Exposure Dose Guidance for Soil and Sediment Ingestion

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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 for assumptions used in calculating doses in our public health evaluations be updated to reflect the best available science.

This soil and sediment exposure dose guidance (EDG) provides health assessors with updated guidance on how to estimate soil- and sediment-ingestion doses to contaminants of concern and will be used to calculate updated CVs.

Background

After a release of chemicals into the environment, health assessors have to evaluate all human exposure pathways. Soil, dust, and sediment ingestion, particularly in residential settings, is usually one of the more commonly evaluated pathways.

Default daily soil, dust, and sediment ingestion rates in ATSDR's Public Health Assessment Guidance Manual (PHAGM) are 100 mg/day for adults, 200 mg/day for children, and 5,000 mg/day for children with soil-pica behavior (ATSDR 2005a).

Definitions

To discuss soil, dust, and sediment ingestion, soil-pica, and geophagy, several definitions are important to know.

Soil (Including Outdoor Settled Dust). Particles of unconsolidated mineral or organic matter or both from the earth's surface located outdoors or used indoors to support plant growth. Soil includes particles that have settled onto outdoor objects and surfaces.

Dust (a/k/a Indoor Settled Dust). Particles in building interiors that have settled onto objects, surfaces, floors, and carpeting. These particles might include soil particles that have been tracked indoors, ambient airborne particulates that enter via open doors and windows, and organic matter and dust from indoor sources.

Sediment. Sediment is soil located beneath water at least for a portion of the year. Sediment should be available for contact by people by being located in shallow water or uncovered on the edge of the water. Sediment is a medium separate from soil, although is evaluated similar to soil.

Soil and Sediment Ingestion. Soil and sediment ingestion refers to the consumption—inadvertently or purposely—of soil, indoor dust, or sediment. Soil ingestion also includes ingestion of indoor dust except in cases where indoor dust ingestion rates are separate from soil ingestion rates. Examples of behavior that lead to inadvertent ingestion include someone putting dirty

hands and objects, such as toys, into his or her mouth and eating dropped food.

Soil-Pica. Pica is the eating of nonfood items, a behavior well documented in children. Soil-pica is eating large amounts of soil. Ingestion rates are in the order of 1,000–5,000 mg/day.

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. It should be noted that ATSDR prefers 0 to 3 inch soil samples. Soil samples from 0 to 12 inches might be useable if documentation exists that proves the soil is well-mixed and that contaminant concentrations are consistent from the surface down to 12 inches.

Geophagy. The intentional eating of earth (e.g., clay), usually as part of a cultural practice.

Central Tendency Exposure (CTE). CTE refers to persons who have average or typical soil intake rate.

Reasonable Maximum Exposure (RME). RME refers to persons who are at the upper end of the exposure distribution (approximately the 95th percentile). The RME scenario assesses exposures that are higher than average but still within a realistic exposure range.

Exposure Factor (EF): An expression of how often (frequency) and how long (duration) a person may be contacting a substance in the environment. In many instances, the exposure factor (EF) will equal 1, representing a daily exposure to the contaminant. However, some exposures may occur on an intermittent or irregular basis. For these exposures, an EF can be used to average the dose over the exposure interval. The EF is calculated by multiplying the exposure frequency (F) by the exposure duration (ED) and dividing by the time period during which the dose is to be averaged (averaging time—AT)**.** The EF for occupational, school, trespassing, and swimming scenarios is likely to be different than 1 (see examples in ATSDR's EDG for Determining Life Expectancy and Exposure Factor) (ATSDR 2016b).

Exposure Duration (ED): The period over which the exposure takes place.

Exposure Frequency (F): How frequently exposure occurs. This parameter is often measured in days per week and weeks per year.

Averaging Time (AT): The period over which the exposure is averaged to arrive at a time-weighted exposure factor. For assessing cancer risks, AT is averaged over a lifetime (78 years); for assessing noncancer risks, AT is

averaged over the exposure duration (days, weeks, or years), which may or may not be a lifetime.

Residential Occupancy Period (ROP): The time in years between when a person moves into a residence and when the person moves out or dies.

Chronic Exposures: Exposures greater than 365 days. Exposure doses derived for chronic exposure scenarios should be evaluated using chronic ATSDR Minimal Risk Levels (MRL). If MRLs are not available, EPA Reference Doses (RfD), EPA Reference Concentrations (RfC) or another suitable health guidance value may be used for the evaluation.

Intermediate Exposures: Exposures of 15 to 364 days. Exposure doses derived for intermediate exposure scenarios should be evaluated using intermediate MRLs or appropriate toxicity information (e.g. utilizing studies of similar duration if available).

Acute Exposures: Exposures up to 14 days. Exposure doses derived for acute exposure scenarios should be evaluated using acute MRLs or appropriate toxicity information (e.g., utilizing studies of similar duration if available).

Exposure Dose Equation

$$D = \frac{C \times IR \times EF \times CF}{BW}$$

where,

D = exposure dose (mg/kg/day)
C = contaminant concentration (mg/kg)
IR = intake rate of contaminated soil or sediment (mg/day)
$EF_{chronic}$ = exposure factor (unitless) = (F x ED)/AT

- F = exposure frequency (d/wk x wk/yr)
- ED = exposure duration yr)
- AT = averaging time
  - noncancer = ED (yr) x F (7 d/wk x 52.14 wk/yr)
  - cancer = 78 yr x F (7 d/wk x 52.14 wk/yr)

CF = conversion factor (10^{-6} kg/mg)
BW = body weight (kg)

Source: The Public Health Assessment Guidance Manual, Appendix G, Exhibit 5 (ATSDR 2005a).

Summary Table of Soil and Sediment Ingestion Rates

ATSDR staff reviewed the soil ingestion rates in the 2005 PHAGM and updated the default ingestion rates based in part on the EPA 2011 EFH, which includes the updated soil ingestion rates released by EPA in September 2017 (EPA 2011, EPA 2017). Unless site-specific conditions warrant using other rates, ATSDR recommends using the default soil and sediment ingestion rates in Table 1 to estimate site-specific doses. Table 1 also contains associated time-weighted body weights (For further information, see the EDG for Body Weight) (ATSDR 2016a).

