Exposure Dose Guidance for Soil/Sediment Dermal Absorption

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Contents This guidance contains the following topics:

Purpose

Based on the availability of updated exposure parameters, many from the 2011 Exposure Factors Handbook (EFH) published by the U.S. Environmental Protection Agency (EPA), it is necessary that assumptions used in calculating doses in our public health evaluations be updated to reflect the best available science.

This exposure dose guidance (EDG) for soil/sediment dermal absorption provides health assessors with guidance on how to estimate dermal absorption of contaminants in soil and sediment.

Refer to the EDG for soil and sediment ingestion to address the oral ingestion pathway (ATSDR 2018).

Background

After a release of chemicals into the environment, health assessors must evaluate all human exposure pathways; dermal absorption from soil and sediment should be evaluated where appropriate. ATSDR initially described its approach for estimating dermal uptake in the following documents.

1. ATSDR's Public Health Assessment Guidance Manual (PHAGM) (ATSDR 2005) provides guidance on the evaluation of the dermal pathway based on the 2001 Risk Assessment for Superfund (RAGS) Part E document (EPA 2001) and the 1997 Exposure Factor Handbook (EFH) (EPA 1997).

2. The PHAGM (ATSDR 2005) recommends that dermal contact with chemicals be evaluated using the following equation (EPA 2001, EPA 1997). ***The equation below is no longer the most current method for evaluating dermal exposure to solid media.***

   $$D = (C \times A \times AF \times EF \times CF) / BW$$

   Where,

   D = dose (mg/kg/day)
   C = contaminant concentration (mg/kg)
   A = total soil adhered (mg)
   AF = bioavailability factor (unitless)
   EF = exposure factor (unit less)
   CF = conversion factor (10^{-6} kg/mg)
   BW = body weight (kg)

3. The 2005 ATSDR PHAGM default dermal exposure values (e.g., skin surface area, soil adherence) used in the above equation ***are no longer appropriate to use.***

4. The 2005 PHAGM has now been replaced with the 2022 PHAGM, which has a section on dermal uptake (ATSDR 2022)

5. Recent data indicate that soil properties influence adherence, soil adherence varies considerably across different body parts, and soil adherence varies with activities. Therefore, an updated approach for evaluating dermal exposures is necessary (EPA 2004).

This EDG provides guidance to health assessors on how to determine the best exposure assumptions needed to calculate dermal exposure dose based on updated EPA guidance: RAGS Part E for Dermal Exposure (EPA 2004) and the Exposure Factors Handbook (EPA 2011) (Appendix A). Examples are provided in Appendix B.

Definitions

Several definitions are important to know in order to discuss dermal absorption from soil and sediment. These definitions follow:

Soil. Particles of unconsolidated mineral or organic matter from the earth's surface that are located outdoors, or are used indoors to support plant growth. Soil includes particles that have settled onto outdoor objects and surfaces.

Sediment. Sediment is soil located beneath water at least for a portion of the year. Sediment should be available for contact by receptors by being located in shallow water or uncovered on the edge of the water. Sediment located at depth beneath water is unlikely to result in appreciable dermal exposure since it will tend to be rapidly washed off. Sediment is a medium separate from soil, although is evaluated similar to soil.

Surface soil. Soil less than 3 inches deep is considered surface soil. Soil samples from other depths (e.g., 0 to 6 inches) are usable, but the depth should be noted.

Dermal Absorption from Soil and Sediment. Dermal absorption from soil and sediment is defined as absorption of chemicals found in soil or sediment through the skin. The amount of chemical that enters the body is dependent on certain properties of the chemical, such as how efficiently it may go through the skin and enter the bloodstream. Note that this EDG does not address direct effects to the skin, such as irritant contact dermatitis.

Dermal Absorption. Dermal absorption refers to the amount of a chemical that is absorbed into the body through the skin. A dermal absorption fraction (ABSd) is included in the dermal dose equation to adjust for the amount of a chemical that is absorbed into the body via the skin.

Administered Dose. Health guidelines, such as MRLs, RfDs and slope factors are provided as administered doses. That is, they reflect the amount of a chemical that is administered orally per unit time and body weight. Site-specific doses derived for oral intake are considered to be administered doses and are compared directly to appropriate health guidelines.

Dermally Absorbed Dose. The dermally absorbed dose is the dose of a contaminant that is absorbed into the body through the skin. To compare the dermally absorbed dose to health guidelines, the dermally absorbed dose needs to be converted from an absorbed dose to an equivalent administered dose. This conversion also allows the dermal dose to be added to the oral dose from soil/sediment ingestion. Equations used to make this adjustment are provided in this EDG.

Central Tendency Exposure (CTE). CTE represents an exposure scenario that reflects average exposure. For dermal absorption from soil/sediment, the default exposure scenario for both CTE and RME (see below) is based on CTE parameters since the values for body weight and skin surface area are

dependent upon each other. Given the dependency of body weight and skin surface area, the noncancer doses generated for CTE and RME exposure are the same. A cancer risk for CTE exposure, however, is derived using a default CTE residential occupancy period of 12 years or a median occupational tenure of 5 years.

