestion), the recommended default value is a conservative, health protective value. To maintain consistency with this approach (i.e., recommending a high-end of a mean), two options exist when recommending default weighted AFs: (1) select a central tendency (i.e., typical) soil contact activity and use the high-end weighted AF (i.e., 95^{th} percentile) for that activity; or (2) select a high-end (i.e., reasonable but higher exposure) soil contact activity and use the central tendency weighted AF (i.e., 50^{th} percentile) for that activity.

It is not recommended that a high-end soil contact activity be used with a high-end weighted AF for that activity, as this use would not be consistent with the use of a reasonable maximum exposure (RME) scenario. The use of these values also needs to be evaluated when combining multiple exposure pathways to insure that an overall RME is being maintained.

Adult resident. Given that there were data available for a wide variety of activities that an adult resident may engage in, a high-end soil contact activity was selected and the central tendency weighted AF (50^{th} percentile) was derived for that activity. In so doing, the recommended weighted AF for an adult resident is 0.07 mg/cm^2, and is based on the 50^{th} percentile weighted AF for gardeners (the activity determined to represent a reasonable, high-end activity). The basis for this recommendation is as follows: (1) although no single activity would represent the activities an adult resident engages in, a comparison of the gardener 50^{th} percentile weighted AF with the other residential-type activities (Appendix C) shows that gardening represents a high-end soil contact activity; (2) common sense suggests that gardening represents a high-end soil contact activity, whereas, determining which of the other activities (i.e., grounds keeping and landscaping/rockery) would represent a reasonable, central tendency (i.e., typical) soil contact activity would be difficult; and (3) selecting the central tendency weighted AF (i.e., 50^{th} percentile) of a high-end soil contact activity is consistent with an RME for contact rates.

Child resident (<1 to <6 years old*)*. Available data on soil AFs for children were limited to children (1-6½ years old) playing indoors and outdoors (3.5-4 hours) at a day care center (reviewed in U.S. EPA, 1997a) and children (8-12 years old) playing for 20 minutes with an assortment of toys and implements in a preconstructed 8'x8' soil bed (i.e., “staged” activity) containing dry or wet soil (see Kissel et al., 1998, and Appendix C). Therefore, it was not possible to identify a reasonable worst-case soil contact activity as was done for the adult resident. As such, both of the following approaches were used in determining the appropriate weighted AF for children: (1) selecting a central tendency (i.e., typical) soil contact activity using the high-end weighted AF (i.e., 95^{th} percentile) for that activity; and, (2) selecting a high-end soil contact activity using the central tendency weighted AF (i.e., 50^{th} percentile) for that activity. The recommended weighted AF for a child resident (<1 to <6 years old) is 0.2 mg/cm^2 and is based on the 95^{th} percentile weighted AF for children playing at a day care center (central tendency soil contact activity) or the 50^{th} percentile for children playing in wet soil (high-end soil contact activity).

EXHIBIT 3-3

ACTIVITY SPECIFIC-SURFACE AREA WEIGHTED SOIL ADHERENCE FACTORS

Exposure Scenario	Age (years)	Weighted Soil Adherence Factor (mg/cm^2)	
		Geometric Mean	95th Percentile
CHILDREN[1]			
Indoor Children	1-13	0.01	0.06
Daycare Children (playing indoors and outdoors)	1-6.5	0.04	0.3
Children Playing (dry soil)	8-12	0.04	0.4
Children Playing (wet soil)	8-12	0.2	3.3
Children-in-Mud[5]	9-14	21	231
RESIDENTIAL ADULTS[2]			
Grounds Keepers	>18	0.01	0.06
Landscaper/Rockery	>18	0.04	0.2
Gardeners	>16	0.07	0.3
COMMERCIAL/INDUSTRIAL ADULTS[3]			
Grounds Keepers	>18	0.02	0.1
Landscaper/Rockery	>18	0.04	0.2
Staged Activity: Pipe Layers (dry soil)	>15	0.07	0.2
Irrigation Installers	>18	0.08	0.3
Gardeners	>16	0.1	0.5
Construction Workers	>18	0.1	0.3
Heavy Equipment Operators	>18	0.2	0.7
Utility Workers	>18	0.2	0.9
Staged Activity: Pipe Layers (wet soil)	>15	0.6	13
MISCELLANEOUS ACTIVITIES[4]			
Soccer Players #1 (teens, moist conditions)	13-15	0.04	0.3
Farmers	>20	0.1	0.4
Rugby Players	>21	0.1	0.6
Archeologists	>19	0.3	0.5
Reed Gatherers	>22	0.3	27
Soccer Players #2 (adults)	>18	0.01	0.08

