6 Dermal Exposure Assessment

6.1 Introduction

Semi-volatile and nonvolatile contaminants emitted into the air can be subsequently deposited onto soil or other surfaces. Exposure to chemicals can occur through skin contact with the contaminated soil. This exposure pathway is considered under the Air Toxics “Hot Spots” Act when evaluating chronic exposure.

For semi-volatile organic compounds (SVOCs), OEHHA has not quantified exposure via the air-to-skin transdermal pathway for the Hot Spots Program. This pathway is inherently included in human and animal whole-body inhalation exposures to chemicals in toxicology and epidemiology studies for both VOCs and SVOCs. Whole-body inhalation studies almost always form the basis for determining Reference Exposure Levels (RELs) and Cancer Potency Factors (CPFs) where the metric of exposure is the airborne concentration. As such, exposure via the air-to-skin pathway is incorporated into the RELs and CPFs for individual chemicals.

The significance of the air-to-skin transdermal pathway for some Hot Spots SVOCs has been shown in a modeling study that utilized physical and chemical principles combined with empirical evidence to critically assess the significance of the dermal pathway as a contributor to total human exposure to SVOCs (Weschler and Nazaroff, 2012). In this study, it is proposed that intake by the air-to-skin transdermal pathway can exceed intake by inhalation for several SVOCs that humans can be exposed to. The air-to-skin pathway is of particular concern for the relatively more volatile SVOCs that both equilibrate rapidly with skin-surface lipids and also permeate the skin relatively quickly. Amphiphilic SVOCs (i.e., containing both hydrophilic and lipophilic properties) in particular are included in this group. Hot Spots chemicals that fall into this group probably include the smaller molecular weight PCBs such as PCB77 and PCB81.

For a second group of SVOCs, direct air-to-skin transport can also contribute to total uptake, but perhaps not to the same fractional extent as the first group owing to slower equilibration with skin-surface lipids or slower migration through the stratum corneum (Weschler and Nazaroff, 2012). Hot Spots chemicals that fall into this group include many of the PAHs such as B(a)P and chrysene. In a third group of SVOCs, the equilibrium time is too long for air-to-skin transport to be important. Hot Spots chemicals in this third group include diethylhexylphthalate and probably the dioxins and furans (e.g., TCDD). However, skin contact with these SVOC-containing materials or surfaces (such as contaminated soil) may contribute to elevated levels in skin-surface lipids. Once sorbed at the skin surface, subsequent migration through the stratum corneum and viable epidermis can be relatively fast.

Although the air-to-skin transdermal pathway is generally taken into account in RELs and CPFs, the importance of this route should be discussed in the event RELs or CPFs are developed for some SVOCs based on studies that use other than whole-body inhalation (e.g., nose-only inhalation). Note that chronic inhalation exposures are always “whole body” for logistic reasons.

Likewise absorption of chemicals dissolved or deposited into water while swimming, bathing, or showering could be significant under certain exposure scenarios but usually not under the airborne release scenario considered in the “Hot Spots” program.

The significance of each of the above exposure pathways varies by type of chemical, but dermal uptake of chemicals from soil and other surfaces is considered the most relevant. This route applies to semivolatile organic chemicals such as PAHs, dioxins and PCBs, and some inorganic metals such as lead and lead compounds. Under the “Hot Spots” program, dermal exposure to soils contaminated with these chemicals is considered the principal dermal exposure pathway. The concentrations in soil around a specific facility due to long term deposition are estimated from facility emissions estimates, air modeling, estimates of soil half-life and soil mixing depth.

As discussed in Section 6.5 below, OEHHA devised a new variate called the Annual Dermal Load, or ADL. This variate is a composite of three variates described in the previous version of this document (OEHHA, 2000): the body surface area (BSA) per kg body weight, exposure frequency, and soil adherence variates, which simplifies the calculation for risk assessors. In addition, ADLs have been determined for California climate zones, expressed as warm, mixed and cold. These climate zones recognize the different amount of time one spends outside during the year (depending on the climate zone), and the amount of clothing one wears in these different climate zones. All of which influences the ADL value.

6.2 Recommended Dermal Exposure Values

For assessing dermal exposure, we are recommending point estimates using the ADL variates presented in Table 6.1. These point estimates are the mean and 95th percentile values from the stochastic distributions shown in Tables 6.2a-d. Using Eq. 6-8 (see below), the variables that are needed to assess dermal exposure include the climate-dependent ADL, the soil concentration of contaminant and the ABS (dermal absorption value from soil).

Table 6.1. Recommended Annual Dermal Load Point Estimates (in mg/kg-yr) for Dermal Exposure

	3rd Trimester	Children 0<2 yrs	Children 2<9 yrs	Children 2<16 yrs	Adults[a]	Off-Site Worker
Warm climate						
Mean	1.2×10^3	3.6×10^3	7.5×10^3	6.4×10^3	1.2×10^3	2.6×10^3
95 th percentile	2.6×10^3	4.3×10^3	9.1×10^3	8.5×10^3	2.6×10^3	5.0×10^3
Mixed climate						
Mean	1.1×10^3	2.2×10^3	6.6×10^3	5.7×10^3	1.1×10^3	2.6×10^3
95 th percentile	2.4×10^3	2.9×10^3	8.7×10^3	8.1×10^3	2.4×10^3	5.0×10^3
Cold climate						
Mean	0.7×10^3	1.2×10^3	3.1×10^3	2.8×10^3	0.7×10^3	2.6×10^3
95 th percentile	2.1×10^3	1.9×10^3	5.2×10^3	5.1×10^3	2.1×10^3	5.0×10^3

[a] Residential adults includes 16<30 and 16-70 year age groups

ADL distributions in Tables 6.2a-d are by age group and climate, with the adult age groups (16-30 and 16-70 years of age) sharing the same values. The ADL for the third trimester of the fetus is based on the ADL of the mother; when normalized to body weight, we assume that exposure to the mother and the fetus will be the same. The mother's exposure is based on the adults age 16-30 years of age in Table 6.2d.

Tables 6.2a-d. Annual Dermal Load Distributions by Age Group and ClimateTable

6.2a. Annual Dermal Load (mg/kg-yr) Distributions for the 0<2 Year Age Group

Climate Type	Warm climate	Mixed climate	Cold climate
Distribution	Student's t	Logistic	Triangular
Minimum			0.2×10^3
Likeliest			0.7×10^3
Maximum			2.6×10^3
Scale	0.41	0.28	
Deg. freedom	3		
Midpoint	3.6×10^3		
Mean	3.6×10^3	2.2×10^3	1.2×10^3
50th percentile	3.6×10^3	2.2×10^3	0.9×10^3
90 th percentile	4.1×10^3	2.8×10^3	1.9×10^3
95 th percentile	4.3×10^3	2.9×10^3	1.9×10^3
99 th percentile	4.7×10^3	3.1×10^3	2.1×10^3

Table 6.2b. Annual Dermal Load (mg/kg-yr) Distributions for the 2<9 Year Age Group

Climate Type	**Warm climate**	**Mixed climate**	**Cold climate**
Distribution	Min extreme	Min extreme	Triangular
Minimum			0.4×10^3
Likeliest	8.0×10^3	7.3×10^3	1.9×10^3
Maximum			6.9×10^3
Scale	0.1	1.3	
Mean	7.5×10^3	6.6×10^3	3.1×10^3
50th percentile	7.7×10^3	6.5×10^3	2.3×10^3
90th percentile	8.7×10^3	8.4×10^3	5.1×10^3
95th percentile	9.1×10^3	8.7×10^3	5.2×10^3
99th percentile	9.7×10^3	9.4×10^3	5.7×10^3

Table 6.2c. Annual Dermal Load (mg/kg-yr) Distributions for the 2<16 Year Age Group

Climate Type	**Warm Climate**	**Mixed climate**	**Cold climate**
Distribution	Min extreme	Logistic	Triangular
Minimum			0.3×10^3
Likeliest	7.2×10^3		1.6×10^3
Maximum			6.9×10^3
Scale	1.29	0.91	
Mean	6.4×10^3	5.7×10^3	2.8×10^3
50th percentile	6.6×10^3	5.7×10^3	2.2×10^3
90th percentile	8.1×10^3	7.7×10^3	4.8×10^3
95th percentile	8.5×10^3	8.1×10^3	5.1×10^3
99th percentile	9.3×10^3	8.9×10^3	5.6×10^3

Table 6.2d. Annual Dermal Load (mg/kg-yr) Distributions for Residential Adults (Age 16-30 and 16-70 Years) and Offsite Workers

Receptor	**Residential Adult**			**Offsite Worker**
Climate Type	**Warm**	**Mixed**	**Cold**	**All Climates**[a]
Distribution	Beta	Beta	Gamma	Lognormal
Minimum	0.2×10^3	0.02×10^3		
Maximum	3.3×10^3	0.3×10^3		
Scale			0.07	
Mean	1.2×10^3	1.1×10^3	0.7×10^3	2.6×10^3
50th percentile	1.2×10^3	1.0×10^3	0.5×10^3	2.3×10^3
90th percentile	2.4×10^3	2.1×10^3	1.6×10^3	4.5×10^3
95th percentile	2.6×10^3	2.4×10^3	2.1×10^3	5.0×10^3
99th percentile	2.9×10^3	2.6×10^3	2.3×10^3	6.4×10^3

[a] Face, hands and forearms are exposed only, regardless of climate

There are several advantages for stochastically combining the four variates from the original dermal dose equation (see Equation 6-1 below) into an annual dermal load variate (OEHHA, 2000). First, using one variate (annual dermal load) rather than four separate variates simplifies calculations for risk assessors. Also, distributional information that previously was separate is now integrated into one distribution. In addition, selecting a high-end value from the annual dermal load distribution reduces the possibility of over-conservatism that can occur when high-end values of the variates are multiplied together as was done with Equation 6-1 in the prior edition of the Stochastic guidelines (OEHHA, 2000).

