



EPA-540-R-03-008
OSWER # 9285.7-76

ASSESSING INTERMITTENT OR VARIABLE EXPOSURES AT LEAD SITES

Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Washington, DC 20460

**U.S. ENVIRONMENTAL PROTECTION AGENCY
TECHNICAL REVIEW WORKGROUP FOR LEAD**

The Technical Review Workgroup for Lead (TRW) is an interoffice workgroup convened by the U.S. EPA Office of Solid Waste and Emergency Response/Office of Superfund Remediation and Technology Innovation (OSWER/OSRTI).

CO-CHAIRPERSONS

Region 8
Jim Luey
Denver, CO

NCEA/Washington
Paul White

MEMBERS

Region 1
Mary Ballew
Boston, MA

NCEA/Washington
Karen Hogan

Region 2
Mark Maddaloni
New York, NY

NCEA/Cincinnati
Harlal Choudhury

Region 4
Kevin Koporec
Atlanta, GA

NCEA/Research Triangle Park
Robert Elias

Region 5
Patricia VanLeeuwen
Chicago, IL

OSRTI Mentor
Larry Zaragoza
Office of Superfund Remediation and Technology
Innovation
Washington, DC

Region 6
Ghassan Khoury
Dallas, TX

Executive Director
Richard Troast
Office of Superfund Remediation and Technology
Innovation
Washington, DC

Region 7
Michael Beringer
Kansas City, KS

Associate
Scott Everett
Department of Environmental Quality
Salt Lake City, UT

Region 10
Marc Stifelman
Seattle, WA

TABLE OF CONTENTS

1.0 SUMMARY	5
2.0 INTRODUCTION	6
2.1 APPROPRIATE USES OF THE TIME-WEIGHTED APPROACH	9
3.0 TIME WEIGHTING EXPOSURE	10
3.1 SIMPLE TIME WEIGHTING	11
3.2 VARYING INTENSITY OF EXPOSURE	12
3.3 MATRIX APPROACH FOR EVALUATING EXPOSURE ASSUMPTIONS	15
3.4 CALCULATING A PRELIMINARY REMEDIATION GOAL (PRG)	16
4.0 APPLICATIONS OF THE APPROACH WITH THE IEUBK	19
4.1 CONTRIBUTION OF TRACKED-IN SOIL	20
4.2 APPLICABILITY OF THE APPROACH TO VARIOUS AGE GROUPS	21
4.2.1 CHILDREN 0-84 MONTHS	21
4.2.2 ADOLESCENTS	22
4.2.3 ADULTS	23
4.3 SEASONAL VARIABILITY IN LEAD EXPOSURE AND PbB	23
4.4 INCREASED SOIL INGESTION (INCREMENTAL APPROACH)	24
5.0 AIR PATHWAY	26
6.0 UNCERTAINTIES IN THE APPROACH	27
6.1 UNCERTAINTIES IN ASSUMPTIONS REGARDING SOIL INTAKE AND ABSORPTION	28
6.2 UNDERESTIMATION OF PEAK PbB	28
6.3 UNCERTAINTY IN HEALTH EFFECTS FROM ACUTE, HIGH-LEVEL EXPOSURES	30
6.4 SEASONAL VS. ANNUAL EXPOSURE	30
APPENDIX A	31
EXAMPLE 1: RECREATION EXPOSURE SCENARIO FOR PARK	32
EXAMPLE 2: RECREATIONAL & TRESPASSING EXPOSURE SCENARIO	34
EXAMPLE 3: DAYCARE EXPOSURE SCENARIO FOR INDUSTRIAL PARK DAYCARE	37
EXAMPLE 4: INTERMITTENT NON-RESIDENTIAL EXPOSURE FOR ADULTS	39
EXAMPLE 5: SEASONAL EXPOSURE: CHILDREN VISITING A SITE 4 MONTHS OF THE YEAR	41
EXAMPLE 6: LAWN MAINTENANCE NEAR A RIVER	43
REFERENCES	46

1.0 SUMMARY

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 secondary locations where media concentrations differ from the residential scenario (*e.g.*, daycare or other caregiver, agricultural work [farming on contaminated land, as well as farming with agrichemicals that contain lead]). In this context, location means any area where media concentrations differ.
- Exposure at neighboring parks or play areas.
- Less frequent exposure connected with recreational or other site visits (more relevant, but perhaps not limited, to older children). These may include:
 - Recreational activity on and around lead sources: contaminated sediments, waste piles, *etc.*
 - Visiting and trespassing scenarios on contaminated site properties.