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

Table 1. ATSDR-recommended soil/indoor dust or sediment ingestion rates*

Exposure Group	Soil/Indoor Dust or Sediment Ingestion mg/day		Body Weight kg
	CTE+	RME++	Mean
Birth to < 1 year	55	150	7.8
1 to < 2 years	90	200	11.4
2 to < 6 years	60	200	17.4
6 to < 11 years	60	200	31.8
11 to < 16 years	30	100	56.8
16 to < 21 years	30	100	71.6
Adults, ≥ 21 years	30	100	80
Special Groups	**CTE**		**Mean**
Children with pica behavior (1 to < 2 and 2 to < 6 years)	5,000 per event		11.4 and 17.4
Gardeners (≥ 21 years)	100		80
Geophagy (≥ 21 years)	50,000		80
Workers—indoor	30		80
Workers—outdoor (low intensity soil contact)	100		80
Workers—outdoor (high intensity soil contact)	330		80
Trespassers (any age)	use CTE and RME age-specific ingestion rates and body weights shown above under exposure group		

* Estimate doses for the most highly exposed group (e.g., usually children birth to < 1 yr) or for the most sensitive group. If the estimated dose for this group exceeds the health guideline (e.g., MRL, RfD), then health assessors should estimate and evaluate doses for other groups.
+Based on average of CTE values from various studies
++Based on average of 95th percentiles values from various studies

Guidelines for Children—Residential Scenarios

Children ingest small amounts of soil and indoor dust daily. Soil and indoor dust ingestion occurs from hand-to-mouth activity, mouthing toys, eating dropped food, and other activities as children interact with their environment. When children contact sediment along water bodies (e.g., wading, sunbathing, playing, fishing), children can ingest small amounts of sediment in similar ways as they do soil and dust. Children less than 1 year of age are considered to have the highest ingestion rate of soil or sediment per body weight. Therefore, this age group should be the focus of the initial exposure evaluation. If the exposure dose exceeds health guidelines, then health assessors should evaluate the risk for older age groups.

Unless site-specific conditions warrant choosing different rates, use the intake rates shown in Table 1. Factors for sediment pathways are often site-specific and are influenced by the nature of the water body, climate, and potentially exposed population. Any site-specific information (exposure frequency, exposure duration, age, person, recreational conditions) should be used to identify the exposed groups and to determine the exposure factor. Activity pattern data from the 2011 EPA EFH (EPA 2011) can assist with some of these determinations (e.g., frequency of contact). Appendix A has dose calculation examples for children.

EPA's EFH is the primary source for the CTE[1] and RME[2] soil ingestion rates for children and adults with standard (non-pica) behavior. The EFH, Update for Chapter 5 described the basis for these rates in detail (EPA 2011. EPA 2017). These CTE and RME soil ingestion rates are used to calculate the CTE and RME soil ingestion doses.

Standard (Non-Pica) Behavior

- Birth < 1 year
  - ✓ Soil/indoor dust or sediment—55 mg/day[3], CTE
  - ✓ Soil/indoor dust or sediment—150 mg/day[4], RME

- 1 year to < 2 yr
  - ✓ Soil/indoor dust or sediment—90 mg/day, CTE
  - ✓ Soil/indoor dust or sediment—200 mg/day, RME

[1] EPA uses the concept of central tendency rather than a specific statistic (e.g., mean, median) because of the uncertainty in the tracer methods used to estimate the distribution of daily soil and dust ingestion. EPA defines the central tendency exposure as a measure of the middle or the center of an exposure distribution. (EPA 2011).

[2]. EPA uses the term upper percentile intake rate rather than an RME intake rate because of the uncertainty in intake rates in this part of the distribution.

[3] Based on the time-weight-average of EPA's CTE soil ingestion rate for children < 6 months (40 mg/day) and children 6 months to < 1 year (70 mg/day).

[4] Based on the time-weight-average of EPA's upper percentile soil ingestion rate for children < 6 months (100 mg/day) and children 6 months to < 1 year (200 mg/day).

- 2 years to < 6 years
  - ✓ Soil/indoor dust or sediment—60 mg/day, CTE
  - ✓ Soil/indoor dust or sediment—200 mg/day, RME

- 6 years to < 11 years
  - ✓ Soil/indoor dust or sediment—60 mg/day, CTE
  - ✓ Soil/indoor dust or sediment—200 mg/day, RME
- 11 years to < 16 years
  - ✓ Soil/indoor dust or sediment—30 mg/day, CTE
  - ✓ Soil/indoor dust or sediment—100 mg/day, RME

- 16 years to < 21 years
  - ✓ Soil/indoor dust or sediment—30 mg/day, CTE
  - ✓ Soil/indoor dust or sediment—100 mg/day, RME

- ≥ 21 years (adults)
  - ✓ Soil/indoor dust or sediment—30 mg/day, CTE
  - ✓ Soil/indoor dust or sediment—100 mg/day, RME

When site-specific environmental data are available separately for both soil and indoor dust, health assessors may use these daily intake rates to estimates soil only doses and indoor dust only doses:

Table 2. Soil only and indoor dust only ingestion rates (EPA 2017)

Age Group	Soil Only or Sediment Only mg/day		Indoor Dust Only mg/day	
	CTE	RME	CTE	RME
Birth < 1 year	25	70	30	80
1 to < 2 years	40	90	50	100
2 to < 6 years	30	90	30	100
6 to < 11 years	30	90	30	100
11 to < 16 years	10	50	20	60
16 to < 21 years	10	50	20	60
≥ 21 years (adults)	10	50	20	60

For scenarios in which sediment is not located at or near the residence and thus not likely to be tracked into the home to become dust, the sediment only intake factors provided in Table 2 should be used.

Guidelines for Children with Soil Pica

Within any population of children, particularly those of preschool age, some could exhibit soil-pica behavior (ATSDR 2001). ATSDR recommends using these soil ingestion rates for children with soil-pica behavior:

- 1,000 and 5,000 mg/episode x 3 episodes per week (i.e., exposure factor = 3/7) to represent a weekly dose for acute exposures or a monthly dose for intermediate durations.