6.3 Dermal Uptake from Contaminated Soil Contact

Although the dermal exposure route is generally considered a minor exposure pathway, a screening study by Johnson and Kissel (1996) of over 200 risk assessments for Superfund sites resulted in identification of 37 sites at which projected lifetime excess cancer risks attributed to dermal contact with contaminated soil were greater than 1 in 10,000. Dermal exposure was the dominant exposure route at 9 sites. Thus it is possible for dermal exposure to reach a level of significance, although the soil concentrations resulting from airborne deposition tend to be lower than when more concentrated pollutants are present in hazardous waste sites. The primary soil contaminants in these dermal risk assessments included dioxins, PAHs, PCBs and arsenic. Johnson and Kissel (1996) highlighted early concern for the dermal pathway and the need for better information for dermal exposure variates, such as the chemical fractional skin absorption, surface area exposure and soil adherence, in order to better assess dermal absorption potential.

The potential for skin contact with soil near the home can be significant. In a national survey known as the Soil Contact Survey, almost half of households reported the presence of bare spots (44.7%) other than gardens in their yards (Wong et al., 2000a).

A majority (63.7%) of respondents with homes also reported a vacant lot or field within walking distance of the home.

As discussed above, dermal absorption varies by exposure pathway and with the properties of the chemical. Other major factors which influence dermal absorption include the anatomical region exposed (Maibach et al., 1971; Wester and Maibach, 1985), the amount of skin exposed, soil or particle type and size, amount of soil adhering to skin (Duff and Kissel, 1996; Choate et al., 2006), type of surface contacted, chemical concentration (Nomeir et al., 1992; Sartorelli et al., 2003), duration of exposure, ambient temperature and humidity (Chang and Riviere, 1991), and activities which limit exposure (e.g., washing the skin).

The inherent variability in some of the exposure factors can be estimated, such as in total skin surface area of children and adults. In other cases, the actual variation is not as well known, such as soil loading on specific body parts in young children. Also, the factor involved may be well known but the net effect on dermal absorption of chemicals may not be readily described or quantified. For example, dermal absorption varies with skin temperature and blood flow, which tends to vary with ambient temperature and physical activity. However, the magnitude of this effect is insufficiently documented to support distribution modeling. Overall, there is generally not enough information to generate probability distributions for all of the key variates for estimating dermal absorption, although ranges are available for some variates.

This discussion of dermal exposure estimates includes the primary variates involved and can be reasonably quantified or estimated, based on the more common human activities that result in soil skin contact (e.g., gardening). Dermal exposure is expressed as a variate called the dermal dose (Eq. 6-1). The dermal dose is defined as the amount of contaminant absorbed through the skin per unit of body weight per day (mg/kg-day). For the Air Toxics “Hot Spots” program, the dermal dose resulting from contact with contaminated soil can be estimated using the following equation:

$$\text{DOSEdermal} = (C_s \times SA \times SL \times EF \times ABS) \;/\; (BW \times 1\text{x}10^6) \qquad \textbf{(Eq. 6-1)}$$

where:

DOSEdermal = exposure dose through dermal absorption (mg/kg-d)
C_s = average concentration of chemical in soil (µg/kg)
SA = surface area of exposed skin (m^2)
SL = soil loading on skin (g/m^2-d)
EF = exposure frequency (d/365 d)
ABS = fraction of chemical absorbed across skin
BW = body weight (kg)
$1\text{x}10^6$ = conversion factors for chemical and soil (µg to mg, g to kg)

The dermal absorption factor (ABS) is a chemical-specific, unitless factor that is discussed in Section 6.4.1 below. The exposure frequency (EF) is set at 350 days per year (i.e., per 365 days) to allow for a two-week vacation away from home each year (US EPA (1991).

Equation 6-1 requires multiplying values together, which could lead to overly conservative exposure estimates when high-end values for variates are used. By combining information from several variates into one composite distribution, over-conservatism may be avoided (see Section 6.5). To this end, OEHHA created a new variate, “annual dermal load”, or ADL, which is a composite of the body surface area (BSA) per kg body weight, exposure frequency, and soil adherence variates:

$$\mathrm{ADL} = (\mathrm{BSA} / \mathrm{BW})^{*} [(\mathrm{SL}_b)(\mathrm{SA}_b\%_b)] * \mathrm{EF} \qquad \textbf{(Eq. 6-2)}$$

Where:

ADL = Annual dermal load (mg/kg BW-yr)
EF = Exposure frequency (d /yr)

Thus, the dermal-dose equation (Eq. 6-1) can be reduced to the following:

$$\text{Dermal dose (mg/kg-d)} = \mathrm{ADL} * C_s * \mathrm{ABS} * (\text{yr}/365\ \text{d}) * 1\text{x}10^{-9} \qquad \textbf{(Eq. 6-3)}$$

Where:

yr/365 d = Conversion factor (years to days)
$1\text{x}10^{-9}$ = Conversion factor for chemical and soil (µg to mg, mg to kg)

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASFs) and the chemical-specific cancer potency factor (CPF) expressed in units of $(\text{mg/kg-day})^{-1}$:

$$\text{RISKdermal} = \text{DOSEdermal} * \text{CPF} * \text{ASF} * \text{ED}/\text{AT} \qquad \textbf{(Eq. 6-4)}$$

RISK is the predicted risk of cancer (unitless) over a lifetime as a result of the exposure, and is usually expressed as chances per million persons exposed (e.g., $5 \text{ X } 10^{-6}$ would be 5 chances per million persons exposed).

The dose-response phase of a cancer risk assessment aims to characterize the relationship between an applied dose of a carcinogen and the risk of tumor appearance in a human. This is usually expressed as a cancer potency factor, or CPF, in the above equation. The CPF is the slope of the extrapolated dose-response curve and is expressed as units of inverse dose $(\text{mg/kg-d})^{-1}$, or inverse concentration $(\mu\text{g/m}^3)^{-1}$.

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (OEHHA, 2009), the exposure for each age grouping must be separately calculated. Because cancer risk has been shown to be greater in sensitive age groups, different ASFs are applied to different life stages used for cancer risk assessment (see below). DOSEdermal can vary depending on the type of outdoor activities that involve soil exposure. The type of outdoor activities may be specific for the age of the individual, such as general outdoor play on bare soil by young children, or gardening by adults. Thus, the DOSEdermal and ED are different for each age grouping.

ED = exposure duration (yrs):

0.25 yrs for third trimester	(ASF = 10)
2 yrs for 0<2 age group	(ASF = 10)
7 yrs for 2<9 age group	(ASF = 3)
14 yrs for 2<16 age group	(ASF = 3)
14 yrs for 16<30 age group	(ASF = 1)
54 yrs for 16-70 age group	(ASF = 1)

DOSEdermal includes indirect exposure to the fetus via direct exposure to the mother during the third trimester of pregnancy. Fetal exposure during the third trimester will be the same as that of the mother on a body weight-normalized basis, and is taken into account in the final determination of the annual dermal load presented in Section 6.2.

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$\text{RISKdermal}_{(\text{lifetime})} = \text{RISKdermal}_{(\text{3rdtri})} + \text{RISKdermal}_{(0<2\text{ yr})} + \text{RISKdermal}_{(2<16\text{ yr})} + \text{RISKdermal}_{(16\text{-}70\text{yr})} \qquad \textbf{(Eq. 6-5)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk in a 9 year residential scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as follows:

$$\text{RISKdermal}_{(\text{9-yr residency})} = \text{RISKdermal}_{(\text{3rdtri})} + \text{RISKdermal}_{(0<2\text{ yr})} + \text{RISKdermal}_{(2<9\text{ yr})} \qquad \textbf{(Eq. 6-6)}$$

For 30-year residential exposure scenario, the 2<16 and 16<30 age group RISKdermal would be added to the risk from the third trimester to 0<2 age group. For 70 year residency risk, Eq 6-5 would apply.

Because distributional data are available for the total surface area, body weight and exposure frequency variates, a stochastic approach can be used to derive one distribution by combining these variates for the specified age groups. This stochastic approach provides an alternative means for estimating dermal exposure and is presented below in Section 6.2.

The term Cs, concentration of the contaminant in soil, can be derived in the Hot Spots Analysis and Reporting Program (HARP) using air dispersion and deposition modeling (CARB, 2003). The concentration is a function of the deposition, accumulation period, chemical-specific soil half-life, mixing depth, and soil bulk density. The formula used is:

$$C_s = [\text{Dep} \times X)] \;/\; [K_s \times \text{SD} \times \text{BD} \times T_t] \qquad \textbf{(Eq. 6-7)}$$

where:

C_s = average soil concentration over the evaluation period (µg/kg)
Dep = deposition on the affected soil area per day (µg/m2-d)
X = integral function accounting for soil half-life (d)
K_s = soil elimination time constant = $0.693/T_{1/2}$
SD = soil mixing depth = 0.01 m for playground setting and 0.15 m for agricultural setting
BD = bulk density of soil = 1333 kg/m3
T_t = 25,550 days (70 yrs), total averaging time for the chemical accumulation period (i.e., 70 yrs, the presumed life of the facility emitting chemicals)

The deposition on the affected soil area per day is expressed as:

$$\mathrm{Dep} = \mathrm{GLC} \times \mathrm{Dep\text{-}rate} \times 86{,}400 \qquad \textbf{(Eq. 6-8)}$$

where:

GLC = ground level concentration from air dispersion modeling (µg/m3)
Dep-rate = vertical rate of deposition (m/sec) (see Chapter 2 for values)
86,400 = seconds per day conversion factor (sec/d)

The integral function, X, is as follows:

$$X = [\{\mathrm{Exp}\,(-K_s \times T_f) - \mathrm{Exp}\,(-K_s \times T0)\} / K_s] + T_t \qquad \textbf{(Eq. 6-9)}$$

where:

Exp = exponent base e = 2.718
K_s = soil elimination constant = $0.693/\ T_{1/2}$
$T_{1/2}$ = chemical-specific soil half-life (d)
T_f = end of exposure period (d)
T_0 = beginning of exposure period (d) = 0 days
T_t = total days of exposure period = Tf - T0 (d)

Chemical-specific soil half-lives ($T_{1/2}$) are presented in Appendix G.
T_f = 25,500 d = 70 yrs. Identifies the total number of days of soil deposition.
T_f = 9,490 d = 25 yr for nursing mother in mother's milk pathway.