Reasonable Maximum Exposure (RME). RME represents a reasonable maximum exposure that assesses exposures that are higher than CTE but are still within a realistic exposure range. As noted above, the noncancer doses associated with dermal contact with soil and sediment are the same for CTE and RME exposure. A cancer risk for RME exposure, however, is derived using a default RME residential occupancy period of 33 years or 95th percentile occupational tenure of 20 years.

Exposure Dose Calculation

The EPA RAGS Part E (EPA 2004) and the updated EFH (EPA 2011) recommend updated equations and exposure factors that health assessors should use to estimate dermal dose. It should be noted that estimating the dermal dose using this equation does not address toxicity that may result from direct dermal contact with a contaminant, such as allergic contact dermatitis, hives, and chemical irritation. The following equation for dermal absorbed dose is based on methodology provided in EPA RAGS Part E (EPA 2004) and EPA EFH (EPA 2011).

$$DAD = \frac{C_{soil/sediment} \; x \; CF x \; AF \; x \; ABS_d \; x \; SA \; x \; EF}{BW}$$

Where:

Parameter	Definition (units)	
DAD	= Dermal Absorbed Dose (mg/kg-day)	
$C_{soil/sediment}$	= Chemical concentration in soil or sediment (mg/kg)	
$EF_{chronic}$	= Exposure Factor (EV x F x ED)/AT • EV = Event Frequency (ev/d) • F = Frequency of Exposure (d/wk x wk/yr) • ED = Exposure Duration (yr) • AT = Averaging Time o noncancer = ED (yr) x F (7d/wk x 52.14 wks/yr) o cancer = 78 yr x F (7 d/wk x 52.14 wk/yr)	
CF	= Conversion factor (10^{-6} kg/mg)	
AF	= Adherence factor of soil/sediment to skin (mg/cm^2-event)	
ABS_d	= Dermal absorption fraction for soil and sediment	
SA	= Surface Area available for contact (cm^2)	
BW	= Body Weight (kg)	

***For default exposure scenarios, the EF = 1 for acute, intermediate and chronic exposure
See the Determining Life Expectancy and Exposure Factor EDG for how to calculate intermediate and acute EFs (ATSDR 2021)

Exposure Parameters for Dermal Contact

Calculating a Dermal Dose for Soil and Sediment: Updated information on several important assumptions and methods for dermal assessment have been released by EPA (EPA 2004, 2011). The general equations for calculating a dermal dose are provided in the previous section. An example calculation is provided in Appendix B.

Exposure factors for exposure frequency and exposure duration are likely to be site-specific. The EDG for Life Expectancy and Exposure Factors (ATSDR 2021) should be consulted to select the most appropriate exposure factors. Recommended exposure values for skin surface area (SA), soil adherence factor (AF), and dermal absorption factor (ABS_d) are provided in Appendix A.

Surface Area (SA):

- Surface Area (SA) in units of cm^2 is the amount of skin surface that is available for contact with soil or sediment.

- Tables 2, 4, and 5 in Appendix A provide a detailed list of the skin surface area of selected body parts for use in both default and site-specific exposure scenarios (from EFH, Table 7-2) (EPA 2011).

- Because surface area is correlated with body weight and because the same body weight is used for CTE and RME scenarios, the mean skin surface area should be used to represent both the CTE and RME exposure scenarios. The body weight for the infant for the evaluation of soil scenarios is 7.8 kg, which represents exposure of children aged birth to < 1 year.

Adherence Factor (AF):

- An Adherence Factor (AF) in units of mg/cm^2 is a measure of soil adherence to skin.

- In the absence of site-specific information, the following default soil adherence factors (AF) should be used:
  - 0.2 mg/cm^2 for child receptors, and
  - 0.07 mg/cm^2 for adult receptors (EPA 2004).

- Table 7 in Appendix A provides weighted soil AFs for children and adults engaged in various activities (EPA 2004). The default value recommended for the child (0.2 mg/cm^2) is based on the 95th percentile soil AF for children playing at a day care center and the 50th percentile for children playing in wet soil. The default skin AF recommended for adults (0.07 mg/cm^2) is based on the 50th percentile soil AF for gardeners.

- Several factors can impact the soil AF for a site: the moisture content of the soil (wet soils and sediment adhere to skin longer than if dry); the soil type (organic soils form a tighter bond with higher molecular weight organics); and the skin barrier (moist, intact skin is more resistant to adherence than dry, broken skin). These factors can be addressed by selecting AFs for specific exposure scenarios (Table 7 in Appendix A) and by discussing uncertainties associated with the AF in the document.

Dermal Absorption Fraction (ABS_d):

- A dermal absorption fraction (ABS_d) represents the fraction of a chemical that is absorbed through the skin after dermal contact. The ABS_d is unitless.
- Use the dermal absorption fraction provided in Table 8 in Appendix A in the dermal evaluation. ABS_d values for many contaminants are also available on the Regional Screening Level (RSL) tables provided by EPA.
- Recommended ABS_d defaults for chemicals not listed in Table 8 are:
  - 0.0005 for Volatile Organic Compounds (VOCs) with vapor pressure similar to benzene
  - 0.03 for VOCs with vapor pressure below benzene
  - 0.1 for Semi-Volatile Organic Compounds (SVOCs)
  - 0.01 for inorganic compounds

Use the default intake parameters in this guidance when calculating dermal exposure doses. If you modify default intake parameters using site- or situation-specific information, explain the basis of those modifications in your documents.