Note that a 5,000 mg/soil-pica episode probably represents the central tendency intake; no reliable upper percentile intake rate is available for soil pica.

When appropriate, consider soil-pica behavior, particularly when evaluating residential scenarios involving preschool children. Soil pica behavior is most likely to occur in preschool children as part of their normal exploratory behavior, with somewhere from 4% to 20% of preschool children exhibiting soil-pica. Children between the ages of 1 and 2 have the greatest tendency for soil-pica behavior, which diminishes as they become older (Barltrop 1966; Robischon 1971; Shellshear 1975; Vermeer and Frate 1979; Calabrese 1993, ATSDR 2005b).

We have only limited information concerning the frequency and duration of soil pica behavior in children. Some preschool children might eat soil once during their preschool years, while others might go through a stage of eating soil several times during a week or even over several months. Soil-pica behavior might occur for several days in a row, or a child might skip days between eating soil (Calabrese and Stanek 1998; Calabrese and Stanek 1993; Wong 1988; ATSDR 2001).

And the amount of soil ingested is uncertain, as is the prevalence and frequency of soil pica behavior. Therefore, in 2001, ATSDR invited a group of soil ingestion and childhood experts to provide advice to ATSDR on these issues. The experts agreed with ATSDR's proposal to use 5,000 mg/event for the amount of soil ingested and that a soil-pica frequency of 3 days a week was acceptable (ATSDR 2001).

Consider the soil-pica scenario when the target population is preschool children and when the estimated soil-pica dose approaches or exceeds harmful levels, as identified from acute or intermediate studies. When the soil-pica dose approaches effects levels, consider estimating a 1-time soil-pica dose to determine whether even a 1-time soil-pica episode could cause harmful effects.

Arsenic soil contamination in residential yards is an example where you should consider the soil-pica scenario, particularly when arsenic soil levels exceed several hundred ppm.

More information is available about exposure factors and body weight from ATSDR guidance documents (ATSDR 2013a, 2013b).

Guidelines for Adults—Residential Scenarios

Use these soil and sediment intake rates unless site-specific conditions warrant choosing different rates. Appendix B has dose calculations for adults.

Adults Residential (≥ 21 years)

30 mg/day—CTE
100 mg/day—RME

Soil and sediment ingestion rates for adults are not well documented. EPA recommends a central tendency intake of 30 mg/day from normal, daily activity.

Adults, Traditional Rural Lifestyle

50 mg/day—CTE
200 mg/day—RME

EPA proposes these soil ingestion rates for rural populations following a traditional rural lifestyle.

Gardeners (≥ 21 years)

100 mg/day—central tendency

Depending on site-specific conditions, use 100 mg/day for gardening days. And to determine the frequency of gardening days, use site-specific conditions or your professional judgment.

Geophagy (≥ 21 years)

50,000 mg/event

Geophagy is the intentional eating of earth (e.g., clay). It is usually part of a cultural practice and occurs predominantly in adults. Geophagy often involves eating clay dug from below ground surface. Geophagy is different from soil-pica behavior, which occurs in children who usually eat the top few inches of surface soil. Estimating these exposure doses is necessary only if site-specific information indicates this practice.

Trespassers

At times, you will need to estimate exposure doses for children and adults who trespass onto a property. Use the soil and sediment ingestion rate appropriate for the age of the trespasser, and incorporate a site-specific EF

term to adjust to an intermittent exposure. Because this scenario usually does not include indoor dust ingestion, use only the outdoor soil ingestion rate. When sediment is not likely to be tracked indoors, use the sediment only ingestion rate.

Commercial and Industrial Workers

Health assessors should use the following rates for various work categories:

- Indoor workers 30 mg/day
- Outdoor workers
  - low intensity soil contact 100 mg/day
  - high intensity soil contact 330 mg/day.

For example, lawn maintenance workers might have low intensity soil contact, while landscape, construction, and excavation workers might have high intensity soil contact.

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 adjust factors (ADAFs) should not be used for vinyl chloride.

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

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

Mutagenic chemicals are identified in the EPA's Regional Screening Levels (RSL) table [https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016] 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 carcingogens 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.

Unknown 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.

Known 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 2016b).

Central Tendency and Reasonable Maximum Dose Estimates

To represent persons with typical and high-end exposures, estimate exposure doses for people using typical intake rates [(the central tendency exposure (CTE)] and doses for people using upper percentile rates [reasonable maximum exposure (RME)]. When feasible, you can present the results as a range of doses in the target population. Numerous sources, and in particular EPA's EFH, are the basis for selected intake rates for children and adults (ATSDR 2001, 2005a, 2005b; EPA 2002, 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.

Public Health Assessment Site Tool (PHAST)

Health assessors should use the public health assessment site tool (PHAST) to estimate the soil ingestion doses. 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 sediment and soil/indoor dust ingestion will improve the consistency of exposure dose estimates in ATSDR- and state-prepared health assessments and consultations.

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Appendices

Dose Calculation Examples

As discussed previously, health assessors should use PHAST to calculate soil ingestion doses, hazard quotients, and cancer risk estimates.

The examples in the appendices show the dose calculations included in PHAST. We show examples here for children and adults and for noncancer and cancer using the following dose formula for soil ingestion:

$$D = \frac{(C \times IR \times EF \times CF)}{BW}$$

D = oral dose in mg/kg/day
C = contaminant concentration in soil in mg/kg
IR = age-specific soil intake rate in mg/day
CF = conversion factor for mg to kg
BW = age-specific body weight in kg

$EF_{chronic}$ = exposure factor = (F x ED)/AT

- F = exposure frequency (d/wk x wk/yr)
- ED = exposure duration (yr)
- AT = averaging time
  - noncancer = ED (yr) x F (7 d/wk x 52.14 wk/yr)
  - cancer = 78 yrs x F (7 d/wk x 52.14 wk/yr)

$EF_{intermediate}$ = Intermediate Exposure Factor (unitless)

- F = exposure frequency (d/wk)
- ED = exposure duration (wk)
- AT = averaging time
  - noncancer = F (d/wk) x ED (wk)

EF_{acute} = 1 (by default)

Appendix A – Examples for Children

Exposure Doses– Children

Scenario #1. A family lives at a residence where the exposure point concentration 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?

