Assessing Intermittent or Variable Exposures at Lead Sites

Office of Superfund Remediation and Technology Innovation
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DISCLAIMER

The document provides technical guidance to U.S. Environmental Protection Agency (EPA) staff for sites contaminated with lead (Pb). The document is designed to implement national policy regarding the characterization and cleanups of lead contaminated sites. This document does not substitute for EPA's statutes or regulations, nor is it a regulation. Thus, it cannot impose legally binding requirements on EPA, states, or the regulated community, and may not apply to a specific situation based upon the circumstances. EPA recognizes that there may be certain cases where site information and professional judgment may provide sufficient rationale to deviate from the recommendations described herein. EPA may change this document in the future, as appropriate. Any decisions regarding a specific situation are expected to be made based on site-specific factors considering EPA guidance, applicable statutes, and the regulations.

U.S. Environmental Protection Agency Technical Review Workgroup Lead Committee

MEMBERS

The members and participants of the Technical Review Workgroup Lead Committee (TRW) are technical staff from EPA Regions, EPA Program Offices, and Agency for Toxic Substances and Disease Registry. TRW Lead Committee members and participants generally have an active interest and recognized scientific expertise in metals risk assessment. For more information see: https://www.epa.gov/superfund/lead-superfund-sites-technical-assistance.

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1.0 SUMMARY

This guidance accounts for aggregate exposures when contact with lead-contaminated media at a second defined source in the community is likely (in addition to exposures to contaminated media at residences). The methodology presented in this guidance may be appropriate for the assessment of lead risks when exposures are not continuous and chronic, such as:

- Exposure at more than one location (e.g., daycare outside of primary residence, recreating at parks or play areas outside of primary residence, trespassing through a lead contaminated area, etc.)
- Track-in of soil from another location (e.g., returning home after hiking along a lead contaminated stream)
- Intermittent air exposures

This methodology is not intended to replace the approaches recommended for assessing standard residential or continuous non-residential exposure scenarios, which are the most common applications for the Integrated Exposure Uptake Biokinetic (IEUBK) model (U.S. EPA, 1994) and the Adult Lead Methodology (ALM) (U.S. EPA, 1996b, 2003), respectively. This methodology is intended to be used when certain criteria (illustrated in Figure 1) are satisfied. Because this approach is supplemental to the typical residential approach for the IEUBK model (children 12-72 months) and non-residential approach for the ALM (adults), users are cautioned that the discussion herein assumes familiarity with the IEUBK model and the ALM and associated guidance (U.S. EPA, 1994, 2003).

This document presents general guidance for many typical scenarios involving intermittent, non-residential exposure to lead sites. EPA and other decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from those described in this guidance. Additional complexity may be appropriate for certain sites. Contact the Technical Review Workgroup (TRW) for more information (https://www.epa.gov/superfund/lead-superfund-sites-technical-assistance).

2.0 Introduction

EPA's lead models simulate soil lead exposures at a single location of concern (*e.g.*, the residence for the IEUBK model, and a single non-residential location for the ALM). This guidance addresses how to use the IEUBK model and ALM to assess a wider variety of exposure scenarios, including exposure from more than one location when the secondary exposure is intermittent, varying intensities of exposure, track-in of soil from another location, and intermittent air exposures. This document describes the methods, assumptions, limitations, and uncertainties associated with time-weighting of exposures to account for intermittent or highly varying exposure levels, and several examples of how the methodology can be applied at sites. This guidance accounts for aggregate exposures when contact with lead-contaminated media at a second defined source in the community is likely (in addition to exposures to contaminated media at residences). For children or youths, secondary lead-contaminated locations can include playgrounds, recreational areas, daycare centers at industrial areas, or traversing contaminated sites on the way to school or play. For adults, secondary locations can include repeated exposure to work areas with different levels of lead contamination, or exposure to contaminated recreational areas.

The time-weighting approach described in this report can be applied to the IEUBK model or the ALM. Because children are the most sensitive receptors, this guidance recommends the IEUBK model be used when exposures occur both at the primary residence and at a second location accessible to young children. If the exposure level or soil ingestion rate at the secondary location is higher than that at the residence, exposure to soil at the secondary location will result in an increase in blood lead (PbB) concentration above the "baseline" PbB concentration attributed to the residential sources of lead. The magnitude and duration of the increase in PbB concentration will vary depending on the temporal pattern of exposure at the secondary location. The increase will be greatest if exposure at the secondary location occurs every day in succession over an extended period (*e.g.,* over the summer); in comparison, intermittent exposures at the secondary locations (*e.g.,* once every 7 days) would give rise to a smaller PbB increase. The TRW has recommended that the IEUBK model and the ALM be applied to exposures that exceed a minimum frequency of one day per week and 13 consecutive weeks (U.S. EPA, 1994); the rest of the time, the receptor is exposed at their residence or other locations. Three months is considered the minimum exposure to produce a quasi-steady-state blood lead (PbB) concentration. The reliability of the models for predicting PbB concentrations for exposure durations shorter than 13 consecutive weeks has not been assessed. Time weighting exposures of less than a full day are also not recommended because 1) there is no basis for assuming uniformity of soil ingestion for time intervals less than a day; 2) time-weighting of hours of exposure within a day could underestimate exposure and risk; and 3) assuming that all of the daily soil ingestion occurs at the recreational site is a reasonable health-protective assumption for risk assessment.

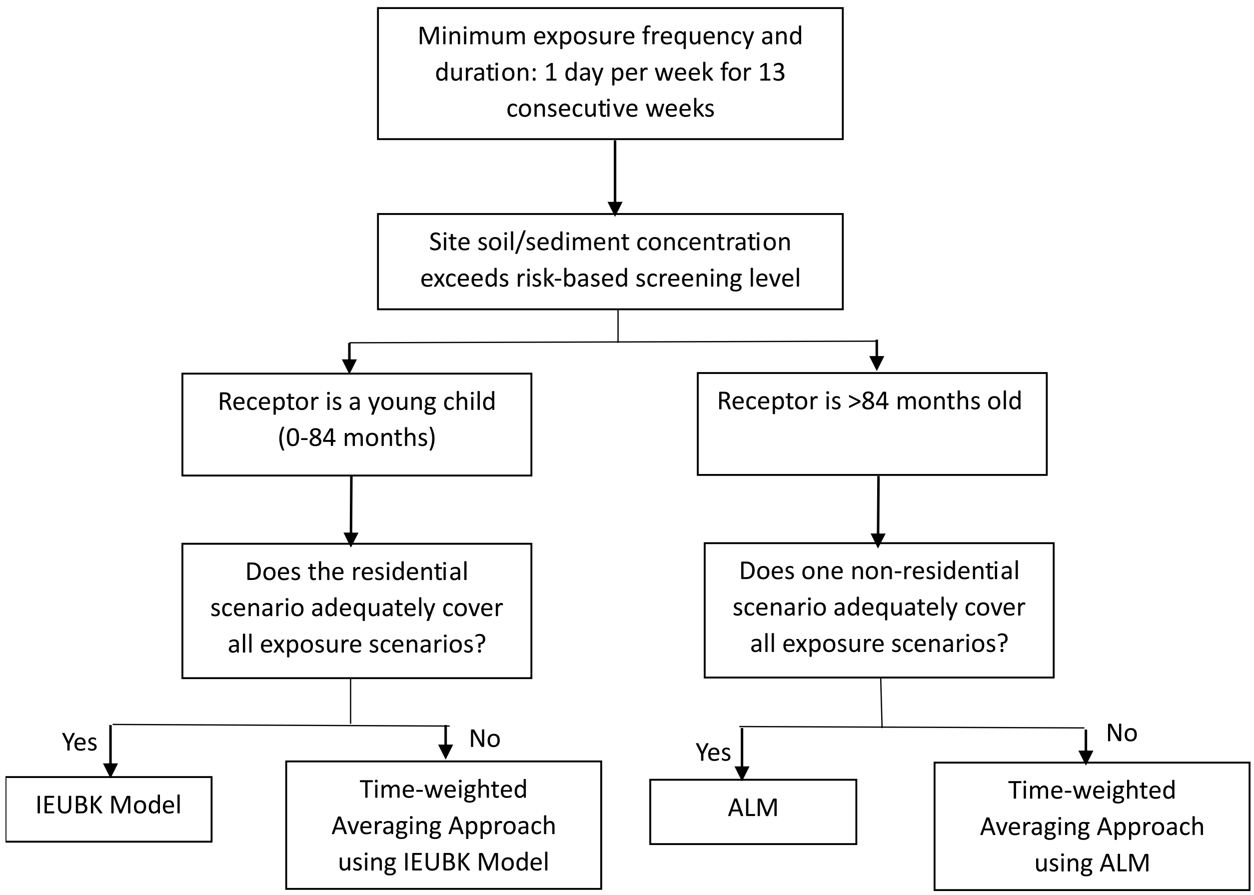
The approaches described herein are consistent with the conceptual structure of the IEUBK model. The IEUBK model (White *et al.*, 1998) was validated using central tendency exposure assumptions to predict a geometric mean blood lead (GM PbB) concentration (Hogan *et al.*, 1998; USEPA 2021a). The following approaches (*i.e.*, time-weighted averaging and incremental approach)-tend to be inherently protective to the extent that observed PbB concentrations integrate all exposures: residential and secondary locations.

Several criteria should be satisfied when considering the assessment of aggregate risks from lead exposures at a primary residence and at a secondary location using the time-weighted approach. A decision tree (Figure 1) is provided to determine whether this approach is suitable to your site. If suitable, this methodology may be used in conjunction with the IEUBK model or the ALM to assess a variety of scenarios where activities may result in additional exposure to contaminated media. Further characterization of plausible site-specific exposure patterns (*e.g.*, exposure duration and likely subpopulations at risk) are also described herein. The TRW recommends considering assessing several plausible alternative scenarios to characterize worst case or upper bound estimates, as well as central tendency risk estimates for situations where there is uncertainty in the frequency or intensity of exposure. For example, if exposure time or frequency are uncertain, users should consider exposure factors that encompass the range of exposures, employing multiple time-weighting scenarios that vary the time potentially spent at each location. Additional complexity can be added to site-exposure scenarios if needed; contact the TRW for more information.

Accordingly, the predicted quasi-steady-state PbB concentrations corresponding to site exposure (not annualized across 1 year) will tend to be higher than the annual average PbB concentrations corresponding to more limited exposure durations. The TRW recommends either the IEUBK model or the ALM for assessing risks associated with short-term exposures of 13 consecutive weeks or longer in duration for the following reasons:

- An extensive body of research has demonstrated an association between chronic health effects of lead and elevated steady-state PbB levels. Currently, the health effects (acute or chronic) of peak PbB levels that occur after acute exposures are not well understood.
- Pharmacokinetic studies of humans (adults) exposed to lead in the diet and of swine and other animals exposed to lead in soil indicate that PbB concentrations will achieve a pseudo-steady state within 1 to 3 months of repeated daily exposure (U.S. EPA, 1994).
- Evaluating the exposure over a 13 consecutive week or longer time period is consistent with the time frame for a time-critical removal action, which is typically defined as a few weeks to 6 months.

Figure 1. Decision tree for determining the appropriate approach to assess cumulative lead risk from one or more locations.