EXHIBIT 3-3 (continued)

ACTIVITY SPECIFIC-SURFACE AREA WEIGHTED SOIL ADHERENCE FACTORS

[1] Weighted AF based on exposure to face, forearms, hands, lower legs, & feet.
[2] Weighted AF based on exposure to face, forearms, hands, & lower legs.
[3] Weighted AF based on exposure to face, forearms, & hands.
Note: this results in different weighted AFs for similar activities between residential and commercial/industrial exposure scenarios.
[4] Weighted AF based on all body parts for which data were available.
[5] Information on soil adherence values for the children-in-mud scenario is provided to illustrate the range of values for this type of activity. However, the application of these data to the dermal dose equations in this guidance may result in a significant overestimation of dermal risk. Therefore, it is recommended that the 95th percentile AF values not be used in a quantitative dermal risk assessment. See Exhibit C-4 for bounding estimates.

Children playing at a day care center represent a central tendency (i.e., typical) activity given that: (1) the children played both indoors and outdoors; (2) the clothing worn was not controlled (i.e., some subjects wore long pants, long-sleeve shirts, and/or shoes); and (3) soil conditions were not controlled (e.g., other soil types, moisture content, etc., could result in higher AFs). The 95th percentile weighted AF for children playing at the day care center is a known, reasonable, "real-life" activity that represents the majority of the population, given that children 1 to 6 years old are either in day care or at home and are likely engaging in activities similar to those at the day care center, and represents a high-end of a typical activity.

EXHIBIT 3-4

RECOMMENDED DERMAL ABSORPTION FRACTION FROM SOIL

Compound	Dermal Absorption Fraction (ABS_d)[1]	Reference
Arsenic	0.03	Wester, et al. (1993a)
Cadmium	0.001	Wester, et al. (1992a) U.S. EPA (1992a)
Chlordane	0.04	Wester, et al. (1992b)
2,4-Dichlorophenoxyacetic acid	0.05	Wester, et al. (1996)
DDT	0.03	Wester, et al. (1990)
TCDD and other dioxins -if soil organic content is >10%	0.03 0.001	U.S. EPA (1992a)
Lindane	0.04	Duff and Kissel (1996)
Benzo(a)pyrene and other PAHs	0.13	Wester, et al. (1990)
Aroclors 1254/1242 and other PCBs	0.14	Wester, et al.(1993b)
Pentachlorophenol	0.25	Wester, et al. (1993c)
Semivolatile organic compounds	0.1	—

[1] The values presented are experimental mean values.

The "staged" activity of children playing in wet soil for 20 minutes under controlled conditions (i.e., all subjects were clothed similarly, the duration of soil contact was controlled, and the soil properties were characterized) is a high-end soil contact activity because: (1) the children were in direct contact with soil for the full duration of the activity; and (2) the children played in wet soil, which is known to have higher AFs than dry soil, for the duration of the activity. The 50th percentile weighted AF for children playing in wet soil is a central tendency estimate of a high-end soil contact activity.

Use of the 95th percentile weighted AF for children playing at a day care center (0.3 mg/cm^2) or the 50th percentile for children playing in wet soil (0.2 mg/cm^2) as a recommended weighted AF for a child resident (<1 to <6 years old) is consistent with recommending a high-end of a mean for contact rates.