The dose calculation for children birth to < 1 year old with typical soil intake living at this residence follows.

$$EF_{chronic} = 1$$

$$\frac{7\ \frac{d}{wk}\ x\ 52.14\ \frac{wk}{yr}\ x\ 1\ yr}{7\ \frac{d}{wk}\ x\ 52.14\ \frac{wk}{yr}\ x\ 1\ yr}$$

$$D_{\text{chronic, birth to < 1 yr, CTE}} = \frac{\text{(40 mg/kg x 55 mg/day x 1 x 1E-6 kg/mg)}}{\text{7.8 kg}}$$

$$D_{\text{chronic, birth to < 1 yr, CTE}} = 0.00028 \text{ mg/kg/day}$$

Note that in this scenario, the calculated dose of 0.0028 mg/kg/day is the same for acute, intermediate, and chronic exposures because the exposure factor is the same for each duration (EF=1).

Table 2 shows the parameters used to calculate the chronic, noncancer CTE and RME doses for children and adults at this residence. Compare these doses to the chronic oral MRL of 2E-5 mg/kg/day to calculate a hazard quotient (HQ).

Aroclor 1254 (EPC: 40 mg/kg; Chronic MRL: 0.00002 mg/kg/day								
Exposure Group	**IR mg/day**		**EF unit-less**	**BW kg**	**Chronic Doses mg/kg/day**		**Chronic Hazard Quotient**	
	CTE	**RME**			**CTE**	**RME**	**CTE**	**RME**
Birth to < 1 yr	55	150	1	7.8	0.00028	0.00077	14	38
1 < 2 yr	90	200	1	11.4	0.00032	0.0007	16	35
2 < 6 yr	60	200	1	17.4	0.00014	0.00046	6.9	23
6 < 11 yr	60	200	1	31.8	0.000075	0.00025	3.8	13
11 < 16 yr	30	100	1	56.8	0.000021	0.00007	1.1	3.5
16 < 21 yr	30	100	1	71.6	0.000017	0.000056	0.8	2.8
Adults	30	100	1	80	0.000015	0.00005	0.8	2.5

Scenario #2. Children ages 1 to 6 years old attend a daycare 5 days a week for a year where the EPC for soil cadmium 300 mg/kg. What is the chronic RME dose for children and teachers at this daycare if they were exposed for four years?

Chronic and Intermediate Doses

The chronic and intermediate dose calculation for children 1 to < 2 years old with RME soil intake follows:

$$EF_{\text{chronic and intermediate}} = 0.714 \quad \frac{5\ \frac{d}{wk}\ x\ 52.14\ \frac{wk}{yr}\ x\ 4\ yr}{7\ \frac{d}{wk}\ x\ 52.14\ \frac{wk}{yr}\ x\ 4\ yr}$$

$$D_{\text{chronic and intermediate, 1 to < 2 yr, RME}} = \frac{(300\ \text{mg/kg x } 200\ \text{mg/day x } 0.714\ \text{x 1E-6 kg/mg})}{11.4\ \text{kg}}$$

$$D_{\text{chronic and intermediate, 1 to < 2 yr, RME}} = 0.0038\ \text{mg/kg/day}$$

Note that in this scenario, the calculated RME dose of 0.0038 mg/kg/day is the same for chronic and intermediate exposures because the exposure factor is the same (EF=0.714).

Table 3 shows the parameters used to calculate the chronic, noncancer doses for children and adults at the daycare. Compare these doses to the chronic oral MRL of 0.0001 mg/kg/day. These doses also can be compared to the intermediate MRL of 0.0005 mg/kg/day to calculate an HQ.

Cadmium (EPC: 300 mg/kg; Chronic MRL: 0.0001 mg/kg/day								
Exposure Group	**IR mg/day**		**EF unit-less**	**BW kg**	**Chronic Doses mg/kg/day**		**Chronic Hazard Quotient**	
	CTE	**RME**			**CTE**	**RME**	**CTE**	**RME**
1 < 2 yr	90	200	0.714	11.4	0.0017	0.0038	17	38
2 < 6 yr	60	200	0.714	17.4	0.00074	0.0025	7.4	25
Adults	30	100	0.714	80	0.00008	0.00027	0.8	2.7

Acute Doses

The acute dose calculation for children 1 to < 2 years old with RME soil intake follows:

$$EF_{\text{acute}} = \frac{5\ \text{d}}{5\ \text{d}} = 1$$

$$D_{\text{acute, 1 to < 2yr, RME}} = \frac{(300\ \text{mg/kg x } 200\ \text{mg/day x 1 x 1E-6 kg/mg})}{11.4\ \text{kg}}$$

$$D_{\text{acute, 1 to < 2 yr, RME}} = 0.0053\ \text{mg/kg/day}$$

Table 4 shows the parameters used to calculate the acute, noncancer doses for children and adults at the daycare.

Cadmium (EPC: 300 mg/kg; Acute MRL: not available							
Exposure Group	**IR mg/day**		**EF unit -less**	**BW kg**	**Acute Doses mg/kg/day**		
	CTE	**RME**			**CTE**	**RME**	**Pica**
1 < 2 yr	90	200	1	11.4	0.0025	0.0054	0.081
2 < 6 yr	60	200	1	17.4	0.0022	0.0035	0.037
Adults	30	100	1	80	0.00013	0.00039	NC

NC = not calculated

An acute MRL is not available for cadmium; therefore, health assessors should compare the estimated acute doses directly to the doses from acute animal and human studies to determine whether acute exposures could cause harmful effects.

In this scenario, the doses will be higher for acute duration compared to chronic and intermediate duration because the EF is 1 instead of 0.714. See the EDG for life expectancy and exposure factor for more discussion and examples of determining the EF for acute, intermediate, and chronic exposures (ATSDR 2016b).