The assumptions in the soil concentration algorithm include:

1) Uniform mixing of pollutants in the soil and a constant concentration over the duration of the exposure.
2) The bulk density (BD) of soils is similar over a wide variety of soil types.
3) Substances are not leached or washed away, except where evidence exists to the contrary
4) For the mother's milk pathway, the mother is exposed for 25 years, the child receives milk for one year (from mother's 25th birthday to 26th birthday), and then is exposed to all other pathways.

6.4 Derivation of Key Dermal Exposure Variates

Other than the soil concentration of a chemical, which is estimated from the emission, meteorological, terrain, and other data using HARP (or other software), the key variates in equation 6-1 are the chemical-specific fractional absorption factor (ABS), the surface area of exposed skin (SA), body weight, the soil loading or soil adherence of contaminated soil on skin (SL) in mg soil per cm^2 skin, and the exposure frequency (EF) in number of days exposed per year. The description of how point estimates or distributions were derived for each of these variates using existing literature sources are summarized below, and in Appendix F for the chemical ABS.

6.4.1 Chemical-specific Absorption Factors

Skin permeability is related to the solubility or strength of binding of the chemical in the delivery matrix (soil or other particles) versus the receptor matrix, the skin’s stratum corneum. This skin layer, which is the major skin permeability barrier, is essentially multiple lipophilic and hydrophilic layers comprised of flattened, dead, epidermal cells. The greatest rate of skin permeation occurs with small moderately lipophilic organic chemicals. However, such chemicals may not have the greatest total uptake, because they may evaporate off the skin. The highest penetration thus is expected from larger, moderately lipophilic chemicals with negligible vapor pressures. Organic chemicals which dissociate in solution, or metal salts that are more soluble in the aqueous phase of stratum corneum and insoluble in the lipid phase, will not penetrate the skin readily.

These principles of skin absorption are presented in US EPA (1992), and summarized in Appendix F of this document as it pertains to dermal absorption from contact with contaminated soil. Fractional dermal absorption point estimate values were derived by OEHHA from available literature sources for the semi-volatile and nonvolatile chemicals in the “Hot Spots” program (Table 6.3). The rationale for the chemical-specific dermal absorption fraction values, and the use of default values in cases where sufficient data are lacking, can be found in Appendix F.

Table 6.3. Dermal Absorption Fraction Factors (ABS) as Percent from Soil for Semi-Volatile and Solid Chemicals under the OEHHA "Hot Spots" Program

Chemical	ABS
Inorganic chemicals	
Arsenic	6
Beryllium	3
Cadmium	0.2
Chromium (VI)	2
Fluorides (soluble compounds)	3
Lead	3
Mercury	4
Nickel	2
Selenium	3
Organic chemicals	
Creosotes	13
Diethylhexylphthalate	9
Hexachlorobenzene	4
Hexachlorocyclohexanes	3
4,4'methylene dianiline	10
Pentachlorophenol	[a]
Polychlorinated biphenyls	14
Polychlorinated dibenzo-p-dioxins and dibenzofurans	3
Polycyclic aromatic hydrocarbons	13

[a] To be assessed for dermal absorption

Most exposure estimates have utilized a single value for presumed dermal uptake rate or percent without distinguishing between the specific skin regions that might be involved under different scenarios. However, it is known that the permeability of skin to chemicals may vary depending on the skin site of absorption. In general, hands are least permeable, and face and neck are most permeable (Maibach et al., 1971; Wester and Maibach, 1985). Other site-specific and scenario-specific factors are involved in dermal absorption, as discussed in Appendix F, which can result in significant differences in dermal uptake under different conditions. Data are inadequate to describe potential changes in fractional dermal absorption with changing scenarios. Thus, point estimate values are used for the ABS.

6.4.2 Body Surface Area / Body Weight Distributional Variate

Total body surface area (BSA) and body weight are known to be highly correlated with a reported correlation coefficient (r) ranging from 0.88-0.96 (Durnin, 1959). Although there are distributional human body weight data, there are no directly measured data for BSA representative of the population. However, Gehan and George (1970) derived a BSA formula based on direct measurements of BSA from 401 individuals. Their formula accounted for over 99% of the variation in BSA and was derived using more BSA measurements that were directly measured than other BSA formulae. The Gehan and George formula is shown as:

$$\text{BSA}\ (m^2) = (\text{Wt}^{0.51456}) \times (\text{Ht}^{0.42246}) \times 0.02350 \qquad \textbf{(Eq. 6-10)}$$

where:
Wt = body weight (kg)
Ht = body height (cm)

For body weight and height data, OEHHA used the National Health and Nutrition Examination Survey (NHANES) 1999-2004 dataset (CDC, 2007). NHANES provides weights for each individual in the dataset and for the study design so that estimates using NHANES data can be weighted to be nationally representative. Total body surface estimates for each individual in the NHANES 1999-2004 dataset were derived using these individuals' body weight and height and equation 6-5. Means and specific percentiles are shown in Table 6.4 and 6.5. The sample size for NHANES, and for many subpopulations within NHANES (e.g., each year of age), is sufficiently large to provide information on interindividual variability and distributions. There are other sources of body weight and height data, but NHANES is the most recent national dataset, thus reflecting the current population, and has data on each individual for the assessment of interindividual variability.

Table 6.4. Summary Distribution Estimates of Total Body Surface Area (in m^2) by Age Group[a]

	Children 0<2 years	**Children 2<9 years**	**Children 2<16 years**	**Adults >16 years**
Sample size	2106	3250	9007	16,718
Mean	0.459	0.884	1.177	1.942
SEM	0.003	0.005	0.006	0.003
50th percentile	0.470	0.824	1.124	1.923
90th percentile	0.564	1.107	1.730	2.302
95th percentile	0.583	1.212	1.880	2.414

[a] Derived using the equation 6.3 and the body height and weight data of the NHANES 1999-2004 study

Table 6.5. Summary Estimates of Total Body Surface Area over Body Weight (m^2/kg) by Age Group[a]

	All ages	**Children 0<2 years**	**Children 2<9 years**	**Children 2<16 years**	**Adults >16 years**
Sample size	27831	2106	3250	9007	16718
Min	0.016	0.034	0.022	0.016	0.016
Max	0.077	0.077	0.054	0.054	0.040
Mean	0.028	0.049	0.039	0.035	0.025
SEM	0.000068	0.0001	0.000019	0.000097	0.000038
50th percentile	0.026	0.048	0.040	0.035	0.025
75th percentile	0.029	0.051	0.043	0.040	0.027
90th percentile	0.038	0.056	0.045	0.043	0.029
95th percentile	0.043	0.059	0.046	0.045	0.029
99th percentile	0.049	0.063	0.048	0.047	0.031

[a] Derived from NHANES 1999-2004 data

6.4.3 Skin Surface Area Exposed

The amount of skin or body region that is exposed to soil contact is dependent on the type of clothing worn. Clothing is expected to significantly reduce exposure to the covered skin area from contaminated soil. Dermal risk assessment procedures used by U.S. EPA (2004) assumes no exposure of skin that is covered with clothing. The few studies that investigated this issue found that clothing had a protective effect for soil exposure, although some exposure may occur under clothing (Kissel et al., 1998; Dor et al., 2000). Considering Kissel et al. (1998) showed incomplete coverage of exposed body parts occurred in a soil exposure study, it appears unlikely that the limited soil exposure that occurs under clothing will underestimate total exposure. Consequently, the model OEHHA uses assumes no exposure to covered skin. Exposed skin is essentially limited to face, hands, forearms, lower legs, feet, or some combination thereof (U.S. EPA, 2004). However, the amount of skin exposed as a result of clothing choices is dependent on exposure activity, age group, and the climatic conditions. Because California has geographically diverse climatic regions, studies investigating clothing choices by children and adults during warm and cold weather outdoor activities were used to estimate skin exposure for different climate regions within the state.

6.4.3.1 Fractional Body Part Surface Area

U.S. EPA (2004) provides data on the percent of surface area for different body parts that may be exposed to soil. When the fractional surface area of a specific body part, such as hands, is multiplied by total surface area, the surface area of the specified body part in m^2 or cm^2 is determined. As mentioned above, normalized surface area can be derived for each individual in the NHANES dataset. Multiplying normalized surface area for each individual by the percent surface area of each body part gives an estimated normalized surface area of each body part for that individual. Individuals are then grouped by age to derive the surface area for each body part for each age group. Because the percent surface area is a constant, multiplying normalized total surface area by the percent surface area maintains the same probability distribution of the NHANES normalized total body surface area. That is, the probability distribution of body surface area from the nationally representative NHANES data is preserved.