While this value (0.2 mg/cm^2) is at the lower end of the range of soil adherence factors reported in DEA and based on Lepow et al. (1975) and Roels et al. (1980) studies, those studies were not designed to study soil adherence and only allowed calculation of soil adherence to hands. In addition, the central-tendency adherence factor of 0.2 mg/cm^2 estimated here is based on soil adherence studies for all of the relevant body parts (i.e., head, hands, forearms, lower-legs, and feet). Kissel et al. (1998) reports soil adherence factors for children's hands of 0.5-3 mg/cm^2 (median of 1 mg/cm^2) for relatively moist soil, which is comparable to the range of values previously reported for soil adherence to children's hands (0.5-1.5 mg/cm^2; U.S. EPA, 1997a). Exhibit C-2 contains data used to calculate the central tendency and high end AFs for children.

Commercial/industrial adult worker. Given that there were data available for a wide variety of activities that a commercial/industrial adult worker may engage in, a high-end soil contact activity was selected and the central tendency weighted AF (50th percentile) derived for that activity. In so doing, the recommended weighted AF for a commercial/industrial adult worker is 0.2 mg/cm^2 and is based on the 50th percentile weighted AF for utility workers (the activity determined to represent a high-end contact activity). The bases for this recommendation are as follows: (1) although no single activity would be representative of activities a commercial/industrial adult worker engages in, a comparison of the utility worker 50th percentile weighted AF with other commercial/industrial-type activities (Exhibit 3-3) shows that the utility worker represents a high-end soil contact activity (i.e., grounds keepers, landscaper/rockery, irrigation installers, gardeners, construction workers); (2) a combination of common sense and data on the weighted AFs supports the assumption that utility worker activities represent a high-end soil contact activity, whereas, determining which of other measured activities might represent a reasonable, central tendency (i.e., typical) soil contact activity would be difficult; and (3) selecting the central tendency weighted AF (i.e., 50th percentile) of a high-end soil contact activity is consistent with a RME forcontact rates.

Recreational. No specific default values are being recommended for a recreational scenario since many site-specific concerns will impact the choice of exposure variables, such as, climate, geography, location, and land-use. The risk assessors, in consultation with the project team, should reach consensus on the need to evaluate this scenario and the inputs before incorporating this into the risk assessment. The EFH should be consulted to obtain appropriate exposure estimates.

3.2.2.4 Dermal Absorption Fraction from Soil

DEA (Chapter 6) presents a methodology for evaluating dermal absorption of soil-borne contaminants. In that document, ORD reviewed the available experimental data for dermal absorption from contaminated soil and presented recommendations for three compounds/classes. Recommendations were presented as ranges to account for uncertainty which may arise from different soil types, loading rates, chemical concentrations, and other conditions. In RAGS Part E, selection of a single value is based on recommended ORD ranges to simplify this risk calculation. In addition, recommended values for other compounds according to review of literature and default values for classes of compounds are provided. For tetrachlorodibenzo-p-dioxin (TCDD), sufficient data allow specific recommendations based on organic content of the soil.

Values in Exhibit 3-4 have been determined to be applicable using the Superfund default human exposure assumptions, and are average absorption values. Other values will be added to this list as results of further research become available. However, as an interim method, dermal exposure to other compounds should be treated qualitatively in the uncertainty section or quantitatively using default values after presenting the relevant studies to the regional risk assessors so that absorption factors can be agreed upon on a site-specific basis before the start of the risk assessment. Particular attention should be given to dermally active compounds, such as benzo(a)pyrene, and they should be addressed fully as to their elevated risk by this route of exposure.

This guidance provides a default dermal absorption fraction for semivolatile organic compounds (SVOCs) of 10% as a screening method for the majority of SVOCs without dermal absorption fractions. This fraction is suggested because the experimental values in Exhibit 3-4 are considered representative of the chemical class for screening evaluations. If these are used quantitatively, they represent another uncertainty that should be presented and discussed in the risk assessment. There are no default dermal absorption values presented for volatile organic compounds nor inorganic classes of compounds. The rationale for this is that in the considered soil exposure scenarios, volatile organic compounds would tend to be volatilized from the soil on skin and should be accounted for via inhalation routes in the combined exposure pathway analysis. For inorganics, the speciation of the compound is critical to the dermal absorption and there are too little data to extrapolate a reasonable default value.