Converting Dermal Absorbed Dose to Administered Dose

The dermal dose in mg/kg/day derived using the dermal exposure equations is an absorbed dose given the inclusion of the dermal absorption fraction (ABS_d). That is, it reflects the amount of a chemical that is absorbed into the body via the dermal exposure route. For this reason, EPA recommends adjusting health guidelines, such as RfDs, MRLs, and oral slope factors, from an administered dose to an absorbed dose. This adjustment is done by using a gastrointestinal (GI) absorption factor (ABS_{GI}), which is the fraction of chemical absorbed by the gastrointestinal tract (EPA 2004).

$$MRL_{ABS} \text{ or } RfD_{ABS} = (\text{Oral MRL or RfD}) \times ABS_{GI}$$

$$\text{Slope Factor}_{ABS} = \text{Oral Slope Factor}/ABS_{GI}$$

As with EPA's efforts, ATSDR also agrees that dermal exposure assessments must make adjustments to account for the dermal dose being an absorbed dose. However, ATSDR converts the dermal absorbed dose to an administered dose rather than adjusting the health guideline or cancer slope factor. The advantage of the ATSDR modified approach is that the doses from the oral and dermal pathways can be added together to create a total dose, which can then be compared to the unadjusted health guideline or cancer slope factor.

The following formula is used to convert the dermal absorbed dose to an equivalent dermal administered dose:

$$\textbf{Dermal Dose}_{\textbf{administered}} = DAD / ABS_{GI}$$

This results in the full dermal absorption equation being:

$$\textbf{Dermal Dose administered} = \frac{C_{soil/sediment} \times CF \times AF \times ABS_d \times SA \times EF}{BW \times ABS_{GI}}$$

For most chemicals, the absorbed dermal dose is the same as the oral administered dose because we assume 100% of the chemical is absorbed through the GI tract, thus ABS_{GI} equals 1. Therefore, no adjustment from absorbed dermal dose to administered oral dose is needed for VOCs, SVOCs, pesticides, PAHs, and PCBs. For these chemicals the absorbed dose calculated from dermal uptake is also an administered dose.

For inorganic compounds where 100% GI absorption is not the case, the absorbed dermal dose must be adjusted using the factor shown in the following table. The list of ABS_{GI} factors comes from EPA RAGS, Part E, Exhibit 4-1 (EPA 2004). While the following ABS_{GI} are recommended, site-specific information, if available, can be used to adjust the ABS_{GI}.

Table 1. Chemical-specific gastrointestinal absorption factors for inorganic elements and compounds.

Compound	ABS_{GI} Adjustment Factor
Antimony	15%
Arsenic	100% absorption assumed; No adjustment;
Barium	7%
Beryllium	0.7%
Cadmium	2.5% (diet) 5% (water)
Chromium III	1.3%
Chromium VI	2.5%
Copper	57%
Cyanate	100% absorption assumed; No adjustment
Manganese	6%
Mercuric chloride (and other soluble salts)	7%
Metallic mercury	80%
Methyl mercury	100% absorption assumed; No adjustment
Nickel	4%
Selenium	30%
Silver	4%
Thallium	100% absorption assumed; No adjustment
Vanadium	2.6%
Zinc	100% absorption assumed; no adjustment

Cancer

EPA's approach to quantitative cancer risk estimates includes a cancer slope factor (CSF). It involves multiplying a carcinogen-specific CSF by a duration-specific estimated dose. This approach allows estimation of cancer risk for adults and children as a function of exposure duration.

Special Cancer Considerations

EPA also has proposed that risk calculations for chemicals that act with a mutagenic mode of action (MOA) for carcinogenesis can be quantified using one of two possible approaches (EPA 2005):

- For some MOA chemicals, sufficient data are available to derive age-specific cancer slope factors. These age-specific CSFs can be used to estimate age-specific and total cancer risk. An example is vinyl chloride which has two CSFs: one for early life exposure and one for adult only exposure. These two CSFs account for differences in susceptibility between exposure that begins in childhood and exposure that begins in adulthood. Therefore, age-dependent adjustment factors (ADAFs) should not be used for vinyl chloride.

- For MOA chemicals without age-specific CSFs, ADAFs should be applied. EPA suggests using the following ADAFs:

  ✓ Children 0 < 2 years 10
  ✓ Children 2 to < 16 years 3
  ✓ Children and adults 16 and older 1

Mutagenic chemicals are identified in EPA's RSL tables and include chemicals commonly found at waste sites, such as polycyclic aromatic hydrocarbons, trichloroethylene, and chromium compounds. Additional information about EPA's approach to evaluating early life exposure to mutagenic carcinogens can be found at https://www3.epa.gov/airtoxics/childrens_supplement_final.pdf.

Noncancer (Annual) Dose and Cancer (Lifetime) Dose Estimates

For (chronic) non-cancer evaluations, annual doses (or doses averaged over 1-year of exposure) are calculated. This allows for the doses to be directly compared with the chronic MRL which has been developed to be protective for exposures of one year or greater.