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), respectively. Instead, this methodology is intended to be used when certain criteria are satisfied. These criteria are illustrated in Figure 1. Because this approach is supplemental to the typical residential approach for the IEUBK model (children 0-84 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 guidance.

This document presents general guidance for many typical scenarios involving intermittent, non-residential exposure to lead sites. This guidance is not a regulation itself, nor does it change or substitute for any regulations. Thus, it does not impose legally binding requirements on EPA, States, or the regulated community. This guidance does not confer legal rights or impose legal obligations upon any member of the public. Interested parties are free to raise questions and objections about the substance of this guidance and the appropriateness of the application of this guidance to a particular situation. 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 (<http://www.epa.gov/superfund/programs/lead>).

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, 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 cumulative 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. 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, if the exposure level or soil ingestion rate at the secondary location is higher than that at the residence. 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 duration of 3 consecutive months (U.S. EPA,

1994). Three months is considered to be the minimum exposure to produce a quasi-steady-state PbB concentration. The reliability of the models for predicting PbB concentrations for exposure durations shorter than 3 months has not been assessed.

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). 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 cumulative risks from 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 and 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 several possible alternative scenarios to characterize worst case or upper bound estimates, as well as central tendency risk estimates. Additional complexity can be added to site-exposure scenarios if needed; contact the TRW for more information.