In the children's Soil Contact Survey by Wong et al. (2000b), the activity patterns of children (≤18 years) that would result in dermal soil contact were investigated. Of 680 households, 500 (73.5%) had children that were reported to play outdoors on bare dirt or mixed grass and dirt surfaces. An age breakdown of the children showed that those reporting little outdoor play were either very young (≤1 year) or relatively old (≥14 years for females; ≥16 years for males).

The Soil Contact Survey also asked about clothing choices during outdoor play in warm weather and determined estimated percentage skin surface area exposed (Table 6.6). For children under 5 years of age, outdoor play was treated as a single activity. Information on outdoor activity of children aged 5 to 17 was categorized as gardening/yardwork and as organized team sports. The combination of short sleeves and short pants was a common clothing choice for outdoor activities. Skin exposure was lowest for participants in organized team sports because that group had the highest fraction wearing shoes and high socks.

The mean skin area exposed for children age 5-17 during gardening and yardwork (33.8%) is essentially the same as the default mean surface area value of 33.9% used by U.S. EPA (2004), based on soil adherence data, for children age 6 years and up. Together, the findings indicate that soil contact exposure in warm weather is primarily limited to face, hands, forearms, and lower legs, with feet exposure most common in young children up to about 6 years of age.

Table 6.6. Estimated Skin Surface Area Exposed During Selected Warm Weather Outdoor Activities by Children[a]

	Skin area exposed (% of total) based on expressed clothing choices		
	Outdoor play (age <5 yrs)	Gardening/yardwork (age 5-17 yrs)	Organized team sports (age 5-17 yrs)
Mean	38.0	33.8	29.0
Median	36.5	33.0	30.0
SD	6.0	8.3	10.5

[a] Table adapted from data in Wong et al. (2000)

In the Soil Contact Survey of adults, Garlock et al. (1999) conducted a regional (Washington and Oregon state) and national telephone survey for four outdoor activities among 450 adults for each sample. The activities included gardening, other yard work, outdoor team sports and home construction or repair with digging. The reported participation rate for any activity was 89% for the regional survey and 79% for the national survey, with more than half of the respondents reporting participation in 2 or 3 of the activities. Table 6.7 presents both the national and regional (in parentheses) percentage skin area exposed during warm and cold months among the outdoor participants for these activities. Warm- and cold-weather months were defined by the respondent.

Table 6.7. Estimated Skin Surface Exposed During Outdoor Activities by Adults in the National and Regional (in parentheses) Surveys[a]

	Skin area exposed (% of total) based on expressed clothing choices			
	Gardening	Other yard work	Team sports	Repair/Digging
Warm months				
Median	33 (33)	33 (31)	33 (33)	28 (28)
95th %tile	69 (68)	68 (68)	43 (68)	67 (67)
Cold months				
Median	8 (3)	3 (3)	8 (8)	3 (3)
95th %tile	33 (14)	31 (12)	33 (30)	14 (14)

[a] Table adapted from data by Garlock et al. (1999).

In most activities, the median and 95th percentiles were remarkably similar between the two surveys. Current U.S. EPA guidelines (U.S. EPA, 2004; 2011) for skin area exposed to soil contact assumes roughly 25% exposure for adults, corresponding to head, forearms, lower legs and hands. These findings show that the median exposure during warm months exceeds 25%, suggesting some exposures occur with no shoes or no shirt (males) or with a halter (women).

Based on the results of the Soil Contact Surveys and the activity-dependent soil adherence data in U.S. EPA (2004), the anticipated exposed body parts for children and adults during cold and warm weather are shown in Table 6.8. In cold weather, the findings by Garlock et al. (1999) for adults suggest that the hands and face are most often exposed for some activities (e.g., gardening and team sports), but that only the face is most often exposed or partially exposed for other activities (e.g., other yard work and repair/digging), corresponding to wearing gloves. Given that the most common activities in this study, gardening and team sports, suggest both hands and face were exposed, our assessment will include both body parts for soil exposure of adults and children in a cold climate. Very limited data suggested body part exposure in young children during cold weather months was similar to findings in adults (Holmes et al., 1999). Accordingly, we will also use hands and faces as the exposed body parts for the cold climate assessments in children.

In warm weather, the adult fractional skin exposure during outdoor activities in the Soil Contact Study had a median ranging from 28-33% (Garlock et al., 1999). This finding is only slightly higher than the median fractional skin exposure of about 27% for face, hands, forearms and lower legs combined shown in Table 6.8. Review of the U.S. EPA (2004) soil adherence data for adults shows that shoes are predominantly worn during outdoor activities, and that a halter (for women) or no shirt were choices of some participants as indicated by the Garlock et al. study. For the stochastic assessment, only face, forearms, hands and lower legs were considered “exposed” in warm weather.

For the offsite worker, fractional skin exposure is similar, but since full length pants are worn, assessments only included faces, hands and forearms.

For children in warm weather climates, the survey by Wong et al. (2000b) observed that in addition to the face, hands, forearms and lower legs, the feet were often exposed. For example, young daycare children ages 1 to 6.5 years with free access to both the indoors and outdoors were all found to go without shoes, exposing bare feet or socks, at least once during the day. No data were presented for children less than one year of age. Nevertheless, for the warm weather exposure assessment of the 0<2 age group, the body parts considered exposed include feet, face, hands, forearms and lower legs.

For older children, Wong et al. (2000b) noted that organized team sports are common activities in children ages 5<17 years which may result in soil contact with skin. However, shoes are likely worn during many of these activities. In another study that monitored children's microactivity patterns, it was observed among children ages 3-13 years that younger children were more likely to be barefoot both indoors and outdoors compared to older children (Freeman et al., 2001). The average age of the barefoot children was 5.8 years, and the average age of children that wore shoes was 8.2 years. To account for the greater tendency of younger children in the 2< 9 and 2<16 year age group to go barefoot during outdoor play, OEHHA designated that feet exposure will be given 2/3 and 1/3 weighting for the 2<9 and 2<16 year age groups, respectively, during warm weather activities. This feet exposure adjustment was assessed in the soil adherence section below, in which the soil adherence value for 2< 9 and 2<16 year-olds was reduced to 2/3 and 1/3, respectively, of the initial soil load.

Table 6.8. Exposed Body Parts by Age Group and Weather Conditions, with the Corresponding Mean Values for the Percentage of Total Body Surface for each Body Part in Parenthesis.

	Children 0<2 yrs[a]	**Children 2<9 yrs**[a]	**Children 2<16 yrs**[a]	**Residential Adult**[b]	**Offsite Worker**[b]
Body Part Exposed	**Cold Weather**				
	Hands (5.5) Face (5.8)	Hands (5.3) Face (4.4)	Hands (5.4) Face (3.7)	Hands (5.2) Face (2.5)	Hands (5.2) Face (2.5)
	Warm Weather				
	Hands (5.5) Face (5.8) Forearms (6.0) Lower legs (8.7) Feet (6.4)	Hands (5.3) Face (4.4) Forearms (5.9) Lower legs (10.8) Feet (7.2)	Hands (5.4) Face (3.7) Forearms (6.0) Lower legs (11.8) Feet (7.2)	Hands (5.2) Face (2.5) Forearms (6.1) Lower legs (12.8)	Hands (5.2) Face (2.5) Forearms (6.1)

[a] The percentage of total body surface area for the specified body parts was estimated for each age group from data in Exhibit C-1 of U.S. EPA (2004). All values are averages for males and females combined.

[b] Body part percentage estimated from data in Table B-3 of U.S. EPA (1985).

OEHHA believes the surface area exposure estimates in Table 6.8 are health protective, but not overly conservative. For example, soil exposure under clothing is not included in the algorithm, even though some studies have shown that a limited degree of exposure may occur under clothing (Kissel et al., 1998; Dor et al., 2000). Also, the neck is not included as an exposed skin region in this document, even though a field study by Dor et al. (2000) showed that soil contact on the exposed neck can occur. Future studies of soil contact to skin may need to include the neck as a potential skin region for soil contact.

6.4.3.2 California Climate Regions and Skin Exposure

Climate will strongly influence people's choice of clothing. Due to California's varied climatic regions and existing data on clothing choices at different temperatures, three levels of climatic conditions, warm, mixed, and cold, are used to describe California's climate regions. The type of climate will, in turn, be used to assess the fraction of exposed skin for soil contact.

The "warm" climate is characteristic of Southern California areas such as Los Angeles, which can have warm to hot temperatures throughout the year. The "cold" climate is representative of San Francisco, Eureka, and other northern coastal communities, which have cool temperatures (daily highs of less than 65 degrees) for the majority of the year and can receive a considerable amount of fog and rainfall. The "mixed" climate is one that has warm-to-hot temperatures during much of the year (daily highs over 80 degrees are common), roughly from April to October, and cold temperatures (lows near or below freezing) during the remainder of the year. The mountains and central valley are examples of a mixed climate. Specifically, the mixed climate is described as seven months/year of warm temperatures, resulting in warm-temperature clothing choices, and the remaining five months a year as a cold climate with cold-temperature clothing choices. Thus, the average surface area exposed over a year is proportional to seven months of warm weather skin exposure and five months of cold weather skin exposure.