Lifetime doses, used to evaluate cancerous effects, can differ depending on exposure duration and are averaged over a lifetime of exposure (i.e., 78 years). For cancer risk evaluations, you can assume either lifetime exposure or some fraction of a lifetime exposure.

You can convert the 1-year annual dose to a lifetime cancer dose by multiplying the annual dose by the site-specific or default exposure duration/averaging time (ED/AT). For default residential scenarios, RME (33 years) and CTE (12 years) residential occupancy periods are used to calculate the RME and CTE cancer risk, respectively. Health assessors have several options available for the presentation of cancer risk estimates, which are discussed below.

Known Exposure Duration

When the residential exposure duration is unknown, the 95th percentile residential occupancy period (i.e., 33 years) may be incorporated into the report and presented in several ways:

- Most commonly, adult and childhood cancer risk are presented separately. Calculate and present the combined cancer risk for children (birth to 21 years) using an ED/AT term of 21/78 and adults (33 years) using an ED/AT term of 33/78.

- Combined childhood and adulthood cancer risk can be presented as one cancer risk estimate**.** This is only appropriate if you are assessing exposures that began at birth and continue into adulthood at the same house or in a house with similar contaminant levels. To incorporate the 33 year default residential occupancy period into this scenario, you should calculate the cancer risk for children exposed from birth to 21 years (using an ED/AT term of 21/78) and calculate an additional 12 years of exposure for adults (using an ED/AT term of 12/78). The childhood and adult cancer risk should be added together to account for 33 years of total exposure.

Unknown Exposure Duration

When an exposure duration is known, you can incorporate the site-specific exposure duration and present cancer risk (1) separately for children and adults (most common scenario) or (2) combine them (if exposures are occurring from childhood through adulthood and site-specific information warrants), as discussed above.

Lifetime Exposure Duration

When site-specific information indicates that exposures may have occurred over an entire lifetime (e.g. a small rural or tribal community), the cancer risk for children (birth to 21 years; ED/AT of 21/78) and adults (additional 57 years; ED/AT of 57/78) should be added together to account for an entire lifetime of exposure. Please note that there should be reliable site-specific information available when considering the presentation of cancer risk with a lifetime exposure duration.

For more information about exposure factors, review the EDG for Determining Life Expectancy and Exposure Factor (ATSDR 2021).

Central Tendency and Reasonable Maximum Dose Estimates

To represent persons with typical and high-end exposures, estimate typical exposure doses for receptors using CTE intake values and rates and high-end doses for receptors using a combination of CTE and RME values and rates. When feasible, you can present the results as a range of doses in the target population. The EPA's EFH is the primary source for CTE and RME tap water intake rates in children and adults (EPA 2011).

Discussion in the public health implications section of your document should include your explanation for estimates for both children and adults. For example, if the risk of harmful effects is only for children with high intake rates (RME), describe the risk of harm for that group and explain that children with typical intake rates (CTE) are not at risk. Likewise, if the risk of harmful effects is for both groups, your estimate explanation should reflect both scenarios.

When evaluating noncancer endpoints, you should estimate doses for the most highly exposed group (e.g., for soil, usually children 1 to 2 yr of age) or for the most sensitive group. If the estimated dose for either or both groups exceeds the health guideline (e.g., MRL, RfD), then estimate and evaluate doses for other groups. Remember that when evaluating cancer risk, you should use site-specific information to identify the age ranges for which you need cancer risk estimates.

Note that for the dermal exposure to soil and sediment pathway, the chronic (annual) dermal dose is the same for CTE and RME because they are derived using exposure factors that are correlated (i.e., body weight and skin surface area). CTE and RME cancer risks, however, will differ because the CTE cancer risk uses a CTE residential occupancy period (i.e., 12 years) and the RME cancer risk uses the RME residential occupancy period (i.e., 33 years). This is also true for occupational exposures.

Public Health Assessment Site Tool (PHAST)

Health assessors should use the public health assessment site tool (PHAST) to estimate the dermal absorbed dose. PHAST provides a *quick summary* of the maximum hazard quotient for chronic, intermediate, and acute exposure as well as the maximum cancer risk for the typical residential exposure scenario involving children and adults. The Quick Summary is based on an RME residential scenario using default exposure parameters from ATSDR's Exposure Dose Guidance and is intended to give health assessors an overview of HQs and cancer risks.

If the HQ exceeds one, review the age-specific dose and hazard quotient calculations to evaluate risk of noncancerous effects in children and adults. If no MRL or RfD is available, compare the maximum site-specific dose directly to NOAELs and LOAELs to determine the possibility of harmful effects. If you decide harmful effects are possible, consider site-specific doses for all age ranges to determine who is at risk of noncancerous harmful effects.

The default cancer risk calculation in the *quick summary* assumes 33 years of residential exposure—the 95th percentile residential-occupancy period. The default 33-year cancer risk assumes 21 years of exposure as a child, followed by 12 years of exposure as an adult at the same residence. If the maximum cancer risk in the *quick summary* exceeds 1E-6, review the cancer risks for children exposed for 21 years and for adults exposed for 33 years. Remember that the quick summary cancer risk is a screen—you should not include it in PHAs/HCs unless you know you have an exposure scenario where children grow up in a house or area and continue to have the same exposure as adults.