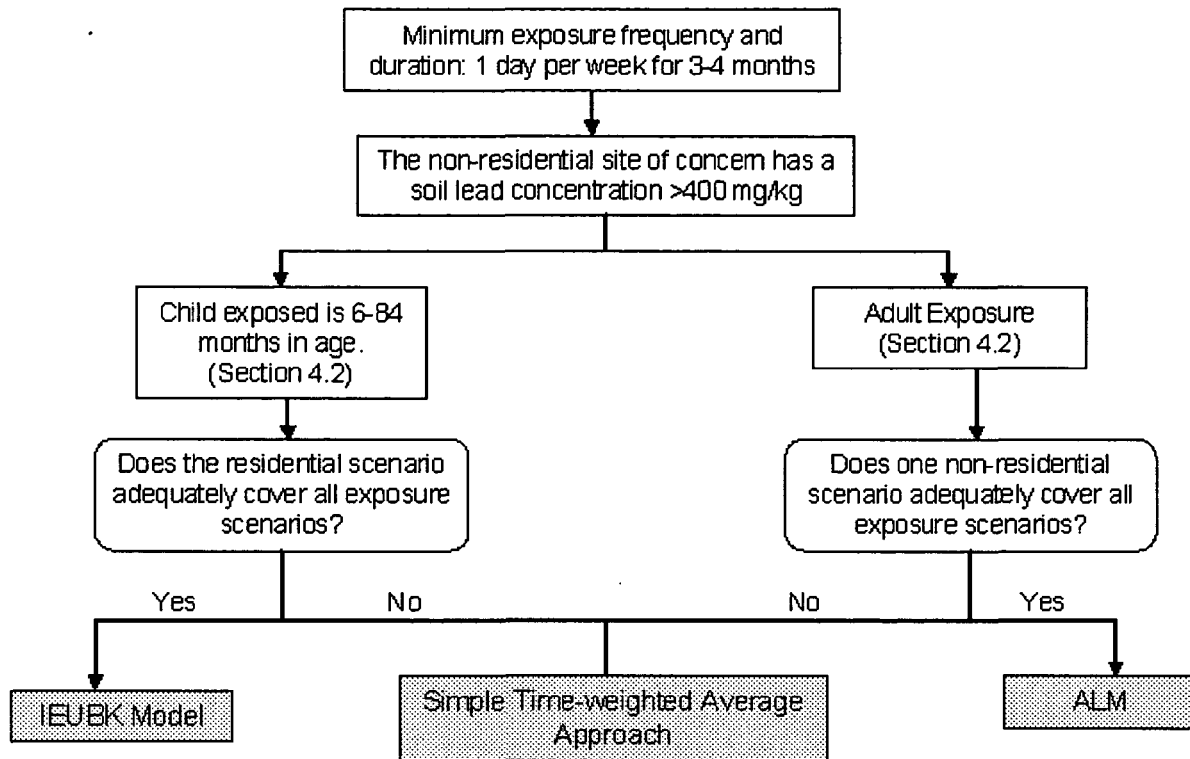


Figure 1. Decision tree for determining the appropriate approach to assess cumulative lead risk from one or more locations.

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 as long as 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. 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 exposure to assess a non-residential exposure in combination with the residence. Time weighing approaches should only be used in the ALM to assess exposures to two or more non-residential locations.

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 3 months as the minimum duration of exposure that is appropriate for modeling exposures that occur no less often than once 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 3 months 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 that occurs each year over a period

of 3 months, the time-weighted exposure inputs would not be further adjusted to account for the exposure period of 90 days per year (see Example 6 in Appendix).

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 3 months 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 3-month 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.

When using the IEUBK model to evaluate short-term continuous exposure of no less than 3 months, 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 3 months of exposure to a given level of lead. It has not been validated 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

The input menus of the IEUBK model and the ALM are somewhat limited for scenarios in which exposures to soil lead from multiple sites occur. The IEUBK input menus for "school", "dust", and "other" assume that exposure to soil from these sources is continuous, and do not

permit the user to assess intermittent exposures from multiple locations. The TRW recommends that, for reasons of feasibility and maximum clarity, separate calculations be made up front (*i.e.*, outside the model) to obtain appropriately weighted average concentrations of soil lead. These average values can then be entered directly into the model as fixed media concentrations. Calculation of the time-averaged 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 assumptions should be stated clearly and reflect plausible estimates of the typical exposure scenarios. The 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. The soil concentrations are weighted based on the estimated fraction of total soil ingestion that occurs at the residence and at the site. Equation 1 shows the fundamental equation for time-weighting exposures to soil from the residence and a secondary location.

$$\text{Weighted PbC}_{\text{medium}} = \sum_{i=1}^n C_i \cdot EF_i \quad \text{Equation 1}$$

where:

Weighted PbC_{medium} = Weighted lead concentration in medium (ppm).

C_i = Media concentration at location *i* (in this case, *i*= *residential yard* or *secondary location*) (*e.g.*, ppm).

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.

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 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 x 4.3 weeks/month x 7 months) (see Example 6 in

Appendix). Although the differences in predicted PbB, in this case, 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. As a *rule of thumb*, the latter will be achieved if the time-weighting factor is the number of exposure events within the event period cycle:

$$TWA = C \times N_p \div P \quad \text{Equation 2}$$

where:

C = Exposure concentration.

N_p = Number of exposure events within the exposure event period.

P = Event period.

While Equation 1 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 waking hours to derive weighted estimates for media concentration. For example, in a 24-hour period, a child's activities might include 12 hours of sleep during the night, and an 8- to 10-hour stay at a daycare facility, with the remaining hours spent awake at home. In this example, roughly 45% (8 to 9 hours per day x 5 days/week = 40 to 45 hours/week at daycare and 12 hours/day x 7 days per week = 84 hours/week) of the child's total waking hours may be spent at daycare. This time-estimate of 45% of a child's waking hours at daycare as compared to waking hours spent at home would then be used to derive a weighted

soil lead concentration based on the child's exposure to daycare soils and home soils. The fraction of soil dust exposure at each location may be calculated as shown in Equation 3.

$$f_i = \frac{\text{Waking hours at location}}{\text{Total waking hours}} \quad \text{Equation 3}$$

where:

f_i = Fraction of total dust and soil exposure that occurs at location i .

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). Equations 4, 5, and 6 show how fractional exposure at each location can be used to derive time-weighted estimates for soil and dust.