6.4.4 Soil Adherence Factors

Assessing risk from dermal exposure with contaminated soil requires an estimate of the amount of soil that will stick to skin long enough for the chemical to transfer from the soil and into the skin. This estimate has been given the term soil loading, or soil adherence, and is expressed in mass of soil per area of skin (usually in mg/cm^2). Because some body parts may have substantially greater soil adherence rates relative to other body parts, we assigned body part-specific soil adherence values to the corresponding body part surface area. Soil adherence estimates utilized published studies that were body part-specific, measuring soil adherence to hands, forearms, face, lower legs, and feet resulting from specific outdoor activities. Knowledge of body-part specific soil adherence and surface area exposure can be applied in equation 6-6 below to determine a weighted soil adherence factor (U.S. EPA, 2004; 2011). The example equation presented here is based on potential skin exposure resulting from a choice of clothing that allows soil contact with face, hands, forearms, lower legs and feet (e.g., children in a warm weather climate):

Weighted AF = **(Eq. 6-9)**

$$\frac{(AF_{face})(SA_{face}) + (AF_{forearms})(SA_{forearms}) + (AF_{hands})(SA_{hands}) + (AF_{feet})(SA_{feet}) + (AF_{lower\ legs})(SA_{lower\ legs})}{SA_{face} + SA_{forearms} + SA_{hands} + SA_{lower\ legs} + SA_{feet}}$$

where:

Weighted AF = overall weighted adherence factor of soil to skin (mg/cm^2-event)
AF_i = adherence factor for specific body part (mg/cm^2-event)
SA_i = specific skin surface area exposed for soil contact (cm^2)

U.S. EPA (2004) provided individual data on body-part-specific soil adherence for numerous activities (e.g., playing in dry soil, gardening, etc.), which were derived from published work (Kissel et al., 1996b; Kissel et al., 1998; Holmes et al., 1999). Although soil load was measured for quite a few activities, the number of individuals measured was small for each activity and soil adherence data for some body parts were not available for certain activities and age groups. Thus, OEHHA chose to use the arithmetic average of the soil loading rate for each body part rather than attempt to define a distribution for soil adherence. Table 6.9 presents the body part-specific soil adherence factors, in g/m^2, resulting from common outdoor activities in children and adults.

Lack of soil adherence data is particularly evident among children in the 0<2 year age group. Soil adherence data are essentially absent under one year of age. For children 1<2 yrs of age, soil adherence on specific body parts can be calculated from a small group of daycare children that had roamed freely indoors and outdoors and had access to outdoor soil (Holmes et al., 1999; U.S. EPA, 2004).

For infants less than 1 yr of age, Wong et al. (2000b) observed that these children remained mostly indoors and were likely given little opportunity for direct contact with soil when outdoors. In another children activity survey, parents reported that only 17% of infants age 7-12 months had contact with outdoor dirt the previous day, while 70% of children age 1 to 4 yrs had contact with outdoor soil the previous day (Black et al., 2005).

Notably, the outdoor soil contact findings by Black et al. (2005) contrast with their findings of time spent by children playing indoors on the floor, with considerably greater time spent on the floor among infants compared to older children. Although this chapter is focused on exposure to contaminated outdoor soil, there is much evidence that shows a significant amount of outdoor soil can be found in indoor house dust (Culbard and Johnson, 1984; Davies et al., 1985; Thornton et al., 1985; Culbard et al., 1988; Fergusson and Kim, 1991; Stanek and Calabrese, 1992). From these studies, an average of about one-third of indoor house dust is composed of soil (range: 20-78%). Because infants <1 year old spend more time indoors and play on the floor more frequently than older children, soil exposure from indoor sources may be important source of dermal contact for this age group. However, lack of soil adherence data for infants and lack of soil adherence data due to indoor soil exposure prevent an estimation of the extent of the risk.

To avoid underestimating indoor soil exposure in infants of the 0<2 age group, the infants (i.e., 0≤1 yr olds) are assumed to have the same soil adherence levels on specified body parts as the 1<2 yr old children in a daycare facility (Holmes et al., 1999; U.S. EPA, 2004). Thus, the average soil adherence for the entire 0<2 age group is based on the 1<2 yr old daycare children and is presented in Table 6.9.

A limitation of this data is the lack of soil adherence data for the faces of the young children. To avoid non-participation in the studies, the faces of the children were not examined for soil adherence. As a surrogate, soil adherence data on the faces of 8-12 yr old children playing in dry and wet soil were averaged and used to represent soil adherence on faces of the 0<2 yr age group (Kissel et al., 1998b; U.S. EPA, 2004).

For the 2<9 and 2<16 year-old child groups, equal weighting for soil adherence was given to three groups of children: those that played in dry soil, those that played in wet soil, and those that played team sports (Kissel et al., 1996b; Kissel et al., 1998; U.S. EPA, 2004). Team sports were included to account for the greater tendency of older children to play team sports as opposed to general play in dry or wet soil (Wong et al., 2000b).

The methodology for outdoor play by the children stipulated that shoes be worn. However, studies show that during unrestricted play by children <8 years of age many go barefoot during outdoor play (Freeman et al., 2001). To account for the tendency of younger children in the 2<9 and 2<16 age groups to be barefoot during outdoor play, the soil adherence data on feet of children with access indoors and outdoors at a daycare facility were used (Holmes et al., 1999; U.S. EPA, 2004). Although the ages of the daycare children ranged from 1 to 6.5 years, these data represent the best information currently available for soil adherence on feet of children. OEHHA decided feet exposure during warm weather activities will be given 2/3 weighting for the 2<9 year-olds and 1/3 weighting for the 2<16 year-olds, corresponding to frequent exposure of bare feet to soil primarily in younger children.

For residential adults, a number of outdoor activities that resulted in soil contact were investigated (U.S. EPA, 2004; 2011). Among these activities, gardeners were chosen to estimate body part-specific soil adherence for adults (Table 6.9). Outdoor gardening represents not only one of the more common activities resulting in soil contact, but is also a high-end soil contact activity relative to some of the other outdoor activities examined.

In addition, a number of soil contact activities by adult workers have been examined for soil adherence (U.S. EPA, 2004). The calculated geometric mean weighted soil adherence factors from these data range from 0.02 (grounds keepers) to 0.6 mg/cm^2 (pipe layers in wet soil). Soil adherence values for adult workers in Table 6.9 were based on utility workers, as soil adherence in this line of work appears to be near the median for soil-contact related jobs presented by the U.S. EPA report.

Table 6.9. Body Part-Specific Soil Adherence Factors (in g/m^2) Resulting from Common Outdoor Activities in Children and Adults

	Children 0<2 years	**Children 2<9 years**	**Children 2<16 years**	**Residential Adults**	**Adult Workers**
Activity	General outdoor play	Sports, play in wet & dry soil	Sports, play in wet & dry soil	Gardening	Utility workers
Hands	1.334	5.919	5.919	3.179	3.487
Face	0.063[a]	0.082	0.082	0.574	1.102
Forearms	0.306	0.228	0.228	0.819	3.279
Lower legs	0.183	1.332	1.332	0.42	na[b]
Feet	0.744	1.23	0.41	na	na

[a] No soil adherence data for the face are available for young children. Soil adherence data for the face in 8-12 year old children playing in wet and dry soil were used as a surrogate.

[b] Not applicable

[c] Soil adherence to bare feet based on 1 to 6.5 year olds. Exposure reduced in 2<9 and 2<16 age groups due to less frequent exposure of bare feet in older children.

There are a number of limitations in these types of soil adherence studies that may result in greater or lesser dermal absorption of contaminants in contact with skin. Equation 6-1 assumes uniform soil coverage over the specific body-parts exposed. Gardening studies in a greenhouse using soil amended with fluorescent marker shows that soil contact is uneven and occurs most predictably on those specific body parts, such as hands and knees, that routinely come in direct contact with surfaces (Kissel et al., 1998). This is potentially significant because contaminant absorption is likely reduced in absolute terms as contact area is reduced and as a percent of total contaminant available as soil loading increases beyond monolayer coverage (Duff and Kissel, 1996). As discussed in greater detail in Appendix F, increasing soil loading beyond monolayer coverage will likely reduce fractional absorption of a chemical in soil, as a portion of the soil-bound chemical will not be in direct contact with skin.

Alternatively, there are factors related to soil loading that may underestimate adherence or chemical absorption estimates. A potential underestimation of risk is that hands were washed before hand press studies to estimate pre-loading soil levels (Kissel et al., 1996; Kissel et al., 1998b). Choate et al. (2006) observed that nonwashed hands had considerably greater soil loading after exposure to soil when compared to soil loading on recently washed hands. The lower adhered mass on prewashed hands was probably due to the removal of oils from the skin that aid in the adherence of soil particles. In addition, Sheppard and Evenden (1992) observed a 30% increase in the concentration of a contaminant in soil adhering to the hands compared to the bulk soil that the hands were pressed in. Sparingly soluble contaminants were observed to accumulate in the clay fraction of the bulk soil, characterized as the smallest particles in soil, which was the fraction adhering to hands in greatest abundance.

6.4.5 Duration and Frequency of Exposure to Contaminated Soil

Frequencies (in days/year) and durations (in hours/day) of soil exposures have not been well characterized in past studies. Recent surveys of adult and child activity patterns in relation to soil contact behavior are now available to help reduce the uncertainty associated with these variates. Regarding soil contact duration, the ABS of a particular chemical is dependent on duration of exposure. Thus, dermal absorption studies that most closely reflect the expected duration of soil contact are the most useful for estimating a chemical-specific ABS.

6.4.5.1 Exposure Duration

US EPA (2004) recommends a soil exposure time of 24 hrs and one soil exposure event per day. The exposure duration of 24 hrs assumes soil adhered to skin for 24-hrs starting from the time of first soil contact with skin to soil removal by hand washing and bathing.

One event per day can be defined as one period of exposure to soil per day. Algorithms have also been developed to assess multiple exposure events per day, which can be thought of as replenishment or replacement with a fresh layer of soil on skin (Bunge and Parks, 1997). If soil replacement is frequent enough, the soil concentration is not depleted before the next exposure, and the concentration remains essentially constant for the entire exposure period. Notably, activities involving multiple soil contacts may be better represented by a single contact scenario, if soil from the initial contact interferes with direct exposure to subsequent soil encounters. For the purposes of simplicity, one exposure event per day will be synonymous to a daily exposure, with the assumption that soil depletion of the chemical does not occur before removal from the skin with washing.