Impact

Using the best available science to update the parameters to calculate exposure doses for dermal absorption from soil and sediment will improve the consistency of exposure dose estimates in ATSDR- and state-prepared health assessments and consultations.

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Appendices

Default Dermal Exposure Factors (Appendix A)
Examples of Exposure Dose Calculations (Appendix B)

Appendix A – Tables for Skin Surface Area (EPA 2011), Dermal Adherence Factor (EPA 2004) and Dermal Absorption (EPA 2004)

Table 2
Derivation of Default Skin Surface Area using Data from EFH (EPA 2011)[a]

Exposure Group	Head	Hands	Forearms[b]	Lower Legs[c]	Feet	Combined SA (cm^2)[d]	Body Weight (kg)
Birth to < 1 year	727	211	247	329	258	1,772	8.2
1 to <2 years	870	300	311	488	330	2,299	11.4
2 to <6 years	585	348	457	739	463	2,592	17.4
6 to < 11 years	660	510	680	1,244	730	3,824	31.8
11 to < 16 years	730	720	1,022	1,932	1,050	5,454	56.8
16 to < 21 years	750	830	1,211	2,172	1,120	6,083	71.6
Adult (≥ 21 years)	1,250	980	1,240	2,560	1,295[e]	6,030	80

a - values from Table 7-2 (surface area of body parts) of EFH 2011 (EPA 2011). The skin surface area for the infant was derived using a time-weighted average value from Table 7-2 in the EFH (EPA 2011).

b - No value is available for the SA of the forearms in females or children, so the value represents approximately 45% of the total SA of the arm (EPA 2011).

c – No value is available for the lower leg in infants, children, or adolescents so the value represents approximately 40% of the total leg value (calculated from adult values; EPA 2007).

d - Combined surface area for body parts exposed during typical outdoor activities. It is assumed that children < 21 years) wear a short-sleeved shirt, shorts and no shoes resulting in exposure of the head, hands, forearms, lower legs and feet. Adults are assumed to wear shoes, so their exposure is limited to the head, hands, forearms and lower legs.

e - If the adult scenario includes being barefoot, the surface area of the feet may be added to the total for the adult.

Table 3
Derivation of Special Group Skin Surface Areas using Data from EFH (EPA 2011)[a]

Exposure Group	Special Group	Head	Hands	Forearms[b]	Lower Legs[c]	Feet	Combined SA (cm^2)[d,e]	Body Weight (kg)
Birth to < 1 month	Infant	530	150	180	240	190	1,290	4.8
1 to < 3 months	Infant	600	170	203	272	210	1,455	5.9
3 to < 6 months	Infant	690	200	234	312	250	1,686	7.4
6 to < 12 months	Infant	820	240	279	372	290	2,001	9.2
1 to < 2 years	Toddler	870	300	311	488	330	2,299	11.4
2 to < 3 years	Toddler	510	280	396	616	380	2,182	13.5
3 to < 5 years[f]	Pre-Kindergarten	671	363	463	779	479	2,755	17.2
5 to < 6 years[f]	Kindergarten	677	414	543	935	554	3,123	20.6
6 to < 11 years	1^{st}–5^{th} grade	660	510	680	1,244	730	3,824	31.8
11 to < 14 years[f]	6^{th}–8^{th} grade	707	651	920	1,667	904	4,849	50.6
14 to < 16 years	9^{th}–10^{th} grade	718	736	1,055	1,928	1,029	5,466	63.7
16 to < 18 years[f]	11^{th}–12^{th} grade	726	804	1,162	2,137	1,128	5,957	67.3
18 ≤ 67 years	Full, part-time worker/educator	1,250	980	1,240	2,560	1,295	6,030[e]	80.6
15 < 45 years	Pregnant Women	1,140	890	1,067	2,392	1,220	5,489 [e]	73
15 < 45 years	Breastfeeding Women	1,140	890	1,067	2,392	1,220	5,489[e]	73

a – values from Table 7-2 (surface area of body parts) of EFH 2011 (EPA 2011). The skin surface area for the infant was derived using a time-weighted average value from Table 7-2 in the EFH (EPA 2011).

b – No value is available for the SA of the forearms in females or children, so the value represents approximately 45% of the total SA of the arm (EPA 2011).

c – No value is available for the lower leg in infants, children, or adolescents so the value represents approximately 40% of the total leg value (calculated from adult values; EPA 2007).

d – Combined surface area for body parts exposed during typical outdoor activities. It is assumed that children < 21 years) wear a short-sleeved shirt, shorts and no shoes resulting in exposure of the head, hands, forearms, lower legs and feet. Adults are assumed to wear shoes, so their exposure is limited to the head, hands, forearms, and lower legs.

e – If the adult scenario includes being barefoot, the surface area of the feet may be added to the total for the adult.

f – the values for these age ranges were determined by using linear regression through the data available in EFH 2011 (EPA 2011) by plotting the tabulated values in Table 7-2 against the average age in the table expressed in months. The equation of the best fit line was used to determine what the SA measurements would be at the average age in this table, also in months, would be. Values for the forearms and lower legs were treated similarly as described in [b] and [c] above.