Scenario #3. Children with soil-pica behavior live at a residence with an arsenic soil EPC of 400 mg/kg. Because soil-pica behavior is assumed to occur for several months, estimate acute (< 2 weeks) and intermediate (e.g., 36 weeks) doses. Assume pica behavior occurs 3 days per week. In addition, a relative bioavailability (RBA) for soil arsenic of 0.6 should be used to adjust the dose (EPA 2016). Soil-pica behavior typically occurs in children 6 years and younger. Dose calculations for children 1 to < 2 years is shown.

Acute Dose

$$EF_{acute} = \frac{3\ d/wk}{7\ d/wk} = 0.429 \text{ or } EF = 3/7$$

$$D_{acute,\ 1\ to\ <\ 2\ yr,\ pica} = \frac{(400\ mg/kg \times 5{,}000\ mg/day \times 0.429 \times 1E\text{-}6\ kg/mg \times 0.6)}{11.4\ kg}$$

$$D_{acute\ 1\ to\ <\ 2\ yr,\ pica} = 0.045\ mg/kg/day$$

Intermediate Dose

$$EF_{intermediate} = 0.429$$

$$\frac{3\ \frac{d}{wk}\ x\ 36\ wk}{7\ \frac{d}{wk}\ x\ 36\ wk}$$

$$D_{\text{intermediate, 1 to < 2 yr, pica}} = \frac{(400 \text{ mg/kg} \times 5{,}000 \text{ mg/day} \times 0.429 \times 1\text{E-}6 \text{ kg/mg} \times 0.6)}{11.4 \text{ kg}}$$

$$D_{\text{intermediate, 1 to < 2yr, pica}} = 0.045 \text{ mg/kg/day}$$

In this scenario, the calculated dose of 0.045 mg/kg/day is the same for acute and intermediate exposures. In locations with cold weather, soil pica is assumed not to occur during winter; therefore a chronic, soil pica dose is not calculated. A chronic dose could be calculated for locations with warm weather year round. In a scenario where soil-pica behavior could occur year-round, the EF becomes:

$$EF_{\text{chronic}} = 0.429 \quad \frac{3 \frac{d}{wk} \times 52.14 \frac{wk}{yr} \times 1 \, yr}{7 \frac{d}{wk} \times 52.14 \frac{wk}{yr} \times 1 \, yr}$$

If soil contamination is very high, health assessors can calculate a one-time pica dose by replacing the EF term of 3/7 with 1. This change is appropriate to evaluate whether a 1-time pica event might cause harmful effects.

A bioavailability term is usually not used to estimate doses because it converts the dose from an administered to an absorbed dose. MRLs and RfDs are administered doses so site-specific doses need to be calculated as administered doses. However, EPA has recommended that a relative bioavailability (RBA) term of 0.6 can be used for arsenic in soil (EPA 2016). Using an RBA term for arsenic keeps the dose an administered dose thus allowing it to be compared to MRLs and RfDs.

Scenario #4. Children 12 to 15 years old attend a campground for one week and wade in and play along a stream that flows near the campground. Stream sediment has been found to contain chlordane, and the EPC has been determined to be 50 mg/kg. Camp counselors inform you that the children play along the stream daily. Note the body weight used in this example is the body weight for children 11 to < 16 years. You may also go to EPA's 2011 EFH to generate a site-specific body for children 12 to 15 years old.

$$EF_{\text{acute}} = \frac{7 \text{ days}}{7 \text{ days}} = 1$$

$$D_{\text{acute, 12 to 15 yr, RME}} = \frac{(50 \text{ mg/kg} \times 100 \text{ mg/day} \times 1 \times 1\text{E-}6 \text{ kg/mg})}{56.8 \text{ kg}}$$

$$D_{\text{acute, 12 to 15 yr, RME}} = 0.000088 \text{ mg/kg/day}$$

Appendix B—Examples for Adults

Exposure Doses–Adults

Scenario #1. A family lives at a residence for 15 years where the soil EPC is 500 mg/kg cadmium. Calculate the RME, non-cancer dose for adults from chronic exposures.

$$EF_{chronic} = 1 = \frac{7\frac{d}{wk}x\ 52.14\frac{wk}{yr}x\ 15\ yr}{7\frac{d}{wk}x\ 52.14\frac{wk}{yr}x\ 15\ yr}$$

Note when exposure occurs daily, the EF term is always 1 for noncancer.

$$D_{chronic,\ adults,\ RME} = \frac{(500\ mg/kg\ x\ 100\ mg/day\ x\ 1\ x\ 1E\text{-}6\ kg/mg)}{80\ kg}$$

$$D_{chronic,\ adults,\ RME} = 0.00063\ mg/kg/day$$

In this scenario, the calculated dose of 0.00063 mg/kg/day is used to evaluate acute, intermediate, and chronic exposures because the exposure occurs every day throughout the year (i.e., EF = 1 for chronic, intermediate, and acute durations).

Table 5 shows the parameters used to calculate the chronic, noncancer doses for children and adults. Compare these doses to the chronic oral MRL of 0.0001 mg/kg/day to calculate HQs.

Cadmium (EPC: 500 mg/kg; Chronic MRL: 0.0001 mg/kg/day)								
Exposure	**IR mg/day**		**EF unit -less**	**BW kg**	**Chronic Doses mg/kg/day**		**Chronic Hazard Quotient**	
	CTE	**RME**			**CTE**	**RME**	**CTE**	**RME**
Birth to < 1 yr	55	150	1	7.8	0.0035	0.0096	35	96
1 < 2 yr	90	200	1	11.4	0.0039	0.0088	39	88
2 < 6 yr	60	200	1	17.4	0.0017	0.0057	17	57
6 < 11 yr	60	200	1	31.8	0.00094	0.0031	9.4	31
11 < 16 yr	30	100	1	56.8	0.00026	0.00088	2.6	8.8
16 < 21 yr	30	100	1	71.6	0.00021	0.0007	2.1	7.0
Adults	30	100	1	80	0.00019	0.00063	1.9	6.3

Because the chronic MRL is exceeded, health assessors should evaluate whether intermediate duration exposure of 2 weeks to 1 year could cause harmful effects.

Table 6 shows the parameters used to calculate the intermediate noncancer doses for children and adults. Compare these doses to the intermediate oral MRL of 0.0005 mg/kg/day to calculate HQs.