2.1 Appropriate Uses of the Time-Weighted Approach

The TRW does not recommend time-weighting unless the criteria shown in Figure 1 are satisfied. If the planned site use is residential, then it is generally not necessary to assess additional exposures if the other areas are not contaminated. For most residential exposure scenarios, the IEUBK model can be used with the residence as the only source of exposure information. Similarly, because the default ALM is based on assessment of non-residential exposure and includes a baseline for residential exposures, most applications will not require time-weighting to assess a non-residential exposure in combination with the residence. Time-weighting approaches should only be used in the ALM to assess exposures to two or more non-residential locations (e.g., exposure to two exposure locations on a regular basis that meet the minimum exposure frequency and duration).

In all cases where this approach is used, the media concentration of lead must exceed the Risk-based screening level. The IEUBK model and the ALM were designed to simulate PbB concentrations associated with exposures of sufficient duration to result in a quasi-steady state (U.S. EPA, 1994, 1996b). The TRW has recommended 13 consecutive weeks as the minimum duration of exposure that is appropriate for modeling exposures that occur no less often than one day per every 7 days (U.S. EPA, 1994, 1996b, 1999a). The reliability of the models for predicting PbB concentrations in children exposed to lead for durations shorter than 13 consecutive weeks has not been assessed. Because the IEUBK model assumes constant exposures during each age-year, it can provide only an approximation of quasi-steady-state PbB concentrations during non-continuous exposure scenarios of less than a year. As a result of this limitation, short-term fluctuations in PbB concentrations that might occur in response to intermittent exposures cannot be explicitly represented in the model and may be underestimated if short-term exposures are time-averaged over the entire year. For public health purposes, it would be reasonable to consider the possibility of adverse health effects from acutely elevated PbB concentrations that could occur over a period of a few months. Therefore, it is generally recommended that time-weighted exposure inputs for the IEUBK model and ALM **not** be annualized and instead, be calculated only for the duration of the shorter-term exposure (with the realization that the IEUBK model will treat such weighted values as applying to a full year exposure duration). For example, for an intermittent exposure of 5 days a week that occurs each year over a period of 13 consecutive weeks, the time-weighted exposure inputs would not be further adjusted to account for the exposure period of 13 weeks per 52-week year (see examples in Appendix).

When using the IEUBK model to evaluate short-term continuous exposure of no less than 13 consecutive weeks, it is recommended that:

- When data for individual children or populations at the site are not available, default inputs to the model should be used rather than maximum values (*e.g.*, use the default soil intake rather than estimates of "high normal" soil intakes or estimates of pica). The IEUBK model is intended to provide a plausible distribution of PbB levels that may be expected to occur at a site based on site-specific exposure inputs to the model.
- The model should only be used to predict the quasi-steady-state PbB concentration that will be achieved within approximately 13 consecutive weeks of exposure to a given level of lead. It has not been evaluated for predicting the rate at which the PbB concentration will decrease after exposure sources are removed or reduced, or how long it will take to reach a new quasi-steady state.

3.0 Time Weighting Exposure: Adjusting the Concentration Term

The input menus of the IEUBK model and the ALM are somewhat limited for scenarios in which exposures to soil lead from multiple locations occur. The IEUBK dust lead multiple source analysis input allows for entry of “school,” “dust,” and “other” assumes that exposure to soil from these sources is continuous, and do not permit the user to assess intermittent exposures from multiple locations. For reasons of feasibility and maximum clarity, the TRW recommends separate calculations be performed outside the model to obtain appropriately weighted average concentrations of soil lead. The TRW Lead Committee has developed a spreadsheet to assist users in time weighting approaches (available on the TRW Lead Committee website: https://www.epa.gov/superfund/lead-superfund-sites). The time-weighted average values can then be entered into the IEUBK model as fixed media concentrations.

The data needed for assessing intermittent exposures at sites where lead is a contaminant of concern include the following:

- Time spent at the residence and at the site (*i.e.*, the secondary location) – how many days per week are spent at the residence, and how many days per week are spent at the secondary location (with the minima being no fewer than 1 day/week for 13 consecutive weeks)
- Average soil lead concentrations for both the secondary location (which could also be sediment instead of soil) and the residence
    - Measured soil lead data for the site decision unit (DU)
    - Residential soil lead concentration may consider any of the following:
        - Measured soil lead concentration (commonly used when there are multiple DUs for the site, with residential DUs distinct from recreational or site DUs)
        - Assumed (commonly 50 milligrams per kilogram [mg/kg] or state standard) or historic cleanup soil lead concentration (based on average

    - clean fill lead concentration from Removal Response Reporting Pollution Reports [POLREPS])
    - State background soil lead concentration (see USGS Soil Lead Survey[1]) may be used when the visitors to the secondary location do not reside locally, or no information is available for residential areas (and no site impact of the residence is expected)
  - These concentrations should be adjusted to account for site-specific bioavailability information if possible (U.S. EPA, 2021b)
- Indoor dust lead concentrations for the residence
  - Assessed using multi-source analysis, using the default or site-specific soil-to-dust mass transfer parameter (M_{sd})
  - The soil concentration that is used in the M_{sd} equation depends on whether the soil from the secondary location may be tracked back to the residence ("track-in")
    - If track-in is reasonably anticipated, then the soil input for the M_{sd} equation should be the time weighted soil concentration (PbS_W)
    - If track-in is not anticipated, then the soil input for the M_{sd} equation should be the residential soil lead concentration.

Calculation of the time-averaged concentration values are described in the next sections.

3.1 Simple Time Weighting

There are no "default" recommendations for the relative weights to be used in calculating time-weighted media concentrations; rather, the site-specific information or assumptions should be stated clearly and reflect plausible estimates of the typical exposure scenarios for the site. The

[1] https://www.epa.gov/superfund/lead-superfund-sites-united-states-geological-survey-usgs-background-soil-lead-survey#map

TRW recommends time-weighted exposure calculations be applied to derive an average value for the two (or more) locations. In this approach, a weighted value is assigned to a medium (*e.g.,* soil) that reflects the fraction of outdoor exposure to residential or site soil, where the "site" refers to a secondary exposure location. The soil concentrations are weighted based on the estimated fraction of total soil ingestion that occurs at the residence and at the secondary exposure location. Equation 1 shows the fundamental equation for time-weighting exposures to soil from the residence and a secondary location (referred to as a site, for simplicity).

$$Weighted\ PbC_{medium} = \sum_{i=1}^{n} C_i \times EF_i \qquad \text{Equation 1}$$

where:

Weighted PbC_{medium}	=	Weighted lead concentration in medium (mg/kg).
C_i	=	Media concentration at location *i* (in this case, *i= residential yard* or *secondary location*) (*e.g.,* mg/kg).
EF_i	=	Exposure frequency at location *i* (in this case, *i= residential yard* or *secondary location*) (*e.g.,* days/week). The sum of the days/week spent at the residential yard and secondary location is 7.

When applied to lead concentrations in soil at two locations (a residence and a secondary location, or site), the equation can be written as follows:

$$PbS_W = \left(PbS_{home} \times \frac{EF_{home}}{Total\ time\ period}\right) + \left(PbS_{site} \times \frac{EF_{site}}{Total\ time\ period}\right) \qquad \text{Equation 2}$$

where:

PbS_W	=	Weighted lead concentration in soil (mg/kg).
PbS_{home}	=	Lead concentration in soil at the residence (mg/kg).
EF_{home}	=	Exposure frequency at residence (days/week).

Total time	=	The sum of the days/week spent at the residential yard and secondary location (7 days/week).
PbS_{site}	=	Lead concentration in soil at the site (mg/kg).
EF_{site}	=	Exposure frequency at site (days/week).

The time-weighting factor should be based on the smallest time-period in which the exposures repeat (the exposure event period). For example, in an exposure scenario in which one expects exposures 3 days per week every week for 210 days, the exposure event period is 7 days since 3 exposure events occur every 7 days; therefore, the time weighting should be 3 days/7 days NOT 90 days/210 days (*i.e.*, 3 days/week × 4.3 weeks/month × 7 months) (see Example 5 in Appendix). Although the differences in predicted PbB in this example are small (<10%), larger differences could arise in more complex time-weighting adjustments that are based on the typical *calendar units* of time, rather than in units that best reflect the exposure event period.

While Equations 1 and 2 may be appropriate for time-weighting exposure media at some sites, the intensity and time of contact with contaminated media may vary with the type of activity for the different locations. This situation is discussed in the following section.

3.2 Varying Intensity of Exposure

The TRW expects that soil ingestion rates will generally tend to be higher for time spent outdoors in comparison with time spent indoors. For home daycare scenarios, however, the TRW does not generally support the use of different ingestion rates for children's activities at daycare as compared to activities at home, since indoor and outdoor play activities will occur at both locations, and there will be a comparable mix of other activities such as meals and "quiet times" at both locations. For alternate residence or daycare scenarios, the TRW recommends that exposure be apportioned according to days/week.

Barring additional site-specific considerations, indoor and outdoor soil ingestion would still be applied according to the IEUBK model default Soil/Dust Ingestion Weighting Factor of 45% soil and 55% dust (U.S. EPA, 1994). To derive an indoor dust concentration when only outdoor soil data are available for multiple exposure locations, apply the soil-to-dust mass transfer parameter (M_{sd}) to weighted outdoor soil lead concentration. Consideration should be given to whether indoor dust sources (particularly lead-based paint) are likely to be present (see U.S. EPA, 1994, 1999b), and whether the soil from the secondary location will be tracked back to the residence or not. The M_{sd} should be applied to the time weighted soil lead concentration if soil from the secondary location is expected to be tracked back to the residence. If soil is not expected to be tracked back to the residence the M_{sd} should only be applied to the residential soil lead concentration. Equations 3, 4, and 5 show how fractional exposure at each location can be used to derive time-weighted estimates for soil and dust.

If indoor dust samples are not collected at both locations, an estimate of the composite residential indoor soil-derived dust (PbD) concentration may be derived using the default M_{sd} if the site-specific conditions indicate that the default M_{sd} would apply to the situation (i.e., if it is reasonable to assume that soil, sediment, or dust would be tracked from the secondary location to the residence). In the absence of further information upon which to evaluate the site-specific mass transfer of soil into dust, the TRW recommends using the default M_{sd} value of 0.70 (+ 100 × outdoor air lead concentration) to estimate PbD levels for this application (U.S. EPA, 1998). This is reasonable if soil lead is the major source of indoor PbD and no enrichment of indoor dust is expected (such as by lead-based paint) (U.S. EPA, 1994, 1998).

The weighted medium concentration is the sum of the fractional concentrations:

Equation 3

$$Weighted\ PbC_{medium} = \sum_{t=1}^{n} C_t \cdot f_t$$

where:

Weighted PbC_{medium} = Weighted lead concentration across all exposure locations (mg/kg).

C_t = Lead concentration for the medium at each location (mg/kg).

f_t = Fraction of time spent at each location (days/week). This is similar to multiplying the concentration by the ratio of the EF to the total time, as shown in Equation 1.

Example for weighted soil concentration from home and site (e.g., secondary location):

$$PbS_W = (PbS_{home} \times f_{home}) + (PbS_{site} \times f_{site}) \qquad \text{Equation 4}$$

where:

PbS_W = Weighted soil lead concentration across both exposure locations (mg/kg).

PbS_{home} = Soil lead concentration for home (mg/kg).

f_{home} = Fraction of time spent at home (e.g., the remaining days/week not spent at the site).

PbS_{site} = Soil lead concentration for site (mg/kg).

f_{site} = Fraction of time spent at site (days/week spent at the site).