Table 4
Default Exposure Scenarios for Determining Exposed Surface Area

Age Interval	Face	Forearms	Hands	Lower Legs	Feet
Assumption for Calculation	*Face is assumed to be 1/3 SA of the head*	*For children and females, SA of the forearms are assumed to be 45% of the arm SA*	*No assumption used.*	*For infants, children, and adolescents, the SA of the lower legs is assumed to be 40% of the total leg sA (EPA 2004).*	*No assumption used.*
Birth to < 1 yr[a]	X	X	X	X	X
1 to < 2 yr[a]	X	X	X	X	X
2 to < 6 yr[a]	X	X	X	X	X
6 to < 11 yr[a]	X	X	X	X	X
11 to < 21 yr[a]	X	X	X	X	X
Adult[b]	X	X	X	X	NA

a – Children are assumed to be wearing short-sleeved shirts, shorts, and no shoes, resulting in skin on the face, hands, forearms, lower legs, and feet being exposed.

b – Adults are assumed to be wearing short-sleeved shirt, shorts, and shoes, resulting in the skin on the face, hands, forearms, and lower legs being exposed.

Table 5
Skin Surface Areas for Standard Age Groups for Other Parts of the Body[a]

Age Interval	Face[b]	Trunk	Arms	Legs	Associated Body Weight (kg)
Child (Birth to < 1 year)	242	1,428	548	823	7.8
Child (1 to <2 years)	290	1,880	690	1,220	11.4
Child (2 to <6 years)	195	2,973	1,015	1,848	17.4
Child (6 to < 11 years	220	4,280	1,510	3,110	31.8
Adolescent (11 to < 16 years)	243	6,300	2,270	4,830	56.8
Adolescent (16 to < 21 years)	250	7,590	2,690	5,430	71.6
Adult (≥ 21 years)	417	7,405	2,755	6,400	80

a - values from Table 7-2 of EFH 2011 (EPA 2011)

b - It is assumed that the SA of the face represents 1/3 the SA of the head (EPA 2011).

Table 6
Skin Surface Areas for Special Age Groups for Other Parts of the Body[a]

Exposure Group	Special Group	Face[b]	Trunk	Arms	Legs	Body Weight (kg)
Birth to < 1 month	Infant	177	1,040	400	600	4.8
1 to < 3 months	Infant	200	1,180	450	680	5.9
3 to < 6 months	Infant	23	1,360	520	780	7.4
6 to < 12 months	Infant	273	1,610	620	930	9.2
1 to < 2 years	Toddler	290	1,880	690	1,220	11.4
2 to < 3 years	Toddler	170	2,500	880	1,540	13.5
3 to < 5 years	Pre-Kindergarten	224	2,806	1,005	1,915	17.2
5 to < 6 years	Kindergarten	226	3,398	1,206	2,379	20.6
6 to < 11 years	1^{st}–5^{th} grade	220	4,280	1,510	3,110	31.8
11 to < 14 years	6^{th}–8^{th} grade	236	6,162	2,144	4,547	50.6
14 to < 16 years	9^{th}–10^{th} grade	239	7,149	2,479	5,321	63.7
16 to < 18 years	11^{th}–12^{th} grade	242	7,939	2,747	5,940	67.3
18 ≤ 67 years	Full, part-time worker/educator	417	7,405	276	6,400	80.6
15 < 45 years	Pregnant Women	380	6,540	237	5,980	73
15 < 45 years	Breastfeeding Women	380	6,540	237	5,980	73

a - the values for these age ranges were determined by using linear regression through the data available in EFH 2011 (EPA, 2011) by plotting the tabulated values in Table 7-2 against the average age in the table expressed in months. The equation of the best fit line was used to determine what the SA measurements would be at the average age in this table, also in months. Values for the forearms and lower legs were treated similarly as described in [b] and [c] above in Table2 and 3.

b - It is assumed that the SA of the face represents 1/3 the SA of the head (EPA 2011).

TABLE 7
ACTIVITY SPECIFIC-SURFACE AREA WEIGHTED SOIL ADHERENCE FACTORS (AF)
(EXHIBIT 3-3 in EPA 2004)

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 Keeper	>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

[1] Weighted AF based on exposure to face, forearms, hands, lower legs and feet.
[2] Weighted AF based on exposure to face, forearms, hands and lower legs.
[3] Weighted AF based on exposure to face, forearms and 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 (EPA 2004) may result in a significant overestimation of dermal risk. Therefore, it is recommended that the 95th percentile AF values for children playing in mud not be used in a quantitative dermal assessment.