Although Equation 3.12 implies that the ABS_d is independent of AF, this independence may not be the case. Experimental evidence suggests that ABS_d may be a function of AF (Duff and Kissel, 1996 and Yang, 1989). Specifically, ABS_d has been observed to increase as the AF decreases below the quantity of soil necessary to completely cover the skin in a thin layer of soil particles, which is discussed in the DEA as the mono-layer concept. This mono-layer will vary according to physical characteristics of the applied soil, e.g., particle size. Most significantly, nearly all experimental determinations of ABS_d have been conducted at loading rates larger than required to completely cover the skin, while the recommended default values for AF for both adult and children are at or less than that required to establish a mono-layer. The absolute effect of soil loading on these parameters is not sufficiently understood to warrant adjustment of the experimentally determined values. Consequently, actual ABS_d could be larger than experimentally determined and the effect of this uncertainty should be appropriately presented in the risk assessment.

Equation 3.12 includes no explicit effect of exposure time, which also adds to the uncertainty and consequently assumes exposure time is the same as in the experimental study that measured ABS_d. For values presented, the exposure time per event is 24 hours. Site-specific exposure scenarios should not adjust ABS_d per event but rather adjust the exposure frequency (EF) and exposure duration (ED) to account for site conditions.

A discussion of theoretical models that estimate DA_{event} on the basis of a soil permeability coefficient rather than ABS_d is presented in DEA. The permeability coefficient approach offers some advantages in that the partitioning coefficient from soil should remain constant over a wider range of conditions, such as the amount of soil on the skin and the concentration of the contaminant in the soil. However, as soil partitioning procedures are not well developed, the Workgroup recommends that the absorbed fraction per event procedures presented in this guidance be used to assess dermal uptake for soil.

3.2.2.5 Age-Adjusted Dermal Factor

An age-adjusted dermal exposure factor (SFS_{adj}) is used when dermal exposure is expected throughout childhood and into adult years. This accounts for changes in surface area, body weight and adherence factors over an extended period of time. The use of SFS_{adj} incorporates body weight, surface area, exposure duration and adherence factor parameters from the risk equation. To calculate SFS_{adj}, assumptions recommended above for the child (age 0-6 years) and adult (age 7-30 years) were calculated using data from the EFH and the methodology described for the residential child. The recommended age-adjusted dermal factor is calculated using Equation 3.21.

3.2.2.6 Event Time, Exposure Frequency, and Duration

This guidance assumes one event per day, during which a percentage of a chemical quantity is absorbed

Age-Adjusted Dermal Exposure Factor

$$SFS_{adj} = \frac{(SA_{1-6})(AF_{1-6})(ED_{1-6})}{(BW_{1-6})} + \frac{(SA_{7-31})(AF_{7-31})(ED_{7-31})}{(BW_{7-31})} \quad (3.21)$$

$$SFS_{adj} = \frac{(2800cm^2)(0.2mg/cm^2\text{-}event)(6yr)}{(15kg)} + \frac{(5700cm^2)(0.07mg/cm^2\text{-}event)(24yr)}{(70kg)}$$

$$SFS_{adj} = 360\ mg\text{-}yrs/kg\text{-}event$$

where:

Parameter		Definition (units)	Default Value
SFS_{adj}	=	Age-adjusted dermal exposure factor (mg-yrs/kg-events)	–
AF_{1-6}	=	Adherence factor of soil to skin for a child (1 - 6 years) (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	0.2 (EFH, EPA 1997a)
AF_{7-31}	=	Adherence factor of soil to skin for an adult (7 - 31 years) (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	0.07 (EFH, EPA 1997a)
SA_{1-6}	=	Skin surface area available for contact during ages 1 - 6 (cm^2)	2,800
SA_{7-31}	=	Skin surface area available for contact during ages 7 - 31 (cm^2)	5,700
ED_{1-6}	=	Exposure duration during ages 1 - 6 (years)	6
ED_{7-31}	=	Exposure duration during ages 7 - 31 (years)	24
BW_{1-6}	=	Average Body weight during ages 1 - 6 (kg)	15
BW_{7-31}	=	Average Body weight during ages 7 - 31 (kg)	70

systemically, and exposure time is the same as in the experimental study that measured ABS_d (i.e., 24 hours), as recommended in Exhibit 3-4.