The TRW recommends that dust samples be collected at both locations for such calculations. If this is not possible (*e.g.*, if the assessment is for a proposed future use), an estimate of the composite residential indoor soil-derived dust (PbD) concentration may be derived using the default soil-to-dust mass transfer parameter if it is reasonable to assume that the site-specific conditions permit using the default mass transfer rate (M_{sd}) to apply to the situation. 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 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:

$$\text{Weighted } PbC_{\text{medium}} = \sum_{i=1}^n C_i \cdot f_i \quad \text{Equation 4}$$

where:

Weighted PbC_{medium} = Weighted lead concentration across all exposure locations (ppm).

C_i = Lead concentration for the medium at each location (ppm).

f_i = Fraction of time spent at each location (hours/day or days/week).

Example for weighted soil concentration from home and daycare:

$$PbS_w = (PbS_i \times f_i) + (PbS_j \times f_j) \quad \text{Equation 5}$$

where:

PbS_w = Weighted soil lead concentration across all exposure locations (ppm).

PbS_i = Soil lead concentration for each location (i = home; j = daycare) (ppm).

f_i = Fraction of time spent at each location (i =home; j = daycare) (hours/day or hours/week).

Example for weighted dust concentration from home and daycare using multi-source analysis:

$$PbD_w = (PbS_{w\text{daycare}} \times M_{sd\text{daycare}}) + (PbS_{w\text{home}} \times M_{sd\text{home}}) \quad \text{Equation 6}$$

where:

PbD_w = Weighted dust lead concentration (ppm).

$PbS_{w\text{daycare}}$ = Weighted soil lead concentration from daycare (ppm).

$M_{sd\text{daycare}}$ = Soil to dust mass transfer parameter (unitless).

$PbS_{w\text{home}}$ = Weighted soil lead concentration from residence (ppm).

$M_{sd\text{home}}$ = 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 sites (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 site.

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).

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 within a range of waking hours 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 is provided in Table 1.

Table 1. Matrix Showing Impact of Various Exposure Assumptions (Number of Site Visits per Week) on Model Predicted Blood Lead Concentration (PbB) and Probability of Exceeding 10 µg/dL (P₁₀).

Exposure scenario	PbS _w ¹	PbD _w ²	GM PbB (µg/dL) ³	P ₁₀ (%) ³
Zero visits per week (residential only scenario)	100	70	2.5	0.1
1 site visit per week	171	120	3.1	0.6
2 site visits per week	242	169	3.7	1.8
3 site visits per week	314	220	4.3	3.8
4 site visits per week	386	270	4.9	6.6
5 site visits per week	458	321	5.5	10.2
6 site visits per week	528	370	6.1	14.3
7 site visits per week	600	420	6.6	18.9
¹ PbS _w = weighted soil lead concentration; calculated using Equation 1. Residential PbS=100 ppm; site PbS=600 ppm. ² PbD _w = weighted dust lead concentration; calculated using Equation 5. ³ Results from IEUBK model. GM= geometric mean. All other parameters were set to IEUBK default values. All runs using 0-84 months in IEUBK model. (Exposure continued throughout the 84-month period.)				

The example in Table 1 shows that 3-4 site visits per week result in PbB concentrations and P₁₀ 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 the risk assessment.

3.4 Calculating a Preliminary Remediation Goal (PRG)

The current version of the IEUBK model does not automatically back-calculate environmental lead levels. 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). However, a risk-based target site concentration can be back-calculated from a site-specific model estimate of the overall soil lead concentration associated with a 5% individual risk 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 is expected to be more conservative than time weighting the exposures.

Equations 7 and 8 illustrate how the weighted values can be used to derive a cleanup goal based on average soil lead concentration at the site. The time-weighting equation (Equation 1) can be expanded to explore site soil concentrations that are risk protective:

$$PbS_w = EF_{site} \times [(f_{site} \times PbS_{site}) + (f_{yard} \times PbS_{yard})] + (EF_{yard} \times PbS_{yard}) \quad \text{Equation 7}$$

where:

PbS_{site} = Average soil lead concentration at an exposure unit on the site (ppm).

PbS_w = Weighted soil lead concentration (ppm).