TABLE 8
Recommended Dermal Absorption Fraction from Soil and Sediment[a]

Compound	Dermal Absorption Fraction (ABS_d)
Arsenic	0.03
Cadmium	0.001
Chlordane	0.04
2,4-Dichlorophenoxyacetic acid	0.05
DDT	0.03
TCDD and other dioxins – if soil organic content is >10%	0.03 0.001
Lindane	0.04
Benzo(a)pyrene and other PAHs	0.13
Aroclors 1254/1242 and other PCBs	0.14
Pentachlorophenol	0.25
Semivolatile organic compounds (SVOCs)	0.1
RECOMMENDED DEFAULTS[b]	
Volatile Organic Compounds (VOCs) - VOCs with vapor pressure similar to benzene (95.2 mm Hg) - VOCs with vapor pressure below 95.2 mm Hg	 0.0005 0.03
Semivolatile Organic Compounds (SVOCs)	0.1
Inorganic Compounds	0.01
Following values available from EPA webpage for RAGS Part E guidance: Additional ABSd factors	
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	0.015
Thiodiglycol	0.0075
Trinitrobenzene	0.019
2,4-Dinitrotoluene (2,4-DNT)	0.102
2,6-Dinitrotoluene (2,6-DNT)	0.099
2-Amino-4,6-dinitrotoluene (2A, 4,6-DNT)	0.006
4-Amino-4,6-dinitrotoluene (4A, 4,6-DNT)	0.009
2,4-Diamino-6-nitrotoluene (2,4-DA-6-NT)	0.011
2,6-Diamino-4-nitrotoluene (2,6-DA-4-NT)	0.005
Trinitrotoluene (TNT)	0.032
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	0.006
Tetryl (N-methyl-N, 2,4,6-tetranitrobenzamine)	0.00065

[a] Exhibit 3-4 from EPA (2004) (EPA RAGS Part E). . These values are also available on the Risk Assessment Information System (RAIS) at https://rais.ornl.gov/

[b] EPA (2004) recommends that, in the absence of chemical-specific data, the default value of 10% (0.10) should be used as a default absorption factor for SVOCs. A list of SVOCs is provided by EPA at EPA Method 8270E (SW-846): Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC-MS) | US EPA. EPA Region 3 (EPA 2003) has used default values for VOCs and inorganics that ATSDR considers to be appropriate for the evaluation of the dermal pathway of exposure. The default values for VOCs are dependent upon vapor pressure – the default value for those with a vapor pressure comparable to benzene (95.2 mm Hg) (e.g., 1,1-dichloroethane, 1,1,1,-trichloroethane) and those with a lower vapor pressure than benzene (resulting in less volatilization from the skin) would have a default value of 0.03 (e.g., ethylbenzene, tetrachloroethene, toluene and xylenes). This guidance was last updated in December 2010.

Appendix B: Example of Exposure Dose Calculations

Health assessors should use the public health assessment site tool (PHAST) to estimate the dermal absorbed dose. PHAST provides a *quick summary* of the maximum hazard quotient for chronic, intermediate, and acute exposure as well as the maximum cancer risk for the typical residential exposure scenario involving children and adults. If the HQ exceeds one review the age-specific dose and hazard quotient calculations to evaluate risk of noncancerous effects in children and adults.

Here, we have provided examples for children and adults and for noncancer and cancer using the dose equations provided above.

Scenario #1. A family lives at a residence where the exposure point concentration (EPC) for Aroclor 1254 in surface soil has been determined to be 40 mg/kg. What's the range of doses and hazard quotients possible in this family resulting from dermal exposure?

The dermal dose administered is calculated for a 1 to <2 yr old child using the following equation described in the main text:

$$\textbf{Dermal Dose administered} = \frac{C_{soil/sediment} \text{ x } CF \text{ x } AF \text{ x } ABS_d \text{ x } SA \text{ x } EF}{BW \text{ x } ABS_{GI}}$$

Where:

Parameter	Definition (units)	Default/Site-Specific Value
DDA	= Dermal Dose $_{administered}$ (mg/kg-day)	n/a
$C_{soil/sediment}$	= Chemical concentration in soil (mg/kg)	40 mg/kg (EPC)
CF	= Conversion factor (10^{-6} k/mg)	10^{-6} kg/mg
AF	= Adherence factor of soil to skin (mg/cm^2-event) (time weighted average)	0.2 mg/cm^2-event, default for child 0.07 mg/cm^2–event, default for adult
ABS_d	= PCB dermal absorption fraction for soil and sediment	PCB = 0.14 -- Table 8, Appendix A See main text for list of defaults for other chemical classes
SA	= Surface Area available for contact (cm^2)	Varies with age –Table 2, Appendix A 2,299 cm^2 for children 1 to < 2 yr (a)
$EF_{chronic}$	= Exposure Factor (EV x F x ED)/AT* • EV = Event Frequency (ev/d) • F = Frequency of Exposure (d/wk x wk/yr) • ED = Exposure Duration (yr) • AT = Averaging Time	 • EV = 1 ev/day • F = 7 d/wk x 52.14 wk/yr • ED = 1 yr • AT =

	○ noncancer = ED x F ○ cancer = 78 yr x F	○ noncancer = 1 yr x 7 d/wk x 52.14 wk/yr ○ cancer = 78 yr x 7 d/wk x 52.14 wk/yr
BW	= Body weight (kg)	Varies with age (ATSDR 2023) 11.4 kg for children 1 to < 2 yr
ABS_{GI}	Gastrointestinal absorption factor, unitless	1 for PCBs, VOCs, SVOCs, pesticides, PAHs See Table 1 for metals

(a) Surface area represents mean surface area for the head, hands, forearms, lower legs and feet of a child aged 1 to < 2 years old.

For this exposure scenario, the skin surface area reflects exposure of the head, forearms, hands, lower legs and feet. The dose and associated hazard quotient for the child aged 1 to < 2 years is 0.00023 mg/kg/day, which is the same for chronic, intermediate and acute exposure since the EF is 1 for all exposure scenarios.