As discussed above, derivation of the indoor dust concentration depends on whether soil from the secondary location is expected to be tracked into the home or not. The following is an equation for calculating the weighted dust concentration from home and secondary location using multi-source analysis <u>where track-in of the soil from the secondary location is expected</u>:

Equation 5

$$PbD_W = (PbS_W \times M_{sd}) + (100 \times air\ lead\ concentration)$$

where:

PbD_W = Weighted dust lead concentration (mg/kg).

PbS_W = Weighted soil lead concentration (calculated using Equation 1) (mg/kg).

M_{sd} = Soil to dust mass transfer parameter (unitless).

Site-specific bioavailability adjustments should be considered in the calculation of PbD_w (see U.S. EPA [2021b] for more information). <u>When no track-in of soil from the secondary location is</u>

expected, the following equation is used for calculating the weighted dust concentration from home and secondary location using multi-source analysis:

Equation 6

$$PbD_W = PbS_{Whome} \times M_{sd\ home} + (100 \times air\ lead\ concentration)$$

where:

PbD_W = Weighted dust lead concentration (mg/kg).
PbS_{Whome} = Weighted soil lead concentration from residence (mg/kg).
M_{sdhome} = Soil to dust mass transfer parameter from residence (unitless).

These time-weighted estimates for PbS_W and PbD_W can be entered directly into the IEUBK model soil and dust media concentration parameter data windows to calculate risk. Similarly, weighted soil estimates for two or more non-residential locations can be entered into the ALM spreadsheet.

Note that this approach does not require separate estimates of the amount of time spent outdoors and indoors at both locations. A more elaborate analysis could be constructed that attempts to apportion children's time spent outdoors and indoors among multiple exposure locations (*e.g.*, daycare and their homes); however, the TRW believes that any plausible estimates based on this approach would depend upon considerable data on the children's specific activity patterns at each location.

This approach is not appropriate for scenarios involving outdoor areas where ingestion is expected to be higher than IEUBK and ALM default values, due to increased soil contact or adhesion (*e.g.*, lake or beach). Such scenarios are discussed in *Increased Contact with Soil (Incremental Approach)* (Section 4.4). This limitation is specifically for apportioning the M_{SD}.

3.3 Matrix Approach for Evaluating Exposure Assumptions

The TRW suggests that a matrix approach be used for evaluating different exposure assumptions. For example, different alternatives may be plausible for the number of days per week spent at each location. The matrix approach permits an evaluation of how activity patterns, using proposed soil cleanup levels, impact estimated risks of elevated PbB and proposed cleanup goals. By conducting several model runs using the alternate values, the implications of alternative assumptions can be evaluated. This approach can also be useful when presenting options to risk managers in cases where there are no data to suggest that one exposure scenario is more plausible than another. An example of the matrix approach, assuming track-in of soil from a secondary exposure location to the residence, is provided in Table 1. Table 2 illustrates the matrix approach assuming no track-in to the residence.

Table 1. Matrix Showing Impact of Various Exposure Assumptions (Number of Visits to Secondary Exposure Location per Week) on Model Predicted Blood Lead Concentration (PbB) and Probability of Exceeding 5 µg/dL (P_5). This scenario is run assuming track-in of soil from the secondary location to the residence.

Exposure scenario	PbS_W[1]	PbD_W[2]	GM PbB (µg/dL)[3]	P_5 (%)[3]
Zero visits per week (residential only scenario)	100	80	1.7	1.1
1 visit to secondary location per week	171	130	2.1	3.5
2 visits to secondary location per week	243	180	2.6	7.6
3 visits to secondary location per week	314	230	3.0	13.4
4 visits to secondary location per week	386	280	3.4	20.1
5 visits to secondary location per week	457	330	3.8	27.5
6 visits to secondary location per week	529	380	4.2	34.7
7 visits to secondary location per week	600	430	4.5	41.9

[1] PbS_W= weighted soil lead concentration; calculated using Equation 2. Residential PbS=100 mg/kg; secondary location PbS=600 mg/kg.
[2] PbD_W= weighted dust lead concentration; calculated using Equation 5 (assumes default Msd of 0.7 and default air concentration of 0.1 µg/m^3).
[3] Results from IEUBK model. GM= geometric mean. All other parameters were set to IEUBK default values. All runs using 12-72 months in IEUBK model. (Exposure continued throughout the 72-month period.)

Table 2. Matrix Showing Impact of Various Exposure Assumptions (Number of Visits to Secondary Exposure Location per Week) on Model Predicted Blood Lead Concentration (PbB) and Probability of Exceeding 5 µg/dL (P_5). This scenario is run assuming no track-in of soil from the secondary location to the residence.

Exposure scenario	PbS_W[1]	PbD[2]	GM PbB (µg/dL)[3]	P_5 (%)[3]
Zero visits per week (residential only scenario)	100	80	1.7	1.1
1 visit to secondary location per week	171	80	1.9	2.2
2 visits to secondary location per week	242	80	2.2	3.8
3 visits to secondary location per week	314	80	2.4	5.9
4 visits to secondary location per week	386	80	2.6	8.5
5 visits to secondary location per week	458	80	2.9	11.5
6 visits to secondary location per week	528	80	3.1	14.9
7 visits to secondary location per week	600	80	3.3	18.6

[1] PbS_W= weighted soil lead concentration; calculated using Equation 2. Residential PbS=100 mg/kg; secondary location PbS=600 mg/kg.
[2] PbD_W= dust lead concentration assuming no track-in of soil from the secondary location; calculated using Equation 6 (assumes default Msd of 0.7 and default air concentration of 0.1 µg/m^3).
[3] Results from IEUBK model. GM= geometric mean. All other parameters were set to IEUBK default values. All runs using 12-72 months in IEUBK model. (Exposure continued throughout the 72-month period.)

The example in Table 1 shows that 1-2 visits to the secondary exposure location per week with track-in to the residence result in PbB concentrations and P_5 values near the target blood lead goal (no more than 5% probability of exceeding 5 µg/dL)). As shown in Table 2, when track-in from the secondary exposure location to the house is eliminated and the lead dust concentration is based solely on the residential soil concentration, 3 visits to the secondary location per week result in PbB concentrations and P_5 values near the EPA goal. The next section explains how the time-weighted approach can be used to develop a preliminary remediation goal (PRG) for a risk assessment.

3.4 Calculating a Preliminary Remediation Goal (PRG)

The current version of the IEUBK model allows users to calculate soil lead PRGs that meets user-defined risk goals. For some intermittent exposure sites, PRG calculation may be complex because the risk managers have the option to remediate the secondary exposure site, the residence, or both. Risk-based target soil concentrations should be determined through several runs of the model by varying the media concentrations until the appropriate risk level is reached (the iterative approach). A risk-based target site (i.e., the secondary location) concentration can be back-calculated from a site-specific model estimate of the overall soil lead concentration associated with a 5% probability of elevated PbB (Equation 7). An alternate approach would be to assess the secondary location alone using a continuous exposure scenario. In cases where the residence (IEUBK) or primary non-residential site (ALM) are less contaminated than the intermittent exposure site, assessing the secondary location as a continuous exposure yields a more health protective result than time weighting the exposures. Site-specific bioavailability adjustments should be considered in the derivation of the PRG (see U.S. EPA [2021b] for more information).

Equations 7 and 8 illustrate how the weighted values can be used to derive a cleanup goal based on average soil lead concentrations at the residence and secondary exposure location. The time-weighting equation (Equation 4) can be expanded to explore soil concentrations at the resident and secondary location that are risk protective. The following equation can be used to calculate the average soil lead concentration at a daycare as an example of a secondary location:

$$PbS_{W} = EF_{site} \times [(f_{site} \times PbS_{site}) + (f_{home} \times PbS_{home})] + (EF_{home} \times PbS_{home}) \qquad \text{Equation 7}$$

where:

PbS_{site} = Average soil lead concentration at an exposure unit at a daycare (secondary location) (mg/kg).

PbS_W = Weighted soil lead concentration (mg/kg).
PbS_{home} = Average soil lead concentration near home (mg/kg).
f_{home} = Fraction of daily outdoor time at local background soil lead concentration (usually near home) = 1-f_{site} (days/week).
EF_{site} = Exposure frequency expressed as fraction of the days/week child visits the secondary location (daycare) during the exposure period.
EF_{home} = Exposure frequency expressed as fraction of the days/week child does not visit the secondary location (daycare) during the exposure period = 1-EF_{site}.
f_{site} = Fraction of daily outdoor time spent at the secondary location (daycare) on days when the secondary location is visited (days/week).

Equation 2 which calculates PbS_w based on the lead soil concentrations at a secondary location and a residence, and the EF for each location, may be rearranged to solve for average soil lead concentration at the secondary location. Starting with the risk-based soil lead screening concentration of (for example) 200 mg/kg, which is associated with a risk goal of no more than 5% probability of exceeding a PbB of 5 µg/dL (P5) in the absence of site-specific relative bioavailability (RBA), for PbS_W, a soil lead concentration for the secondary location (which can be considered a PRG) can be derived that is protective of human health:

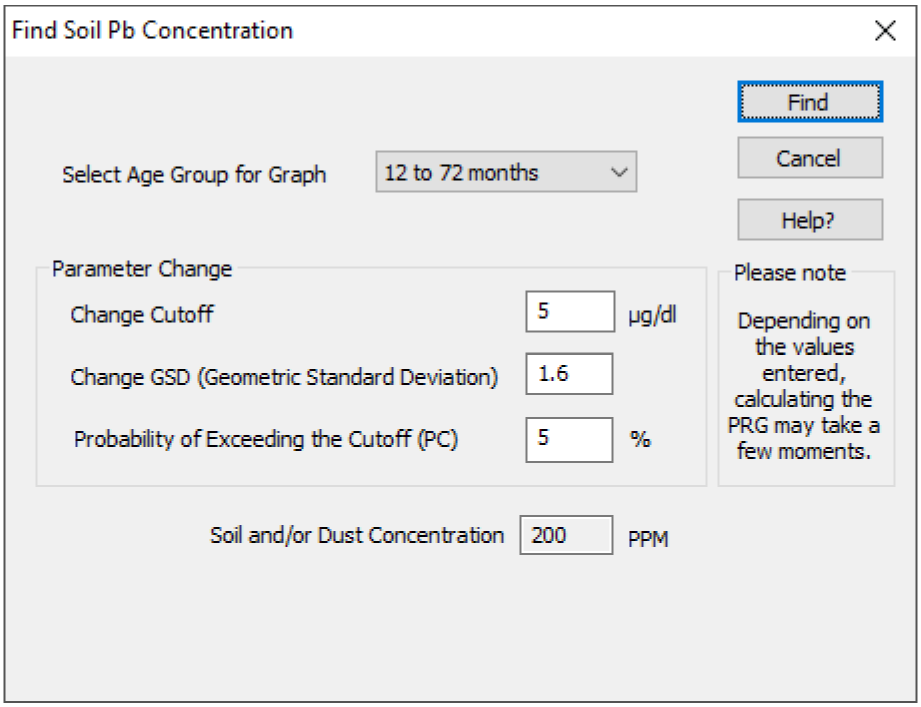
$$PbS_{site} = \frac{PbS_w - \left[PbS_{home} \times \left(\frac{EF_{home}}{Total\ time}\right)\right]}{\left[\frac{EF_{site}}{Total\ time}\right]}$$

Equation 8

Where:

PbS_w = 200 mg/kg (assuming that there is track-in of dust from the secondary location)
PbS_{home} = lead concentration in soil at the residence
EF_{home} = days/week spent at the residence
EF_{site} = days/week spent at the secondary location
Total time = 7 days/week

Table 3 illustrates how various residential lead soil concentrations and exposure assumptions may affect calculation of the site PRG. When there is track-in of soil from the secondary location to the residence, the risk goal for time-weighted soil (PbS_w) can be calculated in the IEUBK model using the "Find Soil Pb Concentration" window (accessed by selecting "FIND" on the menu at the top of the screen) as follows:



This risk-based soil lead concentration of 200 mg/kg (PbS_w) is then used to calculate the dust concentration (PbD_w) using equation 5 (PbD_w = 200 mg/kg × 0.7 + [100 × 0.1] = 150 mg/kg, where the default air lead concentration is used). Equation 8 above can then be used to populate a matrix as shown in Table 3 using different residential soil lead concentrations and exposure frequencies.