PbS_{yard} = Average soil lead concentration near home (ppm).

f_{yard} = Fraction of daily outdoor time at local background soil lead concentration (usually near home) = $1 - f_{site}$ (dimensionless).

EF_{site} = Exposure frequency expressed as fraction of the days/week child visits the secondary location during the exposure period.

EF_{yard} = Exposure frequency expressed as fraction of the days/week child does not visit the secondary location during the exposure period = $1 - EF_{site}$.

f_{site} = Fraction of daily outdoor time spent at the secondary location on days when the site is visited (dimensionless).

Equation 7 may be rearranged to solve for average soil lead concentration at the site. Starting with the Office of Solid Waste and Emergency Response (OSWER) soil lead screening concentration of 400 ppm (associated with a 5% individual risk of elevated PbB when the model defaults are relevant) for PbS_w , a soil lead concentration for the site can be derived that is protective of human health:

$$PbS_{site} = \frac{PbS_w - PbS_{yard} \times [(f_{yard} \times EF_{site}) + EF_{yard}]}{EF_{site} \times f_{site}} \quad \text{Equation 8}$$

It is important to recognize that apportioning cleanup across two or more locations is a risk management decision and not solely a risk assessment decision. Consequently, the TRW suggests that the matrix approach be used to present the range of cleanup options that are health

protective. Table 2 illustrates how various cleanup options and exposure assumptions may be presented to risk managers.

Table 2. Example of Various Exposure Assumptions and Associated Risk Estimates for Presentation to Risk Managers.

Options	Exposure assumption	PbS _w ¹	PbD _w ²	GM PbB ³ (μg/dL)	P ₁₀ (%) ³	Site PRG (ppm) ⁴
1: Site PbS=700 Residence PbS=100	3 site visits per week	357	250	4.7	5.4	676
2: Site PbS=400 Residence PbS=100	5 site visits per week	315	220	4.3	3.8	445
3: Site PbS=300 Residence PbS=100	6 site visits per week	271	189	4.0	2.4	388
¹ PbS _w = weighted soil lead concentration; calculated using Equation 1. ² PbD _w =weighted dust lead concentration; calculated using Equation 5. ³ Results from IEUBK model. GM=geometric mean. All other parameters were set to IEUBK default values. All runs using 0-84 months in IEUBK model. (Exposure continued throughout the 84-month period.) ⁴ Preliminary remediation goal (PRG) for the site. Note that PRGs are typically rounded to the nearest 50 or 100 ppm. The residential soil lead concentration of 100 ppm was unchanged.						

A matrix approach is a useful way to demonstrate to risk managers the health protectiveness of PRGs under various exposure assumptions (Table 2). The OSWER 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 site soils to interior house dust lead when older siblings trespass on the site 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. In such cases, a higher fraction of ingestion would appropriately be attributed to the site than would be suggested by a calculation based on just apportionment of total waking hours (Section 4.4).

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 the trespasser exposure scenario. For instances where there is a strong possibility of trespassing on the site (generally non-residential), one should consider the potential for older children tracking site soils 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. 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 site 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 site in comparison with a residential yard. On the other hand, more intense or sustained play and sporting activities at the site could result in larger “loading” of soil on the children (or adults) that could be tracked into the home. Activities at the site, 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 actually 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 site 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 site 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 + site) is attributed to soil coming from the site, then it is probably appropriate to assume that no more than 20% of the interior dust comes from the site.

4.2 Applicability of the Approach to Various Age Groups

4.2.1 Children 0-84 months

Younger children may not be expected to visit a site; 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 site can have exposure to soil brought home from the site 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.

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. When running the

IEUBK model, one can model six exposure patterns, each with a different 1-year age range of exposure to the composite PbS_w , and each having all other age ranges at the default residential levels. For example, exposure at the site during 1 year can be considered for each of six different age groups: 12-24, 24-36, 36-48, 48-60, 60-72, and 72-84 months. An example of this approach is shown in Table 3.