Cadmium (EPC: 500 mg/kg; Intermediate MRL: 0.0005 mg/kg/day								
Exposure Group	**IR mg/day**		**EF unit -less**	**BW kg**	**Chronic Doses mg/kg/day**		**Chronic Hazard Quotient**	
	CTE	**RME**			**CTE**	**RME**	**CTE**	**RME**
birth to < 1 yr	55	150	1	7.8	0.0035	0.0096	7.1	19
1 < 2 yr	90	200	1	11.4	0.0039	0.0088	7.9	18
2 < 6 yr	60	200	1	17.4	0.0017	0.0057	3.4	11
6 < 11 yr	60	200	1	31.8	0.00094	0.0031	1.9	6.3
11 < 16 yr	30	100	1	56.8	0.00026	0.00088	0.5	1.8
16 < 21 yr	30	100	1	71.6	0.00021	0.0007	0.4	1.4
Adults	30	100	1	80	0.00019	0.00063	0,4	1.3

Because the intermediate MRL is exceeded, health assessors should evaluate whether acute duration exposures of less than 2 weeks could cause harmful effects. An acute MRL is not available for cadmium; therefore, health assessors should compare the estimated doses directly to the doses from acute animal and human studies to determine whether acute exposures could cause harmful effects.

Scenario #2. An adult works in the garden 2 days a week (Saturday and Sunday) for 36 weeks (approx. 9 months). The garden soil is contaminated with cadmium, and the EPC has been determined to be 1,500 mg/kg cadmium. Soils in other parts of the yard are not contaminated. Calculate the doses for chronic, intermediate, and acute exposures:

(A). Scenario #2, adult gardener, *chronic* exposure, > 1 year. Note, the assumption is that for 3 months during winter, the gardener has no exposure, and that the exposure duration is the 95th percentile residential occupancy period (i.e., 33 years).

$$EF_{\text{chronic}} = 0.197 = \frac{2\frac{d}{wk} x\ 36\frac{wk}{yr} x\ 33\ yr}{7\frac{d}{wk} x\ 52.14\frac{wk}{yr} x\ 33\ yr}$$

$$D_{\text{chronic, gardener, RME}} = \frac{(1{,}500\ \text{mg/kg}\ \text{x}\ 100\ \text{mg/day}\ \text{x}\ 0.197\ \text{x}\ 1\text{E-}6\ \text{kg/mg})}{80\ \text{kg}}$$

$$D_{\text{chronic, gardener, RME}} = 0.00037\ \text{mg/kg/day}$$

(B). Scenario #2, adult gardener, *intermediate* exposure, 2 weeks to < 1 year

$$EF_{\text{intermediate}} = 0.2857 = \frac{2\frac{d}{wk} x\ 36\ wk}{7\frac{d}{wk} x\ 36\ wk}$$

$$D_{\text{intermediate, gardener, RME}} = \frac{(1{,}500\ \text{mg/kg} \times 100\ \text{mg/day} \times 0.2857 \times 1\text{E-6 kg/mg})}{80\ \text{kg}}$$

$$D_{\text{intermediate, gardener, RME}} = 0.00054\ \text{mg/kg/day}$$

(C). Scenario #2, adult gardener, *acute* exposure, < 2 weeks. Note, even if the gardener is assumed to work 2 non-consecutive days a week in the garden, the acute EF would still be 1 for acute exposures (from EF = 1/1).

$$EF_{\text{acute}} = \frac{2\ \text{days}}{2\ \text{days}} = 1$$

$$D_{\text{acute, gardener, RME}} = \frac{(1{,}500\ \text{mg/kg} \times 100\ \text{mg/day} \times 1 \times 1\text{E-6 kg/mg})}{80\ \text{kg}}$$

$$D_{\text{acute, gardener, RME}} = 0.0019\ \text{mg/kg/day}$$

Appendix C—Examples for Cancer Risk

Cancer Risk Calculations for Chemicals

PHAST calculates several cancer risks for health assessors to consider. The initial screening cancer risk is based on 33 years of exposure and assumes that a child lives at a house for 21 years and then continues to live at the same house for 12 years. Do not use this cancer risk unless you have a scenario where children are likely to continue to live in their childhood home as adults. Additionally, PHAST calculates cancer risks for children who live at a house for 12 or 21 years and the cancer risk for adults who live at a house for 12 or 33 years. Twelve years represents the mean residential occupancy, and 33 years represents the 95th residential occupancy period.

Scenario #1. Children and adults live at a home where soil contains PCBs and the EPC is determined to be 100 mg/kg. What are the cancer risks for children and adults?

Cancer risk calculations

The cancer risk for children is calculated by summing the age-specific cancer risk for children from birth to 21 years old.

$$\text{Cancer Risk}_{\text{children}} = \Sigma \frac{(\text{Age-specific dose} \times \text{CSF} \times \text{Age-specific \# Years of Exposure})}{\text{Lifetime in Years}}$$

$$\text{Cancer Risk}_{\text{adult}} = \frac{\text{Adult dose} \times \text{CSF} \times \text{\# Years of Exposure}}{\text{Lifetime in Years}}$$

Sample Dose Calculations

Child 1 < 2 years

$$\text{Dose}_{\text{chronic, 1 < 2 yr, RME}} = \frac{(100\ \text{mg/kg} \times 200\ \text{mg/day} \times 1 \times 1\text{E-6 kg/mg})}{11.4\ \text{kg}}$$

$$\text{Dose}_{\text{chronic, 1 < 2 yrs, RME}} = 0.0018\ \text{mg/kg/day}$$

Adult

$$\text{Dose}_{\text{chronic, adult, RME}} = \frac{(100\ \text{mg/kg} \times 100\ \text{mg/day} \times 1 \times 1\text{E-6 kg/mg})}{80\ \text{kg}}$$

$$\text{Dose}_{\text{chronic, adult, RME}} = 0.00012\ \text{mg/kg/day}$$

Table 7 shows the age-specific parameters and doses for children and adults

PCBs (EPC: 100 mg/kg; CSF: 2 (mg/kg/day)$^{-1}$)						
Exposure Group	**IR mg/day**		**EF unit -less**	**BW kg**	**Chronic Doses mg/kg/day**	
	CTE	**RME**			**CTE**	**RME**
Birth to < 1 yr	55	150	1	7.8	0.00071	0.0019
1 < 2 yr	90	200	1	11.4	0.00079	0.0018
2 < 6 yr	60	200	1	17.4	0.00034	0.0011
6 < 11 yr	60	200	1	31.8	0.00019	0.00063
11 < 16 yr	30	100	1	56.8	0.000053	0.00018
16 < 21 yr	30	100	1	71.6	0.000042	0.00014
Adults	30	100	1	80	0.000037	0.00012