Table 3. Example of Site PRG Calculation Assuming a Range of Residential Soil Lead Concentrations, with Track-in of Soil from the Secondary Exposure Location and Various Exposure Assumptions.

Options	Exposure assumption	PbS_W[1]	PbD_W[2]	Site PRG (mg/kg)[3]
1: Residence PbS=50	3 visits per week	200	150	400
2: Residence PbS=100	5 visits per week	200	150	240 (rounds to 250)
3: Residence PbS=200	6 visits per week	200	150	200

[1] PbS_W= target soil lead concentration associated with a risk goal of P5 (5% probably of not exceeding a PbB of 5 µg/dL) assuming no site-specific RBA; calculated in the IEUBK model "Find Soil Pb Concentration" for an age group of 12-72 months.
[2] PbD_W=weighted dust lead concentration assuming track-in from the secondary location; calculated using Equation 5.
[3] Preliminary remediation goal (PRG) for the site, calculated using Equation 8. Note that PRGs are typically rounded to the nearest 50 or 100 mg/kg.

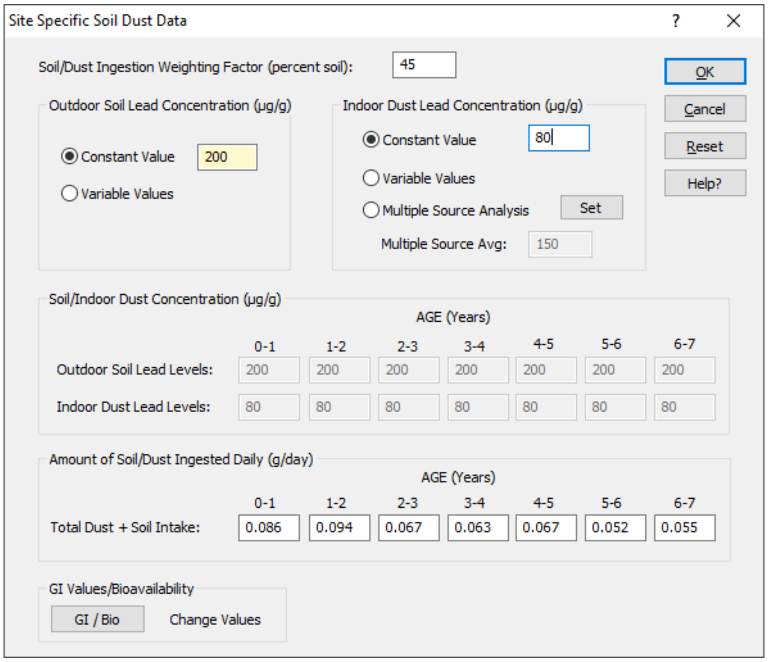
Table 3 illustrates key points in deriving PRGs for time weighting scenarios. First, if the residential exposure meets the target risk benchmark for the site (*e.g.*, 5% probability of exceeding 5 µg/dL PbB, which is a soil concentration of 200 mg/kg), then the site PRG can be no higher than the RBA-adjusted soil concentration that meets the risk benchmark. In Table 3, this is illustrated by the third scenario, when the residential PbS is 200 mg/kg, and there are 6 visits to the secondary location per week; the site PRG is 200 mg/kg. Second, if the residential exposure is less than the target risk benchmark for the site (*e.g.*, less than 200 mg/kg if the risk target is P_5), then the site PRG can be higher. For the first two scenarios in Table 3, where the residential soil concentration is either 50 or 100 mg/kg, the site PRG is greater than 200 mg/kg: 400 mg/kg and 250 mg/kg, respectively. Finally, if the residential exposure exceeds the target risk benchmark for the site (*e.g.*, the site risk benchmark is P5, but residential areas were previously remediated using a risk benchmark of P_{10} [approximately 600 mg/kg]), then there is no plausible soil concentration for the exposure locations at the site that will meet EPA's risk target.

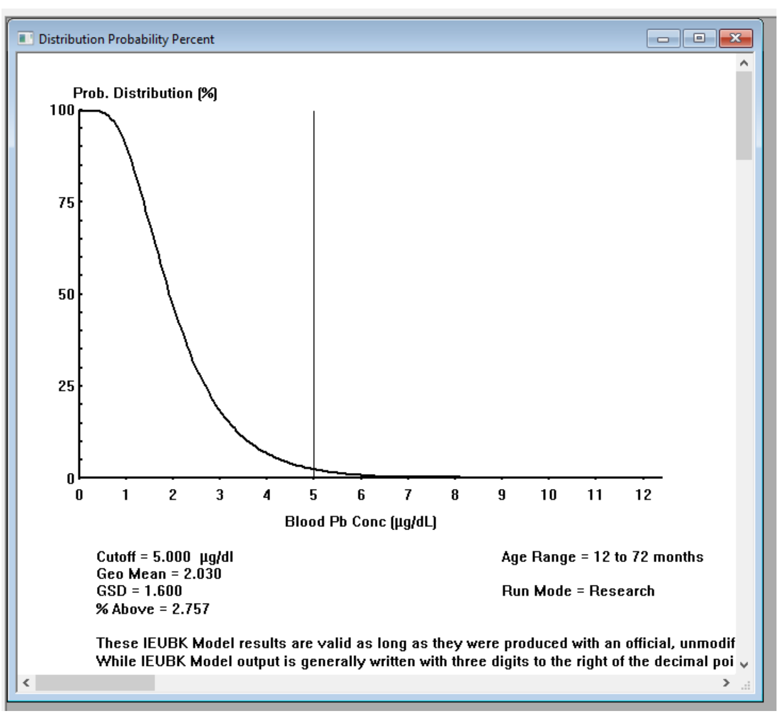
When track-in of soil from the secondary exposure location is not assumed, the PRG calculation requires use of the IEUBK model to solve for PbS_w, as shown in Table 4. The following steps should be taken:

STEP 1. Calculate PbD_w; since there is no track-in of soil from the secondary location, the dust concentration should be calculated from the residential soil concentration. Given a PbS_{home} of 100 mg/kg (as in Table 4) and using Equation 6, $PbD_w = 100 \times 0.7 + (100 \times 0.1) = 80$ mg/kg

STEP 2. Determine PbS_w. This is done using the IEUBK model by inputting the dust concentration of 80 mg/kg, setting the target risk benchmark to 5% of exceeding a PbB of 5 µg/dL (i.e., P5), and inputting different soil concentrations until the risk result is 5% or using the Find Soil PRG function. See the following screenshots for example.

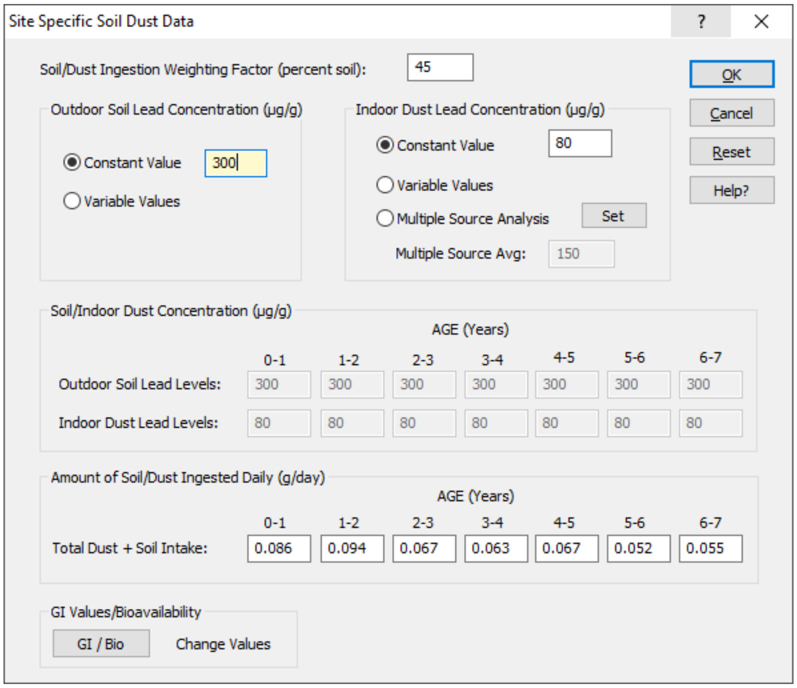
First iteration: PbS_W of 200 mg/kg with a dust concentration of 80 mg/kg:

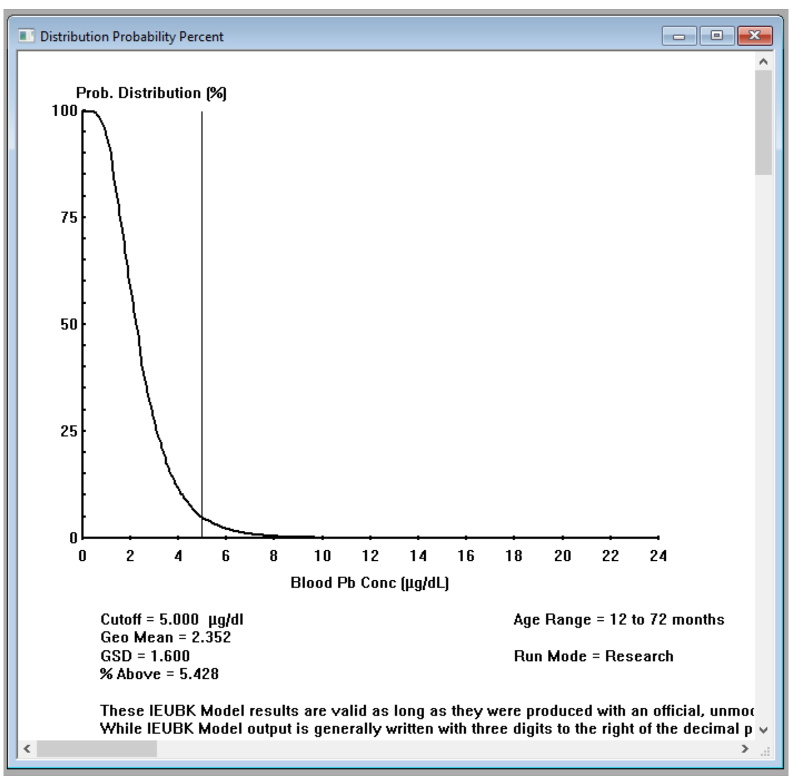




Result is 2.8%.