For children, exposure durations of 24 hrs are supported by national survey data reported in Wong et al. (2000b) which showed a median child bathing of one time per day. Similarly, regional data from Washington and Oregon reported median child bathing of 7 times per week. The 5th percentile for bathing was 2 and 3 times/week for cold and warm weather, respectively. However, Shoaf et al. (2005) reported a median value of two times per week for child bathing. The deviance from the national survey results was considered to be due to parents being more relaxed in interviews and less inclined to report conservative estimates.

Hand washings were more frequent than bathing among children. Wong et al. (2000b) reported median hand washing of 3 to 5 times per day in the national survey and a median hand washing of 4 times per day in the regional survey. The 5th percentile for hand washing was 2 times/day. Again, Shoaf et al. (2005) reported a less frequent median value of one time per day for hand washings. Videotaping of children's microactivity patterns by Freeman et al. (2001) also tends to support fewer hand washings per day than the national and regional surveys reported by Wong et al. (2000b).

Considering that hands tend to have higher soil loadings than other parts of the body, except perhaps the feet, but are washed more frequently than other body parts, 24 hr exposure to contaminated soil is supported by OEHHA as a reasonable estimate for an overall default assumption for exposure duration. This health protective approach is not considered overly conservative given that some studies show bathing behaviors in children may be as few as 2 times per week.

National and regional bathing and hand washing patterns in adults were reported by Garlock et al. (1999). Nearly all respondents in both surveys (72 to 99%) reported washing hands right away after soil contact activities including gardening, yard work, team sports and home repair and digging. Bathing was reported to occur mainly within 1 hr or later in the day after an activity. Only 1 to 8% did not bathe until the next day. Similar to the child bathing/hand washing survey data, the authors cautioned that the washing/bathing findings may be biased towards more socially desirable responses and should be interpreted with caution. Accordingly, the health protective assumption is to also use a soil contact duration of 24 hrs for adults, as recommended by U.S. EPA (2004).

The duration of the activity does not appear to be a good predictor of soil loading. Kissel et al. (1998) noted that initial soil contact involves a substantial portion of key body parts and is followed by continual gain and loss of soil during activity due to abrasion of skin surfaces. Soil amended with fluorescent marker does suggest increasing involvement of skin surfaces with time, but this outcome was not clearly reflected in the gravimetric results.

6.4.5.2 Exposure Frequency

Soil exposure frequency is the final parameter of significance in these exposure estimates. Prior research by Hawley (1985) based estimates for frequency of contact with soils largely on professional judgment. The U.S. EPA (1992) used Hawley's estimate in arriving at a default value for frequency of contact with soil of 40 events (days) per year as typical for adults, with a high-end estimate of 350 events per year. Hawley also estimated soil contact in young (<2-5 years of age) and older children at 130 events per year. In the revised U.S. EPA dermal risk assessment guidelines (U.S. EPA, 2004), a reasonable maximum exposure (RME) frequency for a residential scenario is 350 days/year for both adults and children.

The Soil Contact Surveys in adults (Garlock et al., 1999) and children (Wong et al., 2000b) provided more specific estimates of time or days spent involved in outdoor activities that may result in soil contact. For the child Soil Contact Survey, adult participants with children recorded outdoor play activities of their children in both warm and cold weather. The play participation rate was 73.5% of all children surveyed. The term "play" or "player" referred specifically to participation in outdoor play on bare soil or mixed grass and soil. Of the 500 children reported to play outdoors, 407 were reported to play outdoors during warm weather months and 390 were reported to play outdoors in cold months. Child players in both seasons were 57.4%.

The child frequency in days/week and hours/day for participants of outdoor play activities is shown in Table 6.10. Among child players, the median play frequency was 7 days/week in warm weather (April-October) and 3 days/week in cold weather (November-March). Arithmetic or geometric means were not reported in the study.

Table 6.10. Frequency of Outdoor Activities with Soil Contact Among Child* Participants in Warm and Cold Climates

Percentile	**Cold Months (November-March)**		**Warm Months (April-October)**	
	days/week	hours/day	days/week	hours/day
5	1	1	2	1
50	3	1	7	3
95	7	4	7	8

* Data from Wong et al. (2000b) for children <18 years of age

The exposure frequencies of outdoor play activities in days/week were multiplied by 50 weeks/year (assumes a two-week vacation per year away from the contaminated environment) to arrive at exposure frequencies in days/year (Table 6.11). For a mixed climate, outdoor play activity in days/year was calculated as 7 months of warm climate (e.g., April-October) and 5 months of cold climate (e.g., November-March), with the assumption of one week vacation away from the contaminated environment during each of the cold and warm climate periods.

Table 6.11. Estimated Frequency of Outdoor Activities with Soil Contact in Days/Year for Children <18 Years of Age*

Percentile	**Cold**	**Mixed**	**Warm**
5	50	60	100
50	150	267	350
95	350	350	350

* Extrapolated from data of Wong et al. (2000b)

For adults, outdoor activities in the Soil Contact Survey by Garlock et al. (1999) were categorized as (1) gardening, (2) other yardwork, (3) team sports, and (4) home repair involving digging. The reported participation rate for the first three activities ranged from 79 to 89% while that for the last activity was 30 and 18% for regional and national surveys, respectively. The report presented activity frequency for warm and cold climates, with climate defined by the survey respondents. Results were presented for “doers”, or participants, of the activity as well as all survey respondents. The survey was conducted on a national basis and for a regional area around Hanford, Washington. Because the Hanford area does not get the extreme weather conditions that some areas of the nation outside of California do, the Hanford area data were considered more likely representative of California than the national data. For three of the activities, gardening, other yardwork, and team sports, the results were presented in hours/month. These soil contact frequency data are not directly applicable to the Hot Spots dermal exposure algorithm because the algorithm requires a different unit of measure (days/year). The frequency of each of these three activities was combined and the results are presented in Table 6.12.

Table 6.12. Total Reported Activity Duration (hrs/mo) Among Adult Participants of Three Activities: Gardening, Other Yard Work, and Team Sports[a]

Hanford (regional) Survey[b]		
Percentile	Cold	Warm
5	1	4
50	6	27
95	31	126
National Survey		
Percentile	Cold	Warm
5	2	4
50	9	22
95	130	108

[a] Data from Garlock et al. (1999)

[b] Participants of regional survey were from counties in Oregon and Washington surrounding the Hanford Nuclear Reservation.

The fourth activity surveyed by Garlock et al. (1999), home repair involving digging, was reported in event days per season. No statistical difference was found between the two survey regions in terms of event days/season among participants for this activity. OEHHA chose not to use the “home repair involving digging” activity data because these data add uncertainty (significant bias may exist in the “digging” data due to the low participation rate) with only small gain in sample size. Table 6.13 presents the results for the home repair involving digging activity.

Table 6.13. Frequency of Home Repair Involving Digging in Events/Season (Days/Season)

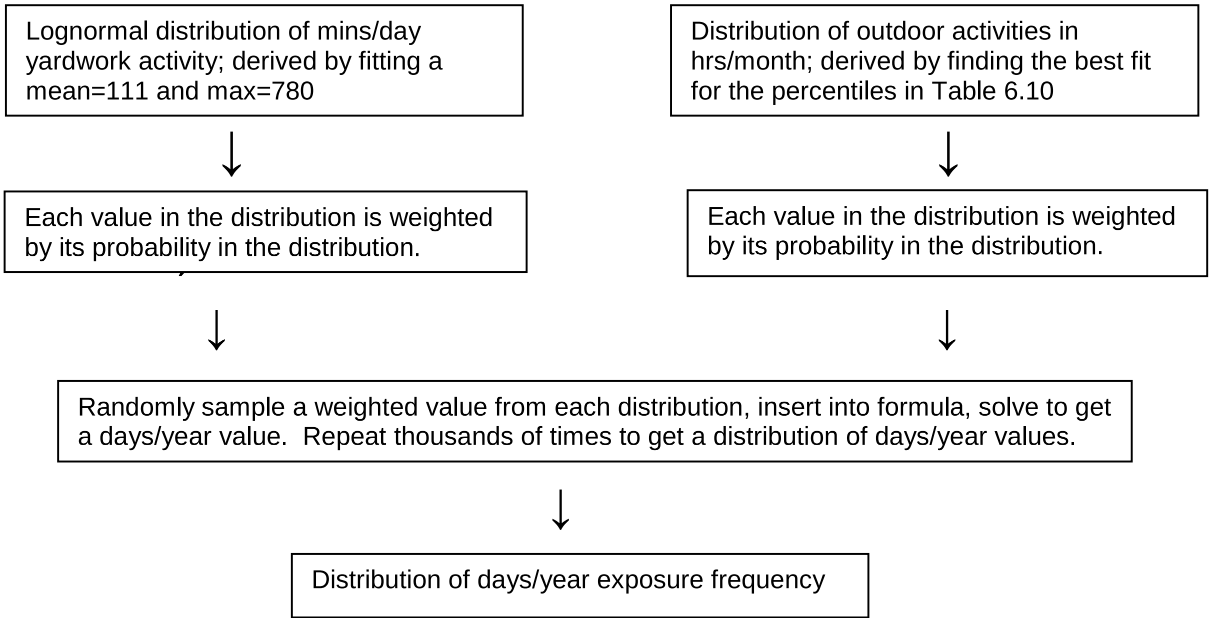
	Cold	**Warm**
	Hanford	
50th percentile	3	4
95th percentile	24	28
	National	
50th percentile	4	6
95th percentile	35	31

OEHHA chose to use the first three of the Garlock et al. activities (gardening, other yardwork, and team sports) for estimating soil contact frequency of adults. Using Monte Carlo simulation in Crystal Ball (Decisioneering, 2008), OEHHA calculated the best fit distribution for exposure frequency in hours/month for each climate (Table 6.12). In order to use these distributions for the exposure variate in these guidelines, the units need to be converted from hours/month to days/year. To do so, a similar activity survey by Jenkins et al. (1992) was employed. The Jenkins et al. study was a statewide survey of Californians’ activity patterns, including “yard work/outdoor chores.” Results were reported in minutes/day and were given for both participants of the activity as well as extrapolated to the population. OEHHA used only the participant results to convert the Garlock et al. study's hours/month data to estimates of days/year. The following formula was used for the conversion:

Days/year = (hrs/mo * 60 mins/hr *12 mos/yr) / (mins/day)

For the time spent by California participants in the "yardwork" activities, Jenkins et al. reported a mean and maximum of 111 and 780 minutes/day, respectively. We fit a lognormal distribution to the mean and maximum values using Monte Carlo simulation (Decisioneering, 2008). For this fit, we considered the maximum to be the 99th percentile. We applied Monte Carlo methods to solve the above formula using the minutes/day and hours/month distributions. We repeated the Monte Carlo analysis of the formula for each climate. As was done for the child exposure frequencies, a mixed climate was considered to have seven months of warm climate (e.g., April-October) and five months of cold climate (e.g., November-March). Diagram 1 outlines the derivation of the distribution of days per year.