Table 3. IEUBK Model Risk Estimates for Various Age Groups. Estimated Geometric Mean (GM) PbB and Probability of PbB >10 $\mu\text{g/dL}$ (P_{10}) Based on IEUBK Model Simulations of Weighted Average Exposures to Site and Residential Soils¹

Age range (months)	1 site visit/week $PbS_w^2 = 460 \text{ ppm}$ $PbD_w^3 = 322 \text{ ppm}$		2 site visits/week $PbS_w = 910 \text{ ppm}$ $PbD_w = 637 \text{ ppm}$		4 site visits/week $PbS_w = 1809 \text{ ppm}$ $PbD_w = 1267 \text{ ppm}$	
	GM PbB ⁴ ($\mu\text{g/dL}$)	P_{10} (%)	GM PbB ($\mu\text{g/dL}$)	P_{10} (%)	GM PbB ($\mu\text{g/dL}$)	P_{10} (%)
0-84	5.5	10.3	8.8	39.4	14.2	77.0
0-12	5.7	11.4	8.6	37.8	13.3	72.5
12-24	6.9	21.5	11.0	58.3	17.5	88.2
24-36	6.5	17.6	10.4	53.1	16.5	85.8
36-48	6.2	15.1	10.0	49.8	16.1	84.5
48-60	5.1	7.8	8.3	34.9	13.7	74.8
60-72	4.4	4.0	7.1	23.0	11.7	63.2
72-84	3.9	2.4	6.3	16.1	10.4	53.5
¹ $PbS_{site} = 3159 \text{ ppm}$, $PbS_{residential} = 10 \text{ ppm}$. Estimates apply to quasi-steady-state elevations in PbB concentrations during the period of exposure (<i>i.e.</i> , no “annualization” of PbS_w or PbD_w). ² PbS_w = weighted soil lead concentration; calculated using Equation 1. ³ PbD_w = weighted dust lead concentration; calculated using Equation 5. ⁴ Results from IEUBK model. GM = geometric mean. All other parameters were set to IEUBK default values. All runs using 0-84 months in IEUBK model. (Exposure continued throughout the 84-month period.)						

Table 3 shows how this approach can illustrate the impact of exposure on a most highly exposed individual, which is typically the toddler. Depending on the conditions of the site, bounding the exposures in this way may be appropriate to illustrate the possible risk to the likely receptor population.

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 (<http://www.epa.gov/superfund/programs/lead/adult.htm>). 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 site soil, 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 PbBs for adult populations exposed to a single non-residential scenario, the default (i.e., not time weighted) 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 site 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 sites 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 are 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 3 months of residency at the sampled locations, at a time of year (late summer) when soil exposure and PbB concentrations were expected to be at 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 sites 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

the site (*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, 1997).

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 site (*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.

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

Age group (months)	Total dirt ingestion rate (g/day)		
	Low scenario ingestion = IEUBK default	Medium scenario ingestion= 1.45 * IEUBK default	High scenario ingestion = 200 mg/day + IEUBK default
0-11 ¹	0.085	0.085	0.085
12-23	0.135	0.196	0.335
24-35	0.135	0.195	0.335
36-47	0.135	0.195	0.335
48-59	0.100	0.145	0.300
60-71	0.090	0.131	0.290
72-84	0.085	0.123	0.285
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 OSWER guidance on assessing risk under the Reasonable Maximum Exposure (RME) scenario.			

Table 4 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 3 months 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-averaged air lead concentrations. In the case of air, the extra exposure would be time averaged and added to exposure to the baseline air concentration which can be set as 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.

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

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 Preliminary Remediation Goal (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 the site, actual ingestion may exceed typical average values. 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 cumulative 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 deriving a time-weighted average to annualize an intermittent exposure is shown in Figure 2.

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 site exposure 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 site for a period each year, and whose added blood lead burden is eliminated during the intervening months between successive annual exposures. Illustrations of this point are presented in Examples 5 (one-year exposure) and 6 (multi-year exposure) of the Appendix. Example 6 shows how different risk management decisions or site-specific conditions can affect the risk calculation approach.

Both examples highlight 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 uses in this scenario are assumed to be primarily recreation. A proposal is being considered whereby the site would be developed as 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_{10} risk estimates for children up to age 84 months.
2. Estimate the lead concentration in site soil that would result in a 5% probability of exceeding a PbB concentration of $10 \mu\text{g/dL}$ (*i.e.*, $P_{10} \leq 5\%$).