Limited data suggest that absorption of a chemical from soil depends on time. However, information is insufficient to determine whether that absorption is linear, sublinear or supralinear with time. Whether these assumptions would result in an over- or under-estimate of exposure and risk is unclear. Site-specific exposure scenarios should not scale the dermal absorption factor of the event time. The exposure frequency for the RME is referenced from RAGS Part A (U.S. EPA, 1989) but may be adjusted to reflect site-specific conditions.

The recommended central tendency and RME values for exposure duration (Exhibit 3-5) are referenced from RAGS Part A (U.S. EPA, 1989), but may be adjusted to reflect site-specific conditions.

3.3 ESTIMATION OF DERMAL EXPOSURES TO CHEMICALS IN SEDIMENT

Exposures to sediment will differ from exposures to soil due to potential differences in the chemical and physical properties between the two media and differing conditions under which these types of exposures occur. Since studies of dermal exposure to sediments are limited, it is recommended that the same risk assessment approach described in this document for soil exposures be used for sediments, with the following considerations:

EXHIBIT 3-5

RECOMMENDED DERMAL EXPOSURE VALUES FOR CENTRAL TENDENCY AND RME RESIDENTIAL AND INDUSTRIAL SCENARIOS – SOIL CONTACT

Exposure Parameters		Central Tendency		RME Scenario	
		Residential	Industrial	Residential	Industrial
Concentration- C_{soil} (mg/kg)		site-specific values			
Event frequency (events/day)		1	1	1	1
Exposure frequency (days/yr)		site-specific	219	350	250
Exposure duration (yr)		9	9	30	25
Skin surface area (cm^2)	Adult	5,700	3,300	5,700	3,300
	Child	2,800	NA	2,800	NA
Soil adherence factor (mg/cm^2)	Adult	0.01	0.02	0.07	0.2
	Child	0.04	NA	0.2	NA
Dermal absorption fraction		chemical-specific values (Exhibit 3-4)			

NA: not applicable

- Sediment samples must be located in areas in which individuals are likely to come into direct contact with the sediments. For wading and swimming, this includes areas which are near shore and in which sediments are exposed at some time during the year. Sediments which are consistently covered by considerable amounts of water are likely to wash off before the individual reaches the shore.

- Since data are generally reported in dry weight, the impact of moisture content in the in situ sample (i.e., wet weight) on exposure and uptake should be considered and discussed in the Uncertainty Section. The greater the moisture content of a sediment sample, the greater the difference in dry vs. wet weight contaminant concentration. Measures of sediment adherence reflect wet weight, therefore dose estimations utilizing sediment concentration recorded in dry weight will serve to over-estimate risk in direct proportion to the moisture content of the sediment sample.

- When applying standard equations for DA_{event} (Eq. 3.12) and DAD (Eq. 3.11) to sediment scenarios, assumptions about surface area exposed, frequency, and duration of exposure will depend on site-specific conditions.

- The amount of chemical absorbed from sediment is dependent on a number of chemical, physical and biological factors. The relative importance of some of these factors on absorption may differ between soils and sediments. Until more information becomes available, the same dermal absorption fraction for soils (Exhibit 3-4) should be applied to sediments. The uncertainties associated with this approach should be discussed in the Uncertainty Section of the risk assessment.

- The adherence factor is perhaps, the most uncertain parameter to estimate for sediment exposures. Increasing moisture content will increase the ability of sediments and soils to adhere to skin, as demonstrated by comparing soil adherence for the same activity in wet and dry soil. The increased moisture content may also affect the relative percent absorbed.

- In addition, assumptions about soil loading (or adherence) will affect absorption estimates For example, as soil loading increases, the fraction absorbed will be constant until a critical level is reached at which the skin surface is uniformly covered by soil (defined as the mono-layer) (Duff and Kissel, 1996). The soil loading at which a mono-layer exists is dependent on grain size. It is recommended that the value chosen for adherence be consistent with the activity and surface area assumptions as well as the mono-layer concept. Exhibit C-4 presents upper bound estimates calculated for the Soil Conservation Service classifications using mean particle diameters and a simplified packing model. These values can be used as bounding estimates in constructing site-specific exposure parameters. The impact of the adherence factor assumptions on absorption should be discussed in the Uncertainty Section.