Diagram 1. Derivation of distribution of days/year using Monte Carlo methods



Lognormal distribution of mins/day yardwork activity; derived by fitting a mean=111 and max=780

Distribution of outdoor activities in hrs/month; derived by finding the best fit for the percentiles in Table 6.10

Each value in the distribution is weighted by its probability in the distribution.

Each value in the distribution is weighted by its probability in the distribution.

Randomly sample a weighted value from each distribution, insert into formula, solve to get a days/year value. Repeat thousands of times to get a distribution of days/year values.

Distribution of days/year exposure frequency

In order to perform a Monte Carlo analysis, we assumed a correlation exists between the number of minutes per day and the number of hours per month spent in outdoor activities. We also assumed a maximum exposure frequency of 350 days/year in the analyses. The analyses resulted in distributions of days/year for each climate (Table 6.14).

Table 6.14. Days/Year of Soil Contact Activities by Adults*

Climate	Cold	Mixed	Warm
Mean	97	150	168
Percentiles 5th	11	25	31
50th	70	135	161
75th	140	220	241
90th	227	290	302
95th	276	318	326
99th	331	343	345

* Derived from data of Garlock et al. (1999) and Jenkins et al. (1992)

Several potential limitations exist for using an unrelated activity survey to estimate exposure frequency in days/year from the Soil Contact Survey. The category yard work/outdoor chores in the California survey may include activities not involving soil contact, and the two survey populations (i.e., Jenkins' California survey and Garlock's regional/national survey) were mainly from different states. The Jenkins study included participants age >11 years, whereas the adult Soil Contact Survey was conducted with adults 18 years and older. However, these survey data together provide the best available estimate for daily exposure to soil in California resulting from common outdoor activities.

Although specific soil exposure frequency of adult workers was not part of the Soil Contact Survey, a reasonable estimate would assume exposure five d/wk with roughly two weeks off per year, regardless of the California climate region, resulting in an exposure frequency of 250 d/yr. U.S. EPA (2004) uses 350 d/yr as a Reasonably Maximally Exposed individual for industrial workers, and an exposure frequency of 219 d/yr as a central tendency for this variate.

Soil exposure frequency estimates in d/yr for use in Hot Spots programs are summarized below in Table 6.15. The exposure frequency percentiles from the child Soil Contact Survey are most representative for children in the 2<9 and 2<16 year age group. Only about 10% of the children in the Survey were under 2 yrs of age. For the 0<2 year age group, as noted above, Wong et al. (2000b) observed that most newborns (20% or less) up to the first year after birth generally stay indoors and are not exposed to outdoor surfaces with bare dirt. However, most children age 1<2 years participate in outdoor play activities, similar to older children.

As discussed above in Section 6.3.3, about 30% of indoor dust is composed of soil that is brought in from outside. The tendency of infants to play on the floor and be exposed to soil in the dust is much greater when compared to older children. Although infants spend significantly less time outdoors than older children, they may be exposed to contaminated soil via indoor dust as often as older children are exposed to soil outdoors. To address this issue, which involves a sensitive age group, OEHHA used a health-protective approach by assuming that the same exposure frequency occurred for the 0<2 age group as the older child age groups (Table 6.15).

Table 6.15. Cumulative Probability Distributions of Soil Exposure Frequency for Children and Adults in Days/Year

Age Group	Cumulative Probability	Warm Climate	Mixed Climate	Cold Climate
0<2 years	5%	100	79	50
	50%	350	267	150
	95%	350	350	350
2< 9 and 2<16 years	5%	100	79	50
	50%	350	267	150
	95%	350	350	350
Adult – residential	5th	31	25	11
	50th	165	137	70
	95th	326	318	276
Adult – offsite worker	central tendency	250	250	250

6.5 *Point Estimates and Stochastic Approach for Dermal Dose Assessment*

The dermal exposure pathway generally contributes only a small portion of the risk of airborne substances under the typical facility operation and exposure scenarios in the Air Toxics “Hot Spots” program. In the previous edition of this exposure guidelines document (OEHHA, 2000), OEHHA recommended using specified average and high-end point estimate values for four of the variates in equation 6-1:

body weight (Table 6.5)

exposed surface area of skin (SA) (Table 6.5)

soil load on skin (SL) (Table 6.9)

frequency of exposure (EF) (Table 6.15)

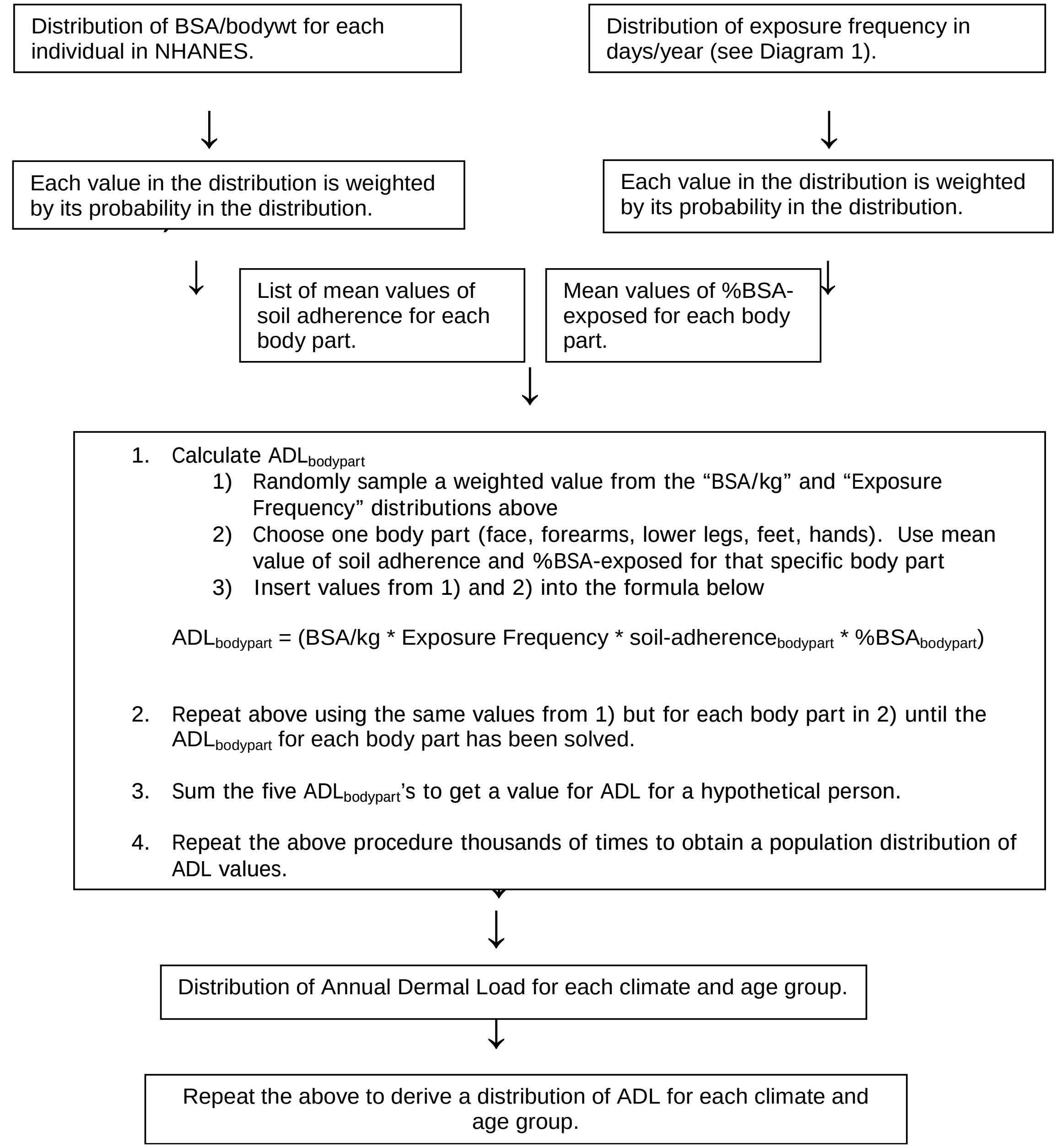
As explained in Section 6.3, OEHHA created a new variate, “annual dermal load”, or ADL, which is a composite of the body surface area (BSA) per kg body weight, exposure frequency, and soil adherence variates. Point estimates from the composite “annual dermal load” can be used for point estimate assessments while parameters and information on the type of distribution (e.g., lognormal) can be used for stochastic assessments.