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); exposure during the remaining waking hours of the day is indoors at the residence.
2. The lead concentrations of site and residential soil are 2000 and 50 ppm, 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 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. In particular, 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. 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 $10 \mu\text{g/dL}$ (P_{10}) for children 0-84 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 (ppm)	PbD _w ² (ppm)	GM PbB (µg/dL) ³	P ₁₀ (%) ³
Zero visits per week	50	35	1.9	0.03
1 site visit per week	329	230	4.5	4.3
2 site visits per week	607	425	6.7	19.3
4 site visits per week	1164	815	10.5	53.8
¹ PbS _w weighted soil lead concentration; calculated using Equation 1. ² PbD _w weighted dust lead concentration; calculated using Equation 6. ³ Results from the IEUBK model. GM = geometric mean. Residential PbS=50 ppm; Site PbS=2000 ppm. All runs using 0-84 months in IEUBK model.				

As shown in Table A-1, scenarios having site exposures that occur 2 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 corresponding to the P₁₀ of no more than 5% for children 0–84 months of age (residential PbS was held at 50 ppm). 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 2000, 1050, and 550 ppm, 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 (ppm)	PbD _w ² (ppm)	GM PbB (µg/dL) ³	P ₁₀ (%) ³
1 site visit per week PbS site = 2000 ppm	329	230	4.5	4.3
2 site visits per week PbS site = 1050 ppm	336	235	4.5	4.5
4 site visits per week PbS site = 550 ppm	335	235	4.5	4.5
¹ PbS _w weighted soil lead concentration; calculated using Equation 1. ² PbD _w weighted dust lead concentration calculated using Equation 5. ³ Results from the IEUBK model. GM = geometric mean. Residential PbS held at 50 ppm. All runs using 0-84 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 ppm 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 ppm, 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 ppm. 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 ($PbD_w = 0.7 * PbS_w$). 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 imply that an additional 10% of typical total dirt ingestion would occur at the site.

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 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	0.085	0.085	0.085
12-23	0.135	0.195	0.335
24-35	0.135	0.195	0.335
36-47	0.135	0.195	0.335
48-59	0.100	0.145	0.300
60-71	0.090	0.131	0.290
72-84	0.085	0.125	0.285
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 OSWER guidance on assessing risk for Reasonably Maximally Exposed (RME) individuals.			

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.

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 ₁₀ (%)	GM PbB (µg/dL)	P ₁₀ (%)	GM PbB (µg/dL)	P ₁₀ (%)
0-11	5.0	7.0	5.0	7.0	5.0	7.0
12-23	6.0	13.6	7.4	26.0	10.3	52.8
24-35	5.6	10.8	7.2	23.8	10.4	53.5
36-47	5.3	8.9	6.8	20.9	10.0	50.3
48-59	4.4	4.2	5.7	11.6	9.2	42.8
60-71	3.8	2.0	4.9	6.3	8.4	35.6
72-84	3.4	1.6	4.4	3.9	7.8	29.5
¹ IEUBK inputs were PbS _w = 370 ppm and PbD _w = 259 (using Equation 5). All others were default. GM = geometric mean. P ₁₀ = probability of exceeding 10 µg/dL.						

This matrix demonstrates to the risk manager that the State Applicable or Relevant and Appropriate Requirements (ARAR) is not protective for these exposure scenarios.

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 ppm) 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 ppm, 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.
4. Site sampling indicates a mean residential soil concentration of 100 ppm.

After estimating media concentrations for each location, the fraction of waking hours that a child spends in each location should be estimated to determine a reasonable estimate of the time-weighted average concentration across all locations. The fraction of waking hours for each location then can be used to calculate the time-weighted average soil and dust concentrations that can be entered directly into the IEUBK model.