Sample Cancer Risk Calculations

Age-specific cancer risk estimates

CSF_{PCB} = 2 mg/kg/day^{-1}
Exposure Duration = 21 years (children); 33 years (adults)
Lifetime = 78 years

Child 1 < 2 yr

$$\text{Cancer Risk}_{\text{child, 1< 2 yr, RME}} = \frac{(0.001754 \text{ mg/kg/day} \times 2 \text{ (mg/kg/day)}^{-1} \times 1 \text{ yr})}{78 \text{ yr}}$$

Cancer Risk child, $_{1 < 2 \text{ yr, RME}}$ = 4.5E-5

Adults

$$\text{Cancer Risk}_{\text{adults, RME}} = \frac{(0.00012 \text{ mg/kg/day x } 2 \text{ (mg/kg/day)}^{-1} \text{ x } 33 \text{ yr})}{78 \text{ yr}}$$

Cancer Risk $_{\text{adults, RME}}$ = 1.1E-4

Polychlorinated Biphenyls (EPC: 100 mg/kg; CSF: 2 (mg/kg/day)$^{-1}$)						
Exposure Group	**Chronic Dose (mg/kg/day)**		**Cancer Risk**			
	CTE	**RME**	**CTE**	**ED (yrs)**	**RME**	**ED (yrs)**
Birth < 1 yr	0.00071	0.0019	1.8E-5*	1	4.9E-5*	0.88
1 < 2 yr	0.00079	0.0018	2.0E-5*	1	4.5E-5*	1
2 < 6 yr	0.00034	0.0011	3.5E-5*	4	1.2E-4*	4
6 < 11 yr	0.00019	0.00063	2.4E-5*	5	8.1E-5*	5
11 < 16 yr	0.000053	0.00018	1.4E-5*	1	2.3E-5*	5
16 < 21 yr	0.000042	0.00014	0		1.8E-5*	5
Total cancer risk and exposure duration for child			1.1E-4	12	3.4E-4	21
Adults > 21 yr	0.000037	0.00012	1.1E-5	12	1.1E-4	33
Birth to < 21 years + 12 years during adulthood	Do not use this cancer risk unless you have a scenario where children are likely to continue to live in their childhood home as adults.				3.7E-4**	33

* Generally, do not report age-range specific cancer risks for children in your document. These age-specific cancer risks for children are provided here to show how they add up to the total cancer risk from 12 or 21 years of exposure

**Sum of RME cancer risks for children birth to < 21 years (3.4E-4_and RME cancer risks for 12 years exposure continued as adults (3.7E-5) at the same location. Total years of exposure is 33 years.

For properties with 100 mg/kg PCBs in soil, the estimated number of additional cancers ranges from 1 (CTE exposure) to 3 (RME exposure) for every 10,000 children. The estimated number of additional cancers ranges from 0.1 (CTE exposure) to 1 (RME exposure) for every 10,000 adults.

Health assessors can change the duration of exposure for estimating cancer risk depending upon site-specific exposure conditions. For example, if exposure occurred for 15 years, health assessors can change the adult exposure duration to 15/78. Children's cancer risk can be estimated by totaling the age-specific cancer risks for the first 15 years of life. (See the EDG for Life Expectancy and Exposure Factor for further information about residential occupancy periods.) (ATSDR 2016b).

Cancer Risk Calculations for Chemicals with a Mutagenic Mode of Action

Typically when calculating the cancer risk for a carcinogen, the chronic dose is adjusted for a lifetime exposure by multiplying the chronic (annual) dose by the number of years of exposure divided by 78 years (the average human life span).

$$\text{Cancer risk} = (\text{Chronic dose}_{\text{non-cancer}}) \times \frac{\text{(\# years of exposure)}}{\text{78 years}} \times \text{cancer slope factor}$$

As mentioned previously, EPA has classified certain chemicals as having a mutagenic MOA; therefore, the cancer risk estimates for MOA chemicals include age-dependent adjustment factors (ADAF) (EPA 2005).

$$\text{Cancer risk}_{\text{MOA chemicals}} = (\text{Chronic dose}_{\text{non-cancer, age-specific}}) \times \frac{\text{(\# years of exposure)}}{\text{78 years}} \times (\text{ADAF}_{\text{age-specific}}) \times (\text{CSF})$$

EPA suggests using these ADAFs for chemicals with a mutagenic mode of action that do not have age-specific CSFs:

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

Scenario #1: Children and adults live at a home where soil contains polycyclic aromatic hydrocarbons (PAHs), an MOA chemical. The exposure point concentration for benzo(a)pyrene—B(a)P—equivalents has been determined to be 100 mg/kg. The following sample calculations show the use of soil intake rates to estimate chronic exposure doses, which are then used to estimate cancer risk.

(a) Exposure Doses for Noncancer Evaluation

Table 9 shows the exposure doses for ATSDR's standard age groups. The highest exposure dose is associated with 1 to < 2-year old children and is derived using the following equation:

$$EF_{\text{1 to < 2 yr}} = \frac{7\frac{d}{wk}\ x\ 52.14\frac{wk}{yr} x\ 1\ yr}{7\frac{d}{wk}\ x\ 52.14\frac{wk}{yr} x\ 1\ yr}$$

$$\text{Dose}_{\text{1 to < 2 yr, RME}} = \frac{\text{(100 mg/kg x 200 mg/day x 1 x 1E-6 kg/mg)}}{\text{11.4 kg}}$$

$$\text{Dose}_{\text{1 to < 2 yr, RME}} = 0.0018 \text{ mg/kg/day}$$

Table 9 shows the parameters used to calculate the chronic, noncancer doses for ATSDR's standard age groups, which are then used to calculate cancer risks.