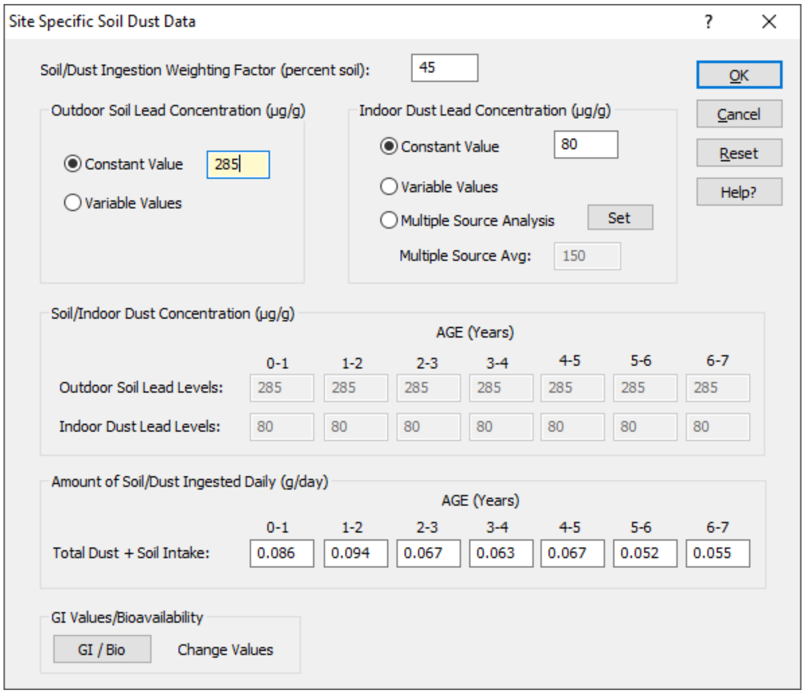
Second iteration: PbS_W of 300 mg/kg with a dust concentration of 80 mg/kg:

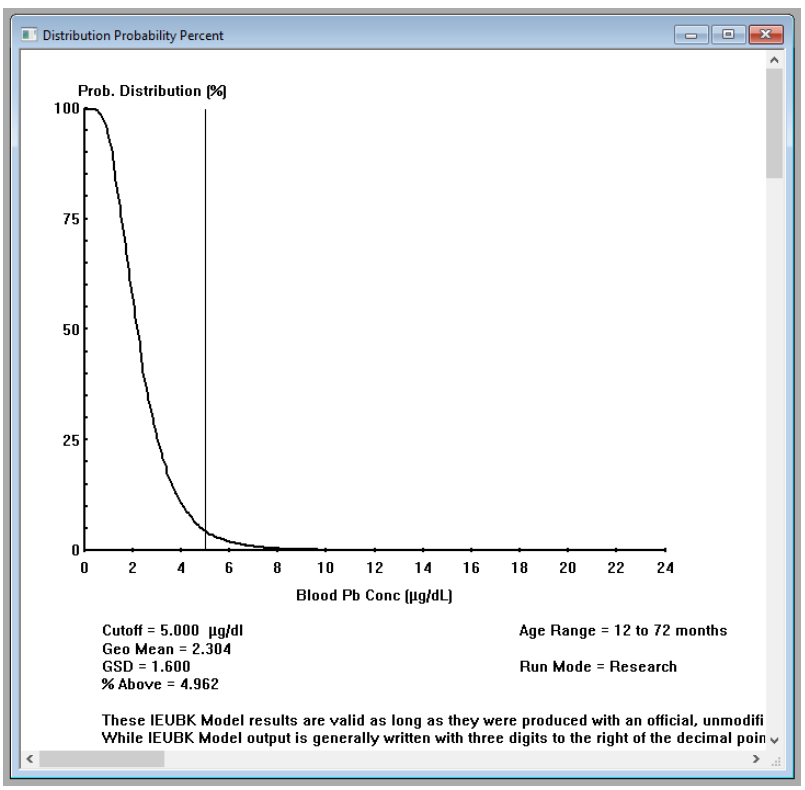




Result is 5.4%.

Third iteration: PbS_W of 285 mg/kg with a dust concentration of 80 mg/kg:





Result is 5.0%.

STEP 3. Calculate Site PRG (PbS_{site}) using equation 8, based on the PbS_w derived in Step 2 and the exposure frequencies for the time weighting. See Table 4 for various site PRGs based on varying exposure assumptions.

Table 4. Example of Site PRG Calculation Assuming Various Exposure Assumptions (e.g., Visits to a Secondary Exposure Location).

Options	Exposure assumption	PbS_W[1]	PbD_W[2]	Site PRG (mg/kg)[4]
1: Residence PbS=100	3 visits per week	285	80	532 (rounded to 550)
2: Residence PbS=100	5 visits per week	285	80	359 (rounded to 400)
3: Residence PbS=100	6 visits per week	285	80	316 (rounded to 350)

[1] PbS_W= weighted soil lead concentration associated with a risk goal of P5 (5% probably of not exceeding a PbB of 5 µg/dL) assuming no site-specific RBA; calculated using the IEUBK model and PbD_w for an age group of 12-72 months.
[2] PbD_W=weighted dust lead concentration assuming no track-in; calculated using Equation 6.
[3]Preliminary remediation goal (PRG) for the site, calculated using Equation 8. Note that PRGs are typically rounded to the nearest 50 or 100 mg/kg. The residential soil lead concentration of 100 mg/kg was unchanged.

Because apportioning cleanup across two or more locations is a risk management decision and not solely a risk assessment decision, the TRW recommends a matrix approach be used to present the range of health protective cleanup options to the risk manager. A matrix approach is a useful way to demonstrate to risk managers the health protectiveness of PRGs under various exposure assumptions (Tables 3 and 4) which may differ in terms of cost, implementability, resource utilization, or other considerations. OLEM soil lead guidance limits the individual risk of elevated PbB for a typical child to less than 5%, which is not the same as limiting the population risk to less than 5% (see U.S. EPA, 1994).

4.0 Applications of the Approach with the IEUBK

In certain cases, additional assumptions may be appropriate for the risk assessment to reflect the added contribution of soils from a secondary location to interior house dust lead when older siblings trespass or recreate at a secondary exposure location and track soils into the home, thus exposing younger siblings (Section 4.1). The approach can be applied to various age groups, including children, teens, and adults (Section 4.2). Although modeling of seasonal variability in lead exposures is difficult and usually unnecessary for characterizing maximum seasonal exposures, the temporal pattern of exposure should be considered in assessments (Section 4.3). In addition, the incremental approach can be used to assess playground or trespasser scenarios where activities may result in more intense contact with contaminated soils than at home, daycare, or other residential sites.

4.1 Contribution of Tracked-In Soil

Developing a modeling approach for exposures occurring via soil and dust ingestion from multiple locations also has applications to any scenario involving a second exposure where the contamination is likely to be tracked back to the residence. For instances where there is a strong possibility of access to the secondary location (generally non-residential), one should consider the potential for older children tracking soils from the secondary location into the home, thereby increasing interior dust lead levels and increasing residential exposure for younger children. The IEUBK model should only be used to assess risks to children from 0 to 84 months of age (The TRW recommends the 12-72 month age range be used to assess lead risk at Superfund sites [U.S. EPA, 2017b]). When older children (>84 months) are expected to be exposed, the ALM should be used with appropriate consideration given to the inputs (see Section 4.2.2). Pets may also track soil into the house, which would contribute to dust lead. Contribution of tracked-in, contaminated soil to indoor dust is expected to affect default dust concentration if no site-specific data are available.

The IEUBK model default assumption for the transfer of residential PbS to PbD was not developed for a situation where a significant source of lead in soil is distant from the house. Some track-in from the secondary location is likely, but all other things being equal, track-in may be less than if the soil source is the residential yard. There would likely be fewer incidents of track-in per day per person visiting the secondary location in comparison with a residential yard. On the other hand, more intense or sustained play and sporting activities at the secondary location could result in larger "loading" of soil on the children (or adults) that could be tracked into the home. Activities at the secondary location, such as organized sports, could contribute to a greater than usual accumulation of soil to bring back to the residence. The extent to which this soil is transferred into the residence would depend on a variety of site- and individual-specific factors. For example, soil adhering to outerwear has more time to drop off clothing the more distant the secondary location is from the residence. On the other hand, if weather conditions are damp, then the maximum mass of soil picked up is more likely to be tracked back to the residence. For more information on track-in of contaminated outdoor soil, see Bornschein *et al.* (1985) and Matte *et al.* (1991).

Without some actual measurements of house PbD concentrations under these conditions, estimates of PbD concentrations are uncertain. Given this uncertainty, the TRW recommends that the fraction of interior dust attributable to the non-residential secondary location should not exceed the fraction of the trespassing child's total soil exposure thought to come from the site. For example, if the end assumption is that 20% of the trespassing child's combined soil exposure (home + secondary location) is attributed to soil coming from the secondary location, then it is probably appropriate to assume that no more than 20% of the interior dust comes from the secondary location.

4.2 Applicability of the Approach to Various Age Groups

4.2.1 Children 12-72 months

Younger children may not be expected to visit a secondary location; however, in some cases, it may be appropriate to consider exposures to these children to assess increased exposure in these situations. As described in the preceding section on track-in, children who do not visit the secondary location can have exposure to soil brought home from the secondary location by older children and adults. Also, cases have been documented where older children brought younger children to visit areas where adult supervision would be desired. To assess such scenarios, the IEUBK model (as previously described) can be run using the increased media concentrations of lead at the residence (this may be accomplished by assuming that young children are experiencing the exposure [most health protective approach] or by adjusting the home dust lead concentration term for young children to account for the track-in to the residence). Before choosing a cleanup goal, it is useful to consider both the entire population in general and the most highly exposed individual in developing a set of use patterns. In the context of IEUBK model runs, exposure to lead-contaminated media differs by age.

4.2.2 Adolescents

In general, the TRW expects that cleanup goals designed to be protective for children less than 84 months old, the most sensitive subpopulation for chronic health effects, will be at least as protective for older children. Although the IEUBK model is limited to 0-84 months, the ALM could be used to assess older children. When using the ALM to assess older children, however, it may be necessary to adjust default ALM values for ingestion rate and bioavailability (which are defined for adults) to appropriate values for the exposed population. Users should refer to the Frequently Asked Questions on the ALM for more discussion on the evaluation of the adolescent scenario (https://www.epa.gov/superfund/lead-superfund-sites-frequent-questions-risk-assessors-adult-lead-methodology). While the IEUBK and the ALM results could be considered bounds for the risk of elevated PbBs and for cleanup goals for adolescents with direct exposure to soil from a secondary location, the toxicokinetics of adolescents are not well understood, so that any scaling, such as linear interpolation, between the predictions of the two models cannot be supported. Contact the TRW for guidance concerning use of the ALM in such instances.

4.2.3 Adults

To estimate PbB_s for adult populations exposed to a single non-residential scenario, the default ALM is recommended. As with the IEUBK model, it is necessary to perform calculations outside the model to derive weighted soil lead concentrations for use in the ALM if contact with contaminated media occurs at more than one non-residential location. Note that if the exposure scenario includes a residence, then the IEUBK model should be used to assess that location; the ALM should only be used in this context when the two exposure locations are both non-residential (*e.g.*, adult exposures to contamination in a warehouse and a factory). As noted earlier, consideration should be given to track-in of soil from these areas to the home. Example 4 in the appendix to this report provides an example of how the ALM can be used to assess intermittent exposures.

4.3 Seasonal Variability in Lead Exposure and PbB

The IEUBK model was designed to consider routine seasonal variability in media exposures for children. Although the model was calibrated with environmental data that were taken to represent sustained daily exposures, the seasonal fluctuation of PbB concentrations is suspected to represent seasonal variability in both exposure and physiological factors. In some geographic regions of the U.S., children may have less direct exposure to soil in the colder months, and their decreased outdoor activity also corresponds to a lower contribution of soil to indoor dust lead. During the winter months in some regions of the U.S., exposures to exterior soil may be greatly reduced because the ground is frozen and covered with snow. Interior dust lead and PbB concentrations were as much as 50% lower in the coldest months in Boston (U.S. EPA, 1995). Nevertheless, exposure to soil may not be negligible during the winter months, occurring outdoors or from soil tracked into the home.