Distributional data are available for the body surface area per kg of body weight (BSA/BW) and exposure frequency variates. Thus, a stochastic approach could be used to derive a distribution by combining these variates. On the other hand, only point estimates for soil loading and percent of surface area for specific body parts for activities that result in soil contact are available. These constant values (means) can be used in the stochastic derivation of a composite distribution because they will not affect the distributional type or shape of the combined BSA/KG and exposure frequency distribution. Using a Monte Carlo simulation in Crystal Ball (Decisioneering, 2008) a distribution for the ADL was derived combining these variates. The ADL is in units of mg of soil loaded onto skin per kg body weight per year (mg / kg-yr)

To derive a distribution of ADL values that can be used to stochastically derive dermal dose, nationally representative values of “BSA per kg body weight” and “exposure frequency” distribution data are used together with mean values of “soil adherence” and “%BSA-exposed”. For each age group and climate, a value is sampled from each of the “BSA/BW” and “Exposure Frequency” distributions based on its probability in the distribution. These values are multiplied by the mean “soil adherence” and “%BSA-exposed” values for a given body part (and age group and climate). This product gives an ADL for that body part ($ADL_{bodypart}$). This process is repeated for up to four more times using the same “BSA/kg” and “Exposure Frequency” values but with “soil adherence” and “%BSA-exposed” values for a different body part each time. This results in five $ADL_{bodypart}$ values, one for each of face, hands, feet, forearms, and lower legs. The five $ADL_{bodypart}$’s are summed to give an ADL for a hypothetical person for a specific age group and climate.

This process of deriving an ADL for a hypothetical person is repeated thousands of times to give a distribution of ADL values (for that age group and climate). This distribution of ADL values has incorporated the population distribution information from the “body surface area normalized to body weight” and “exposure frequency” variates. Diagram 2 outlines the procedure of stochastically estimating a probability distribution of ADL values and Table 6.2 in Section 6.2 above present the stochastically-derived ADL distributions for each of the five age groupings.

Diagram 2. Derivation of Annual Dermal Load (ADL) using Monte Carlo methodology



Distribution of BSA/bodywt for each individual in NHANES.

Distribution of exposure frequency in days/year (see Diagram 1).

Each value in the distribution is weighted by its probability in the distribution.

Each value in the distribution is weighted by its probability in the distribution.

List of mean values of soil adherence for each body part.

Mean values of %BSA-exposed for each body part.

1. Calculate $ADL_{bodypart}$
    1) Randomly sample a weighted value from the “BSA/kg” and “Exposure Frequency” distributions above
    2) Choose one body part (face, forearms, lower legs, feet, hands). Use mean value of soil adherence and %BSA-exposed for that specific body part
    3) Insert values from 1) and 2) into the formula below

$$ADL_{bodypart} = (BSA/kg * \text{Exposure Frequency} * \text{soil-adherence}_{bodypart} * \%BSA_{bodypart})$$

2. Repeat above using the same values from 1) but for each body part in 2) until the $ADL_{bodypart}$ for each body part has been solved.
3. Sum the five $ADL_{bodypart}$’s to get a value for ADL for a hypothetical person.
4. Repeat the above procedure thousands of times to obtain a population distribution of ADL values.

Distribution of Annual Dermal Load for each climate and age group.

Repeat the above to derive a distribution of ADL for each climate and age group.

6.6 Dermal Uptake Equations by Other Agencies

6.6.1 U.S. EPA Exposure Estimates

The U.S. EPA (2004) suggested using the following equation for estimating dermal exposure to chemicals from soil:

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT} \qquad \textbf{(Eq. 6-12)}$$

where:

DAD = dermal absorbed dose (mg/kg-d)
DAevent = absorbed dose per event (mg/cm2-event)
EV = event frequency (events/d)
EF = exposure frequency (d/yr)
ED = exposure duration (yrs)
SA = skin surface area available for contact (cm2)
BW = body weight (kg)
AT = averaging time (d); for noncarcinogenic effects, AT = ED x 365 d/yr for carcinogenic effects, AT = 70 yrs or 25,550 d

The absorbed dose per event, DA_{event}, uses a percent absorption calculation which considers chemical-specific absorption estimates and the soil type and skin adherence factor:

$$DA_{event} = C_{soil} \times CF \times AF \times ABS_d \qquad \textbf{Eq. 6-13}$$

where:

DAevent = absorbed dose per event (mg/cm2-event)
Csoil = chemical concentration in soil (mg/kg)
CF = conversion factor (10-6/mg)
AF = adherence factor of soil to skin (mg/cm2-event)
ABSd = dermal absorption fraction

US EPA (2004) recommends an age-adjusted dermal exposure factor (SFS_{adj}) when dermal exposure is expected throughout childhood and into the adult years. This accounts for changes in surface area, body weight and adherence factors over time. The SFS_{adj} is calculated using the US EPA age groupings of 1-6 years (children) and 7-31 years (adult):

$$SFS_{adj} = \frac{(SA_{1-6})(AF_{1-6})(ED_{1-6})}{(BW_{1-6})} + \frac{(SA_{7-31})(AF_{7-31})(ED_{7-31})}{(BW_{7-31})} \qquad \textbf{Eq. 6-14}$$

where:

SFSadj = age-adjusted dermal exposure factor (mg-yrs/kg-events)
AF1-6 = adherence factor of soil to skin for a child 1-6 yrs (mg/cm^2-event)
AF7-31 = adherence factor of soil to skin for an adult 7-31 yrs (mg/cm^2-event)
SA1-6 = skin surface area available for contact during ages 1-6 yrs (cm^2)
SA7-31 = skin surface area available for contact during ages 7-31 yrs (cm^2)
ED1-6 = exposure duration during ages 1-6 (yrs)
ED7-31 = exposure duration during ages 7-31 (yrs)
BW1-6 = average body weight during ages 1-6 yrs (kg)
BW7-31 = average body weight during ages 7-31 yrs (kg)

6.6.2 Cal/EPA Department of Pesticide Regulation Guidance for the Preparation of Human Pesticide Exposure Assessment Documents

The Department of Pesticide Regulation (DPR) has developed guidelines for exposure assessment that include a dermal absorption component for occupational exposure to pesticides. The guidelines are currently under revision and have not been posted as of this writing (DPR, 2007). Previously, the DPR dermal absorption estimate procedure used a default uptake value of 100% unless a pesticide registrant chooses to collect specific data. However, DPR has revised the dermal absorption default for pesticides to 50% absorption on the basis of a survey of previous pesticide absorption studies, and the finding that 100% absorption in humans has not been observed for any pesticide (DPR, 1996). Experimental absorption values prior to the current revision process were calculated from *in vivo* data as follows:

$$\text{Percent dermal absorption} = \frac{\text{Applied dose} - \text{Unabsorbed dose}}{\text{Applied dose}} \times 100 \qquad \text{Eq. 6-15}$$

The absorbed portion may also be calculated from the sum of all residues found in excreta, expired air, blood, carcass, and skin at the site of application (after washing), or estimated from the asymptotic plot of all (radioactively-labelled) residues excreted in feces, urine, and air. Absorption rate in an animal experiment in vivo is assumed to be applicable to humans, unless it can be corrected with the ratio of *in vitro* uptake in animal vs. human skin.

6.6.3 CalTOX

The Department of Toxic Substances Control (DTSC) developed the CalTOX computer program to estimate potential exposure to chemicals at hazardous waste sites (DTSC, 1993; 1994). The program incorporates variable parameters in each exposure pathway to estimate multimedia uptake of a chemical by all exposure routes, with the uncertainty assumptions explicitly presented. The program provides a mechanism for screening health risks at hazardous waste sites. CalTOX incorporates explicit assumptions for distributions of all exposure parameters, but with regard to dermal exposure, is focused on dermal uptake of contaminants poured directly onto soil, and at concentrations higher than one would anticipate from airborne deposition. The basic uptake model is:

$$ADD = AR_s \times SA_b \times 0.3 \times 15 \times EF_{sl}/365 \times C_g \qquad \text{(Eq.6-16)}$$

where:

ADD = average daily dose in mg/kg-day, for one exposure event/d
AR_s = ratio of the absorbed dose to the soil concentration, e.g., uptake per unit area of skin per unit concentration in soil in mg/cm^2 per mg/cm^3
SA_b = body surface area per kg, in m^2/kg
0.3 = fraction of total body exposed to soil, default value; coefficient of variation (CV) assumed = 0.04
15 = conversion factor for soil density, in kg/cm-m^2, based on a soil bulk density of 1500 kg/m^3
$EF_{sl}/365$ = exposure frequency in days/year, divided by the days in a year; mean assumed = 137, CV = 0.6
C_g = chemical concentration in soil (mg chemical/kg soil).

The absorbed dose for each event is calculated with the following equation:

$$AR_s = T_s \times \left\{ 1 - \exp\left[\frac{-K^s_p \times ET_{sl}}{T_s} \right] \right\} \qquad \text{(Eq. 6-17)}$$

where:

AR_s = skin uptake as defined above
T_s = thickness of soil layer on skin, in cm
K^s_p = permeability factor for chemical movement from soil into skin, in cm/hr
ET_{sl} = soil exposure time, in hrs/d

The thickness of the soil layer on skin, T_s, depends on the soil loading factor, which was assumed to be 0.5 mg/cm^2, with CV = 0.4. The permeability factor, K^s_p, is derived from permeability values, K_p, from water, with a correction for decreased skin hydration. ET_{sl} is set equal to half the total exposure time at home.

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