BENZO(A)PYRENE (EPC: 100 mg/kg; Chronic MRL/RfD: NA; CSF: 7.3 (mg/kg/day)$^{-1}$; ADAF mutagen)						
Age Group	**Ingestion Rate mg/day**		**Exposure Factor unitless**	**BW**	**Chronic Dose mg/kg/day**	
	CTE	**RME**			**CTE**	**RME**
Birth < 1 yr	55	150	1	7.8	0.00071	0.0019
1 to < 2 yr	90	200	1	11.4	0.00079	0.0018
2 to < 6 yr	60	200	1	17.4	0.00034	0.0011
6 to < 11 yr	60	200	1	31.8	0.00019	0.00063
11 to < 16 yr	30	100	1	56.8	0.000053	0.00018
16 to < 21 yr	30	100	1	71.6	0.000042	0.00014
Adult	30	100	1	80	0.000037	0.00012

(b) Exposure Dose for Cancer evaluation

Because the exposure duration is unknown, health assessors should estimate the adult cancer risk using the 95th percentile residential occupancy period (i.e., 33 years) and using the mean residential occupancy period (i.e., 12 years). For further information about residential occupancy periods, see the EDG for Determining Life Expectancy and Exposure Factor (ATSDR 2016b). The chronic (annual) exposure doses shown in Table 9 can be used to adjust the dose to a lifetime dose using the appropriate ADAF, which can be used to calculate the cancer risk.

(c) Cancer Risk Calculation for 12 and 33 year residential occupancy period

Using the exposure scenario and doses previously presented in Table 9, the following cancer risks can be estimated:

- RME cancer risk for children by assuming that they are exposed from birth to 21 years; RME cancer risk for adults by assuming 33 years of exposure as an adult.
- CTE cancer risk for children by assuming that they are exposed from birth to 12 years; CTE cancer risk for adults by assuming 12 years of exposure as an adult.
- A screening cancer risk, using the 95th percentile residential occupancy, also can be calculated by adding the cancer risk for children exposed for 21 years (birth to 21 years) with an adult cancer risk (additional 12 years of exposure). This screening cancer risk assumes exposure occurred from birth into adulthood at the same residence (for a total of 33 years).

(d) Age-specific Cancer Risk Calculations

Cancer Dose =

$$\text{chronic dose (age-specific; Table 9)} \times \frac{\text{age-specific exposure duration (ED)}}{\text{lifetime (AT)}}$$

Cancer Risk = Σ age-specific cancer doses x CSF x age-specific ADAF

where:

$CSF_{benzo(a)pyrene}$ = 7.3 $(mg/kg\text{-}day)^{-1}$ (age-specific ADAF mutagen)

Exposure duration (years):

Children 12 years (CTE) or 21 years (RME);
Adults 12 years (CTE) or 33 years (RME);
Lifetime (Averaging time; AT) = 78 years

Cancer risks are calculated for CTE and RME doses and durations.

Cancer risks for children are calculated for each age-specific group and are summed to get the total cancer risk for children birth to 12 years (CTE) or birth to 21 years (RME). Cancer risks for adults are calculated using either 12 years (CTE) or 33 years (RME) as the residential occupancy period (see Table 10).

(e) Sample Cancer Risk Calculation: Child 1 < 2 yr (RME)

$$\text{Cancer risk}_{1 \text{ to} < 2 \text{ yr}} = \frac{((0.0018 \text{ mg/kg/day} \times 7.3 \text{ (mg/kg/day)}^{-1} \times 10 \times 1 \text{ yr}))}{78 \text{ years}}$$

$$\text{Cancer risk}_{1 \text{ to} < 2 \text{ yr}} = 1.6\text{E-}3$$

At properties with 100 ppm B(a)P equivalents in soil, the estimated number of additional cancers ranges from 26 (CTE) to 54 (RME) for every 1,000 children exposed. The estimated number of additional cancers ranges from 0.7 to 4 for every 10,000 adults exposed.

You can change the duration of exposure for estimating cancer risk depending on site-specific exposure conditions. For example, if exposure occurred for 15 years, you can change the adult exposure duration to 15/78. You can estimate children's cancer risk by totaling the age-specific cancer risks from the first 15 years of life. (See the Exposure Factor Guidance for further information about residential occupancy periods.)

Table 10. Cancer risk summary.

BENZO(A)PYRENE (EPC: 100 mg/kg; Chronic MRL/RfD: NA; CSF: 1 (mg/kg/day)$^{-1}$; ADAF mutagen)							
Exposure Group	**Chronic Dose mg/kg/day**		**ADAF**	**Cancer risk**			
	CTE	**RME**		**CTE**	**ED (yrs)**	**RME**	**ED (yrs)**
Birth < 1 yr	0.00071	0.0019	10	9.0E-5*	1	2.5E-4*	1
1 to < 2 yr	0.00079	0.0018	10	1.0E-4*	1	2.2E-4*	1
2 to < 6 yr	0.00034	0.0011	3	5.4E-5*	4	1.8E-4*	4
6 to < 11 yr	0.00019	0.00063	3	3.6E-5*	5	1.2E-4*	5
11 to < 16 yr	0.000053	0.00018	3	1.0E-5*	1	3.3E-5*	5
16 to < 21 yr	0.000042	0.00014	1	0	0	9.0E-6*	5
Total cancer risk and exposure duration for child				2.9E-4	12	8.1E-4	21
Adult	0.000037	0.00012	1	5.7E-6	12	3.9E-4	21
Birth to < 21 years + 12 years during adulthood		Do not use this cancer risk unless you have a scenario where children are likely to continue to live in their childhood home as adults.				5.6E-3**	33

* Generally, do not report age-range specific cancer risks in your document. These age-specific cancer risks are provided here to show how they add up to the total cancer risk from 12 or 21 years of exposure.

** Sum of RME cancer risks for children birth to < 21 years (8.1E-4) and RME cancer risks for 12 years exposure as adults (1.8E-5) at the same location. Total years exposure is 33 years.