The calibration and validation data sets that have been used with the IEUBK model were generated cross-sectionally, including children with at least 13 consecutive weeks of residency at the sampled locations, at a time of year (late summer) when soil exposure and PbB concentrations were expected to be at an annual maximum (Hogan *et al.*, 1998). IEUBK predictions are therefore expected to approximate the PbB concentrations related to the higher lead exposure levels in an annual cycle of lead exposure, where measured lead concentrations in soil are expected to remain relatively constant. In addition, from a public health perspective, it may be more appropriate to focus on the seasonal maximum exposures than to try to quantify variability in seasonal exposures. Consequently, users should focus analyses on plausible exposure estimates during seasons when PbB concentrations are likely to peak.

4.4 Increased Soil Ingestion (Incremental Approach)

Soil ingestion may be greater than default levels in connection with at least some contact-intensive activities. For example, soil contact and ingestion may be increased at secondary exposure location where increased soil adherence would be expected, such as at contaminated waterfront areas or when dirt biking on contaminated areas. Because of the potential for higher contact rates with soil at these secondary locations (*e.g.*, when children dirt bike on a slag pile), scenarios entailing additional soil ingestion may be warranted. In the absence of site-specific data, risk assessors may want to explore the impact of a variety of reasonable soil ingestion rates. A recommended approach would be to bound risk estimates using several reasonable soil ingestion rates. Additional guidance on soil ingestion is available from U.S. EPA's Exposure Factors Handbook (U.S. EPA, 2017a).

A hypothetical example would be to set the default soil ingestion rates as a lower bound. A reasonable medium exposure scenario of 145% of default rates could also be assumed to occur at the secondary location (*i.e.*, the default, **plus an additional 45%** to account for outdoor activities). For a Reasonable Maximum Exposure (RME) scenario, the 200 mg/day value that has been used in Superfund assessments as a high average daily soil ingestion rate could be **added to** the model's default total dirt ingestion rates. This approach (or a 10% increase in ingestion rate) may also be applied to secondary locations where increased soil exposure is anticipated (e.g., especially dry dusty conditions, the exposure scenario involves off-road vehicles that generate a lot of dust).

Just as model limitations require external calculations to achieve the composited PbS_W and PbD_W input values for multiple-site scenarios, so must composite ingestion rates be calculated external to the model when non-residential ingestion rates are reasonably expected to exceed model default values (Table 5). The methodology suggested herein is a somewhat simplified and conservative approach, since it may in fact overstate the child's total daily exposure time (because time spent at the secondary location would be time that is not spent at the residence).

Table 5. Examples of a Range of Hypothetical Dirt (soil/dust) Ingestion Rates Associated with Exposure at Non-Residential Locations.

Age group (months)	Total dirt ingestion rate (g/day)		
	Low scenario ingestion = IEUBK default	Medium scenario ingestion= 1.45 * IEUBK default	High scenario[2] ingestion = 200 mg/day + IEUBK default
0-11[1]	0.086	0.086	0.086
12-23	0.094	0.136	0.294
24-35	0.067	0.097	0.267
36-47	0.063	0.091	0.263
48-59	0.067	0.097	0.267
60-71	0.052	0.075	0.252
72-84	0.055	0.080	0.255

[1] Additional soil contact is not applicable to children <1 year, since they are not likely to have significant additional exposure to site soil.
[2] The high exposure scenario is shown for consistency with OLEM guidance on assessing risk under the Reasonable Maximum Exposure (RME) scenario (U.S. EPA, 1989).

Table 5 provides an example of a plausible range of hypothetical total dirt ingestion rates associated with greater soil ingestion rates. An example of how the additional soil ingestion rate values are incorporated in an assessment is shown in Example 2 of the Appendix.

5.0 Air Pathway

In some instances, receptors do not need to be at different locations to have intermittent exposures. The IEUBK model was designed to predict PbB concentrations associated with relatively stable, long-term exposures that result in quasi-steady-state PbB concentrations (*e.g.*, relatively constant exposures of at least 13 consecutive weeks in duration). The model has not been evaluated for predicting PbB concentrations that might occur with rapidly varying exposures, such as those that often result from air emissions from remediation activities at contaminated sites where lead is a major contaminant. On the other hand, varying air lead exposures of an episodic nature may be assessed using a time-weighted approach. In this case, continually changing concentrations that occur each week or within a day could be assessed using the IEUBK model or the ALM. The potential for recontamination of soil and dust by ongoing deposition of airborne lead should also be considered.

To simulate intermittent exposures, a variation of Equation 1 using air instead of soil can be used to derive time-weighted air lead concentrations. In the case of air, the extra exposure would be time weighted and added to exposure to the baseline air concentration which can be set as the IEUBK default (0.1 µg/m³) or based on upwind site sampling. An example of this approach for adults (using the ALM) is shown in Equation 9.

$$PbA_W = \frac{PbA_{site} \cdot EF + PbA_{base} \cdot (AT - EF)}{AT} \qquad \text{Equation 9}$$

where:
PbA_W = weighted air lead concentration (µg/m³).
PbA_{site} = observed or expected air lead concentration from the site (µg/m³).
PbA_{base} = baseline air lead exposure concentration that would be expected to occur in the absence of site exposure (0.1 µg/m³ or based site-specific data).
EF = the exposure frequency (days/week).
AT = the averaging time (days/week).

The intermittent exposure scenario and time-weighting equations are also applicable to fugitive emission scenarios. At some sites air data may be lacking, yet it would be helpful to take fugitive emissions from lead-contaminated soil into account. One way to do this is to estimate the fugitive emissions, then use that equation to modify the cleanup goal for lead. Additional information concerning the fugitive emission pathway including equations specific to site activities are available from the Soil Screening Guidance (U.S. EPA, 2001) in which soil- and site-specific Particulate Emission Factors (PEFs) modify cleanup goals. For example, the PRG for a site can be derived when direct soil contact and fugitive emissions come from two different sources of lead-contaminated material. In this example, the residence is located near a pile of lead-contaminated fines (subject to fugitive dust contamination) and the child's playground (located in an area apart from the residence) has been contaminated with fill material containing lead. In this example, time-weighted averages would be used in the IEUBK (because the residence is used) to account for soil exposure in combination with the fugitive dust equation from the Soil Screening Guidance.

6.0 Uncertainties in the Approach

Various factors could contribute to either an overestimate or an underestimate of the PbB concentration when weighted exposures to media concentrations are used as inputs to the IEUBK model and the ALM. These factors need to be considered in interpreting model predictions that are based on such an approach. Several areas of uncertainty should be considered, including absorption assumptions (Section 6.1), peak blood lead for successive exposure scenarios (Section 6.2), health effects from acute high-term exposures (Section 6.3), and seasonal versus annual exposure (washout) (Section 6.4).

6.1 Uncertainties in Assumptions Regarding Soil Intake and Absorption

Estimates for soil and dust ingestion rates used in the model are intended as average daily rates for typical children. Depending on play routines, sports activities, and soil exposure while at a secondary exposure location, actual ingestion may exceed typical average values. The time weighting approach is not necessarily appropriate for scenarios involving outdoor areas where soil ingestion is expected to be significantly higher than IEUBK default values, due to increased soil contact or adhesion. This limitation is specifically for apportioning the M_{SD}. The TRW recommends that users consider the potential for alternative higher ingestion rates that may occur during soil contact-intensive activities and include risk calculations using these rates in the assessment to bound the results (see Section 4.4 and table 4). Also, the IEUBK model predicts that the relative absorption fractions will decrease when higher quantities of lead are ingested. Thus, time averaging may result in a higher predicted absorption fraction than would be predicted for periods when actual intakes are higher than the time-weighted average intake.

6.2 Underestimation of Peak PbB for Successive Exposure Scenarios

If exposures to contaminated media from a secondary location were to occur over a number of days in succession, the aggregate effect would be a temporary elevation of the PbB concentration during and after this period of exposure. This elevation may be greater in magnitude (though of shorter duration) than that estimated using a time-weighted average approach, because the IEUBK model can provide only a quasi-steady-state approximation to PbB concentrations during non-continuous exposure scenarios (the IEUBK model only allows for changing exposure variables annually). A hypothetical example of the difference in predicted PbB when using different approaches to derive a time-weighted average to annualize an intermittent exposure is shown in Figure 2.

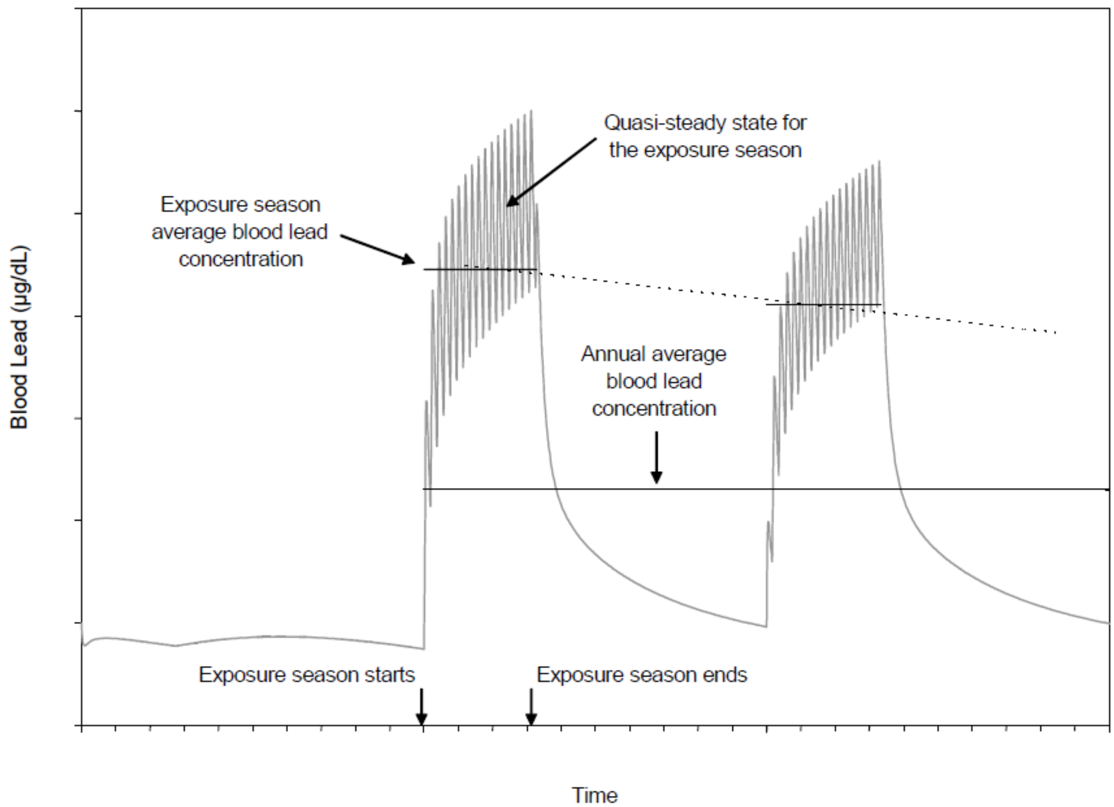


Figure 2. Hypothetical blood lead concentrations illustrating difference between two approaches to modeling intermittent exposure when exposure is time weighted for models limited to annual averages. The graphed line shows expected blood lead concentration resulting from an intermittent exposure without time weighting. The dotted line shows the results of time weighting the exposure soil concentration only over the exposure season (ignores washout period). The solid line shows the result of time weighting the exposure soil concentration over the year (accounts for washout period). Note that exposure to lead is not zero when the seasonal exposure ends but returns to baseline exposure. The second exposure

is lower than the first because a childhood scenario was used in which the ingestion rate for the second year is lower than the first.