Dermal Dose $_{\text{administered, child 1 < 2 yr}}$ =

$$\frac{40 \text{ mg/kg} \times 1E\text{-}6 \text{ kg/mg} \times 0.2 \text{ mg/cm}^2\text{-event} \times 0.14 \times 2{,}299 \text{ cm}^2}{11.4 \text{ kg}} \times \frac{1 \text{ ev/d} \times 7 \text{ d/wk} \times 52.14 \text{ wks/yr} \times 1 \text{ yr}}{7 \text{ d/wk} \times 52.14 \text{ wks/yr} \times 1 \text{ yr}}$$

Dermal Dose $_{\text{administered, child 1 < 2 yr}}$ = 0.00023 mg/kg/day

Table 9 below shows the parameters used to calculate the chronic, noncancer doses for children and adults at this residence. The doses are the same for chronic, intermediate and acute exposure because the EF is 1 for all scenarios. Comparing the chronic doses to the chronic oral MRL of 2E-5 mg/kg/day results in the Hazard Quotients below.

Table 9. Parameters, dermal dose administered, and hazard quotient for all age groups.

Exposure Group	Skin Surface Area (cm2)	AF (mg/cm²-event)	EF (unitless)	BW (kg)	ABS_{GI} (unitless)	Chronic	
						Dermal Dose administered (mg/kg/day)	Hazard Quotient
Birth to < 1 yr	1,772	0.2	1	8.2	1	0.00024	12
1 < 2 yr	2,299	0.2	1	11.4	1	0.00023	11
2 < 6 yr	2,592	0.2	1	17.4	1	0.00017	8.3
6 < 11 yr	3,824	0.2	1	31.8	1	0.00013	6.7
11 < 16 yr	5,454	0.2	1	56.8	1	0.00011	5.4
16 < 21 yr	6,083	0.2	1	71.6	1	0.000095	4.8
Adults (≥ 21 yr)	6,030	0.07	1	80	1	0.00003	1.5

The EDG for Soil/Sediment Ingestion provides additional examples that assess differences in dose calculations associated with differing Exposure Factors (e.g., 5 days/7 days instead of daily exposure) and pica behavior (i.e., children having much higher oral intake of soil/sediment due to pica behavior). These examples can be found in the EDG for Soil/Sediment Ingestion (ATSDR 2018).

Appendix C: Sample Table from PHAST

Appendix C provides tables produced by PHAST for the example provided above in Appendix B. They are intended to show the format of tables produced by PHAST. The table below shows the dermal absorbed doses for a residential exposure scenario with 40 ppm Aroclor 1254 in soil using the default 95th residential occupancy period of 33 years.

Dermal Only: Collapse All

– Chronic Exposure

Exposure Group	Default Residential Scenario					
	Chronic Dose (mg/kg/day)	Chronic Hazard Quotient	Cancer Risk §			
			CTE	ED (yrs)	RME	ED (yrs)
– Aroclor 1254 (EPC: 40 mg/kg; Chronic MRL: 2E-05 mg/kg/day; CSF: NA[1])						
● Birth to < 1 year	0.00025	13 †	NC	1	NC	1
● 1 to < 2 years	0.00023	11 †		1		1
● 2 to < 6 years	0.00017	8.3 †		4		4
● 6 to < 11 years	0.00013	6.7 †		5		5
● 11 to < 16 years	0.00011	5.4 †		1		5
● 16 to < 21 years	9.5E-05	4.8 †		0		5
● Total exposure duration for child cancer risk				12		21
▲ Adult	3.0E-05	1.5 †	NC	12	NC	33

● Standard Child Age Group ▲ Standard Adult Group ■ Special Group ☁ Custom Group ◆ Screening Cancer Risk

The table below shows the combined results (dermal absorption and oral ingestion) for the same scenario.

Default Combined Ingestion and Dermal Residential Results for Standard Age Groups Hide

You can click on individual doses, hazard quotients, and cancer risks to see the separate ingestion and dermal results.

● Standard Child Age Group ▲ Standard Adult Group ◆ Screening Cancer Risk

– Chronic Exposure

Exposure Group	Default Residential Scenario							
	Chronic Dose (mg/kg/day)		Chronic Hazard Quotient		Cancer Risk §			
	CTE	RME	CTE	RME	CTE	ED (yrs)	RME	ED (yrs)
– Aroclor 1254 (EPC: 40 mg/kg; Chronic MRL: 2E-05 mg/kg/day; CSF: NA[1])								
● Birth to < 1 year	0.00054	0.0010	27 †	51 †	NC	1	NC	1
● 1 to < 2 years	0.00054	0.00093	27 †	46 †		1		1
● 2 to < 6 years	0.00030	0.00063	15 †	31 †		4		4
● 6 to < 11 years	0.00021	0.00039	11 †	19 †		5		5
● 11 to < 16 years	0.00013	0.00018	6.4 †	8.9 †		1		5
● 16 to < 21 years	0.00011	0.00015	5.6 †	7.6 †		0		5
● Total exposure duration for child cancer risk						12		21
▲ Adult	4.5E-05	8.0E-05	2.2 †	4.0 †	NC	12	NC	33