6.3 Uncertainty in Health Effects from Acute, High-Level Exposures

The time-weighted approach assumes that the adverse health effects of lead are related to long-term average PbB concentrations. While this has been established for chronic effects of lead, the health effects (acute or chronic) of elevated PbB levels that occur after acute exposures resulting in short-term PbB concentrations less than 20 µg/dL are not well understood.

6.4 Seasonal vs. Annual Exposure

For seasonal exposures that are restricted to only a fraction of a year (*e.g.*, summer months), some of the lead burden accumulated during the exposure season will be eliminated during the intervening months between seasonal exposures. However, the IEUBK model cannot simulate this loss of lead; model predictions correspond to a full year of exposure to a constant exposure level regardless of the actual exposure period. For seasonal exposures that occur in successive years, the TRW recommends that exposures be simulated for individual age-years and predicted blood lead concentrations for each age-year of exposure be averaged.

For risk assessment purposes, the impact of repeated shorter-term exposure from a secondary location on an annual basis is important to consider. This can be approached by first considering the case where exposure occurs only once and is not repeated annually. Such an exposure estimate would also characterize children who return to the secondary location for a period each year, and whose added blood lead burden is eliminated during the intervening months between successive annual exposures. An illustration of this point is presented in Example 5 (multi-year exposure) of the Appendix. Example 5 shows how different risk management decisions or site-specific conditions can affect the risk calculation approach.

This example highlights the importance of closely examining the exposure assumptions for the site and how those exposure assumptions are used as parameter estimates for the IEUBK model and ALM. The TRW recommends running the models with several reasonable sets of assumptions (plausible combinations) to present a range of possible risks or cleanup options for the site.

APPENDIX A

Case Studies

This appendix provides case studies that illustrate the considerations inherent in assessing risks posed by lead from a variety of intermittent exposure scenarios using both the ALM and the IEUBK model. The terms used herein are defined in the body of the report.

Example 1: Recreation Exposure Scenario for Park

The site use in this scenario is assumed to be primarily recreation. A proposal is being considered whereby the site would be developed as a recreational area. The goal of the cleanup is to minimize lead exposure for children who would visit the site during the warmer months for recreation.

Goals:

1. Calculate the PbB and P_5 risk estimates for children 12-72 months of age.
2. Estimate the lead concentration in site soil that would result in a 5% probability of exceeding a PbB concentration of 5 µg/dL (*i.e.,* P_5 ≤5%).

Assumptions for the scenario:

1. Children have exposure to site soil each day the site is visited, for a total of 52 days spread evenly over 1 year, 6 months, or 3 months (*i.e.,* 1, 2, or 4 days per week, respectively).
2. The lead concentrations of site and residential soil are 2000 and 50 mg/kg, respectively.

The above assumptions yielded PbS_W and PbD_W concentrations for 1, 2, or 4 visits/week to the site (the default M_{sd} of 0.70 + [100 × air lead concentration of 0.1 µg/m^3) to estimate PbD levels for this application). These were used as inputs to the IEUBK model, along with default values for all other model variables. Residential dust concentrations were calculated using the weighted mean soil concentration to which the child was assumed to be exposed and the model default assumptions for the mass transfer of soil into house dust (track-in of dust was assumed). In all cases, all other inputs were kept at default values, including soil ingestion rates. Note that for simplicity, these calculations assume that total soil ingestion occurs at the default rate. The predicted geometric mean PbB concentrations and estimates of the probability (%) of exceeding 5 µg/dL (P_5) for children 12-72 months old are shown in Table A-1.

Table A-1. Matrix Showing Presentation of Various Exposure Assumptions for Evaluation by Risk Managers.

Exposure scenario	PbS_W[1] (mg/kg)	PbD_W[2] (mg/kg)	GM PbB (µg/dL)[3]	P_5 (%)[3]
Zero visits per week	50	45	1.4	0.3
1 site visit per week	329	240	3.1	14.8
2 site visits per week	607	435	4.6	42.8
4 site visits per week	1164	825	7.4	79.5

[1] PbS_W weighted soil lead concentration; calculated using Equation 1.
[2] PbD_W weighted dust lead concentration, assuming track-in; calculated using Equation 5.
[3] Results from the IEUBK model. GM = geometric mean. Residential PbS=50 mg/kg; Site PbS=2000 mg/kg. All runs using 12-72 months in IEUBK model.

As shown in Table A-1, scenarios having site exposures that occur 1 or more times per week produce risk estimates that exceed the 5% goal. Multiple iterations of the IEUBK model were run using all model defaults to identify the weighted PbS concentrations (PbS_w) corresponding to the P_5 of no more than 5% for children 12-72 months of age (residential PbS was held at 50 mg/kg). Equation 7 was then used to calculate cleanup goals corresponding to the three use patterns. These cleanup goals are summarized in Table A-2. For exposure scenarios in which site visits occurred on 1, 2, or 4 days per week, the risk-based soil goals were 1100, 550, and 300 mg/kg, respectively as calculated by Equation 8.

Table A-2. Matrix Showing Possible Site Cleanup Goals Based on Various Exposure Assumptions.

Exposure Scenario	PbS_W[1] (mg/kg)	PbD_W[2] (mg/kg)	GM PbB (µg/dL)[3]	P_5 (%)[3]
1 site visit per week PbS site = 1100 mg/kg	200	150	2.3	4.98
2 site visits per week PbS site = 550 mg/kg	200	150	2.3	4.98
4 site visits per week PbS site = 300 mg/kg	200	150	2.3	4.98

[1] PbS_W = target soil lead concentration associated with a risk goal of P5 (5% probably of not exceeding a PbB of 5 µg/dL) assuming no site-specific RBA; calculated in the IEUBK model "Find Soil Pb Concentration" for an age group of 12-72 months.
[2] PbD_W weighted dust lead concentration assuming track-in from the site; calculated using Equation 5.
[3] Results from the IEUBK model. GM = geometric mean. Residential PbS held at 50 mg/kg. All runs using 12-72 months in IEUBK model.

EXAMPLE 2: RECREATIONAL & TRESPASSING EXPOSURE SCENARIO

The site in this scenario is a slag pile in an area where the use is assumed to be primarily industrial and commercial. Although the site does not contain a developed recreational area, the slag pile is an attractive nuisance and children have been observed dirt biking on the hill. The goal of the soil cleanup level is to minimize lead exposure for children who would visit the site during the warmer months for recreation or possibly trespassing.

The State standard for non-residential areas is 1000 mg/kg for lead. This soil lead concentration was used to evaluate the possible impacts of child exposure. It was averaged with a default residential soil lead concentration of 100 mg/kg, based on the assumption that 30% of soil ingested would be from the site and 70% from the home, yielding a PbS_W of 370 mg/kg ([100 mg/kg × 70%] + [1000 mg/kg × 30%]). This weighted concentration was not averaged over the entire year, since exposures were expected to occur for only part of the year (4 continuous months). In all cases, other model inputs were kept at default values, including soil ingestion rates ($PbD_W = 0.7 * PbS_W$ + [100 × air lead concentration of 0.1 $\mu g/m^3$]). Note that for simplicity, these calculations assume that total soil ingestion occurs at the default rate.

In addition to typical residential exposure to lead in soil, it was expected that dirt biking would result in additional soil ingestion. The assumption that 10% of waking hours (1.2 hours/12 hours) could be spent at the site was incorporated into the calculations to inform additional 10% of typical total dirt ingestion would occur at the site due to the intensity of the exposure (dirt biking is a dusty activity that would be expected to result in additional soil-dust intake beyond the default assumption).

The following assumptions were made in running the IEUBK model:

1. Site exposure would include an additional 10% of typical total dirt ingestion.
2. Daily lead intake over the 4 months was averaged over 12 months for input to the IEUBK model.
3. An exposure period of 112 days/year was selected (7 days/week for 16 weeks).

4. Residential exposure was characterized by the IEUBK default exposure levels since no site-specific data for the residence were available. This is appropriate for 0-11 month age children, because they are not expected to have significant contact with site soil based on the likely exposure pathway.

To evaluate the possible impact of soil ingestion assumptions and in the absence of site-specific information concerning soil ingestion, various soil ingestion assumptions were explored to bound the results. For the purposes of this assessment, the default total soil ingestion rates were used to bound the low-exposure scenario. Because of the potential for higher contact rates with soil at the site, additional contact-intensive scenarios are also warranted. A low-exposure scenario using the IEUBK model defaults was chosen. For a medium-exposure scenario, the total dirt ingestion rates would be 145% of default rates. For a high-exposure scenario, an additional 200 mg/day was used. The various exposure assumptions are shown in Table A-3.

Table A-3. Calculation of a Plausible Range of Dirt (soil/dust) Ingestion Rates for Site to Bound Risk Estimates When Site-Specific Soil Ingestion is Unknown.

Age group (months)	Total dirt ingestion rates (g/day)		
	Low exposure scenario	Medium exposure scenario	High exposure scenario[2]
	Total=default	Total=145% of default total	Total=0.200 g/day + default
0-11[1]	0.086	0.086	0.086
12-24	0.094	0.136	0.294
24-36	0.067	0.097	0.267
36-48	0.063	0.091	0.263
48-60	0.067	0.097	0.267
60-72	0.052	0.075	0.252
72-84	0.055	0.080	0.255

[1] Additional soil contact is not applicable to children <1 year, since they are not likely to have significant additional exposure to site soil.
[2] The high exposure scenario is based on adding 200 mg/day to the default ingestion rates, consistent with OLEM guidance on assessing risk for Reasonably Maximally Exposed (RME) individuals (U.S. EPA, 1989).

Since daily exposure to lead in soil for 4 months is expected to produce a pseudo-steady-state PbB concentration, the daily average soil concentration over the 4-month period for this application is the most relevant input to the IEUBK model. Use of an annualized daily concentration does not allow for estimating the body burden that results during sustained shorter periods of relatively higher exposure. Thus, the TRW expects a serious underestimation of the actual PbB distribution to result from averaging the site exposure over the entire year. However, IEUBK predictions using the average daily exposure level for a 4-month period might be expected to be somewhat of an overestimate, since the model was designed to project PbB concentrations from sustained daily exposure over the first 84 months of childhood. This built-in assumption of sustained, chronic daily exposure does not allow for a wash-out period between the annual 4-month exposures, which would be associated with the exposure scenario for this site. EPA generally anticipates that there will be some seasonal fluctuation of exposure conditions. IEUBK predictions are therefore expected to approximate the PbB concentrations related to the higher lead exposure levels in an annual cycle of lead exposure, where measured lead concentrations in soil are expected to remain relatively constant.

This matrix (Table A-4) demonstrates to the risk manager that the State Applicable or Relevant and Appropriate Requirements (ARAR) is not protective for these exposure scenarios, as even the low exposure scenario, not accounting for additional soil ingestion from dirt bike riding, results in exceedance of the target risk benchmark at all child age ranges.

Table A-4. Risk Estimates for the Various Alternate Soil Ingestion Scenarios Using Each Age Group in the IEUBK Model Using Daily Average Soil Concentration over the 4-Month Period.

Age group (months)	Risk estimates for each ingestion scenario[1]					
	Default (low)		Medium		High	
	GM PbB (µg/dL)	P_5 (%)	GM PbB (µg/dL)	P_5 (%)	GM PbB (µg/dL)	P_5 (%)
0-12	4.4	38.5	4.4	38.5	4.4	38.5
12-24	4.5	40.7	5.5	58.6	9.0	89.6
24-36	3.4	21.4	4.4	39.8	8.8	88.6
36-48	3.0	13.9	3.8	28.5	8.2	85.5
48-60	2.9	12.8	3.7	26.8	8.0	84.0
60-72	2.6	8.2	3.3	18.4	7.5	80.3
72-84	2.4	5.5	3.0	13.4	7.0	75.9

[1] IEUBK inputs were PbS_W = 370 mg/kg and PbD_W = 269 (using Equation 5). All others were default. GM = geometric mean. P_5 = probability of exceeding 5 µg/dL.

EXAMPLE 3: DAYCARE EXPOSURE SCENARIO FOR INDUSTRIAL PARK DAYCARE

The site in this scenario is a proposed daycare facility in an area that is zoned for industrial and commercial land use. The goal is to determine whether the proposed soil cleanup for the site (700 mg/kg) is protective of children exposed at the proposed daycare facility.

The following assumptions were considered plausible:

1. Children may be exposed to lead in exterior soil and interior dust both at the daycare facility as well as at home (located outside the site).
2. The concentration of lead in exterior soil at the daycare facility is 700 mg/kg, the proposed cleanup level for the site.
3. A child visits the daycare facility 5 days per week and stays home 2 days per week. This exposure occurs for at least 3 consecutive months.[2]
4. Site sampling indicates a mean residential soil concentration of 100 mg/kg.

The media concentrations for each location are used to derive time-weighted average concentration across all locations based on the number of days per week at each location. The calculated time-weighted average soil and dust concentrations can be entered directly into the IEUBK model. Deriving a weighted soil concentration from home and daycare (Equation 5):

$$PbS_w = (5/7 \times 700 \text{ mg/kg}) + (2/7 \times 100 \text{ mg/kg})$$
$$PbS_w = (500 \text{ mg/kg}) + (28.6 \text{ mg/kg})$$
$$PbS_w = 528.6 \text{ mg/kg}$$

The estimated ratios of indoor dust lead concentration are applied to soil lead concentration (IEUBK default for M_{sd} is 0.7). Because the residences were relatively new homes, lead-based paint was not expected to contribute to indoor dust.

Example for weighted dust concentration from home and daycare:

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[2] Because of the exposure model averaging time in the IEUBK Model, the 3-month duration exposure is treated as if it occurred across the entire year and the exposure is not time-averaged across an entire year since this would underestimate the blood leads occurring during the more limited periods of elevated exposure, i.e., the day care period (Lorenzana et al., 2005).

$$PbD_w = PbS_w \times M_{sd} + (100 \times \text{air lead concentration})$$
$$PbD_w = 528.6 \text{ mg/kg} \times 0.7 + (100 \times 0.1)$$
$$PbD_w = 380 \text{ mg/kg}$$

According to the IEUBK model, for the 12-72- month age range, these weighted concentrations result in a GM PbB of 4.2 µg/dL and a P_5 of 35%. These results indicate that the proposed soil lead concentration at the daycare facility (700 mg/kg) would not be protective of children.

EXAMPLE 4: INTERMITTENT NON-RESIDENTIAL EXPOSURE FOR ADULTS

The following example shows how the ALM can be used to assess risk posed by lead contamination at a non-residential site under two different exposure scenarios. The site soil lead concentration is 500 mg/kg indoors and 1000 mg/kg outdoors. In this example, a utility worker is laying new line at a contaminated site. The new line is expected to take 3 days/week for 13 weeks during the year. The worker is otherwise employed indoors at the site for the other 2 days of the week. Site data suggest that the worker is involved in contact-intensive jobs both indoors (sweeping) and outdoors (digging); thus, a site-specific soil central tendency ingestion rate of 100 mg/day is appropriate for both indoors and outdoors.

To calculate the time-weighted soil concentration to which the worker is exposed, the following equation applies (Equation 1):

$$PbS_W = (PbS_{Indoors} \times EF_{Indoors}) + (PbS_{Outdoors} \times EF_{Outdoors})$$
$$PbS_W = (500\ mg/kg \times 2\ days/7\ days) + (1000\ mg/kg \times 3\ days/7\ days)$$
$$PbS_W = 142.8\ mg/kg + 428.6\ mg/kg$$
$$PbS_W = 571\ mg/kg$$

This PbS_W can then be entered into the ALM with the following changes:

- Averaging time (AT) = 91 days (13 weeks × 7 days/week).
- Exposure frequency (EF) = 65 days (13 weeks × 5 days/week).
- Site-specific soil ingestion rate of 100 mg/day for both indoors and outdoors.
- Baseline PbB_0 and GSD for the range of inputs were selected from Analysis of NHANES 2013-2018.

Note that residential exposure to lead is not reflected in this time weighting calculation, since the residential contribution is reflected in baseline blood lead. To assess residential lead contamination, the IEUBK model should be used. The ALM would be run as shown in Table A-5. The P_5 is 10.2% for this group, which exceeds the 5% EPA goal. This suggests that the outdoor soil lead concentration of 1000 mg/kg at this site is not protective under the conditions described.

Table A-5. ALM Inputs and Results for the Utility Worker Exposure Scenario Using Time-Weighted Average Soil Lead Concentration.

Exposure variable	Description of exposure variable	Units	Inputs
PbS	Soil lead concentration	µg/g or mg/kg	571
$R_{fetal/maternal}$	Fetal/maternal PbB ratio	--	0.9
BKSF	Biokinetic slope factor	µg/dL per µg/day	0.4
GSD_i	Geometric standard deviation PbB	--	1.9
PbB_0	Baseline PbB	µg/dL	0.5
IRS	Soil ingestion rate (including soil-derived indoor dust)	g/day	0.1
$AF_{S, D}$	Absorption fraction (same for soil and dust)	--	0.12
$EF_{S, D}$	Exposure frequency (same for soil and dust)	days/year	65
$AT_{S, D}$	Averaging time (same for soil and dust)	days/year	91
RESULTS			
PbB_{adult}	PbB of adult worker, geometric mean	µg/dL	2.5
$PbB_{fetal, 0.95}$	95th percentile PbB among fetuses of adult workers	µg/dL	6.4
PbB_t	Target PbB level of concern (e.g., 10 µg/dL)	µg/dL	5
$P(PbB_{fetal} > PbB_t)$	Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	10.2%

EXAMPLE 5: LAWN MAINTENANCE NEAR A RIVER

For a lead-contaminated site (mean soil lead concentration at the site is 2000 mg/kg) located along a river, the most likely future use of the property was lawn mowing and other minor groundskeeping activities. This scenario was not envisioned as including soil-intensive activities due to the extensive ground cover at the site, so it assumes a central tendency soil ingestion of 50 mg/day (U.S. EPA, 1997). For the ALM, the central tendency value would be appropriate. The goal is to develop PRG for the site based on the most likely receptor, the lawn maintenance worker. The PRG spreadsheet of the ALM model may be used with the following changes.

Based on current activities at this site, it was assumed that the lawn would be mowed for three days out of the week for seven months of the year. Because of vagaries in the Gregorian calendar and for consistency with lead biokinetic models (as explained in section 3.1 of the text), risk can be assessed as a time-weighted average soil concentration based on 3 days of exposure out of 7 days. Alternately, the exposure could be expressed as an exposure frequency (EF) of 90 (3 days/week × 4.3 weeks/month × 7 months) days and an averaging time (AT) of 211 (7 days/week × 4.3 weeks/month × 7 months) days. In the EF/AT relationship, the factors of 4.3 weeks/month and 7 months drop out in the calculation, resulting in an EF of 3 and an AT of 7 for the spreadsheet.

The exposure scenario specified at this site, using the ALM, results in 7 months of exposure (3 times per week) and 5 months of “washout” when no excess site-related lead exposure occurs (see Figure 2 of the text). In determining whether the “washout” period should be considered in the risk calculation, a determination must be made whether the duration of site exposure could reasonably produce a body burden of lead that results in an adverse health effect. In this example, 7 months of exposure would satisfy the minimum exposure duration to achieve a quasi-steady state PbB concentration (13 consecutive weeks). Moreover, this exposure duration would also likely be sufficient time for a body burden of lead to develop that would be associated with adverse health effects. Therefore, a plausible risk calculation for this site would be based on 3 days of exposure out of 7 days as if the exposure occurred for the entire year and ignores the effect of the 5 months of the year when site exposure does not occur. This can also be interpreted as follows: the increase in blood lead concentration during the exposure season is the basis for the risk calculation, and the "washout" period is not considered in the calculation of the PRG.

To calculate the time-weighted soil concentration to which the lawn worker is exposed, the PRG spreadsheet of the ALM is used with the following changes (see Table A-6):

- Averaging time (AT) = 7.
- Exposure frequency (EF) = 3.
- Site-specific soil ingestion rate (IRS) of 50 mg/day for both indoors and outdoors.
- Other parameters set as specified in the ALM Guidance.
- Baseline PbB_0 and GSD for the range of inputs were selected from Analysis of NHANES 2013-2018.

Note that residential exposure to lead is not reflected in this time weighting calculation, since the residential contribution is reflected in baseline blood lead. To assess residential lead contamination, the IEUBK model should be used. This information can be entered into the spreadsheets provided for the calculation of blood lead or preliminary remediation goals (PRGs). For a site where it is assumed that the population has a high baseline blood lead concentration and a high geometric standard deviation of the blood lead, the PRG value was 1393 mg/kg (see Table A-6). In this case, a decision was made to average exposure during the quasi-steady state period (exposure season) and consider this as if it occurred throughout the year, ignoring the "washout" period. This is a reasonably conservative approach for the site.

Table A-6. ALM Inputs and Results for the Lawn Maintenance Worker Exposure Scenario (#1) Using ALM PRG Spreadsheet.

Exposure variable	Description of exposure variable	Units	Inputs
$PbB_{fetal, 0.95}$	95th percentile PbB among fetuses of adult workers	μg/dL	5
$R_{fetal/maternal}$	Fetal/maternal PbB ratio	--	0.9
BKSF	Biokinetic slope factor	μg/dL per μg/day	0.4
GSD_i	Geometric standard deviation PbB	--	1.9
PbB_0	Baseline PbB	μg/dL	0.5
IR_S	Soil ingestion rate (including soil-derived indoor dust)	g/day	0.05
$AF_{S, D}$	Absorption fraction (same for soil and dust)	--	0.12
$EF_{S, D}$	Exposure frequency (same for soil and dust)	days/week	3
$AT_{S, D}$	Averaging time (same for soil and dust)	days/week	7
PRG	Preliminary Remediation Goal	mg/kg	1393

IR_S = Intake rate of soil, and outdoor soil derived dust.

$EF_{S,D}$ = Exposure frequency for contact with assessed soils and/or dust derived in part from these soils. In this example, based on 3 days/week × 4.3 weeks/month × 7 months.

$AT_{S,D}$ = Averaging time; the total period during which soil contact may occur. Based on 7 days/week × 4.3 weeks/month × 7 months.

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