Apportioning exposure across locations according to hours awake:

$$F_{\text{daycare}} = \frac{8 \text{ hours/day} \cdot 5 \text{ days/week}}{12 \text{ hours/day} \cdot 7 \text{ days/week}} = \frac{40}{84} = 0.48$$

Note that the equation needs to be modified to account for the hours that a child spends on different days at the location. This would be true for the home (weekday versus weekend activities); however, the home fraction can be more easily calculated by subtracting the fraction of hours spent at other locations from 1.0; thus, the remaining time spent awake at home:

$$F_{\text{home}} = (1.0 - 0.48) = 0.52$$

Deriving a weighted soil concentration from home and daycare (Equation 5):

$$\begin{aligned}PbS_w &= (PbS_{Home} \times F_{Home}) + (PbS_{Daycare} \times F_{Daycare}) \\PbS_w &= (100 \text{ ppm} \times 0.52) + (700 \text{ ppm} \times 0.48) \\PbS_w &= 52 \text{ ppm} + 336 \text{ ppm} \\PbS_w &= 388 \text{ ppm}\end{aligned}$$

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:

$$\begin{aligned}PbD_w &= PbS_w \times M_{sd} \\PbD_w &= 388 \text{ ppm} \times 0.7 \\PbD_w &= 272 \text{ ppm}\end{aligned}$$

According to the IEUBK model, these weighted concentrations result in a GM PbB of 4.9 $\mu\text{g/dL}$ and a P_{10} of 6.7%. These results suggest that the proposed soil lead concentration at the daycare facility (700 ppm) 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 ppm indoors and 1000 ppm 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):

$$\begin{aligned}\text{PbS}_w &= (\text{PbS}_{\text{Indoors}} \times \text{EF}_{\text{Indoors}}) + (\text{PbS}_{\text{Outdoors}} \times \text{EF}_{\text{Outdoors}}) \\ \text{PbS}_w &= (500 \text{ ppm} \times 2 \text{ days/7 days}) + (1000 \text{ ppm} \times 3 \text{ days/7 days}) \\ \text{PbS}_w &= 142.8 \text{ ppm} + 428.6 \text{ ppm} \\ \text{PbS}_w &= 571 \text{ ppm}\end{aligned}$$

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

Averaging time (AT) = 91 days (13 weeks x 7 days/week).

Exposure frequency (EF) = 65 days (13 weeks x 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 NHANES III analysis to span the range from all races/ethnic groups in the U.S. to the Mexican American group in the U.S.

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 results suggest a range of P_{10} values for the fetus depending on the site conditions (GSD for homogeneous or heterogeneous site exposure histories of the population at the site). Because the site workers are anticipated to reflect people from throughout a varied community, a heterogeneous GSD (2.3) would be appropriate to protect the most sensitive population. The P_{10}

is 4.4% for this group, which is less than the 5% EPA goal. This suggests that the outdoor soil lead concentration of 1000 ppm at this site would be 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 ppm	571	571
Rfetal/maternal	Fetal/maternal PbB ratio	--	0.9	0.9
BKSF	Biokinetic slope factor	µg/dL per µg/day	0.4	0.4
GSDi	Geometric standard deviation PbB	--	2.1	2.3
PbB0	Baseline PbB	µg/dL	1.5	1.7
IRS	Soil ingestion rate (including soil-derived indoor dust)	g/day	0.1	0.1
AFS, D	Absorption fraction (same for soil and dust)	--	0.12	0.12
EFS, D	Exposure frequency (same for soil and dust)	days/year	65	65
ATS, D	Averaging time (same for soil and dust)	days/year	91	91
RESULTS				
PbBadult	PbB of adult worker, geometric mean	µg/dL	2.5	2.7
PbBfetal, 0.95	95th percentile PbB among fetuses of adult workers	µg/dL	7.6	9.5
PbBt	Target PbB level of concern (e.g., 10 µg/dL)	µg/dL	10	10
P(PbBfetal > PbBt)	Probability that fetal PbB > PbBt, assuming lognormal distribution	%	2.2%	4.4%

EXAMPLE 5: SEASONAL EXPOSURE: CHILDREN VISITING A SITE 4 MONTHS OF THE YEAR

One cannot simulate exposures as discrete 4-month exposure events using the IEUBK model and ALM. In these models, the exposure must be time-weighted to calculate risk. Table A-6 summarizes the predicted mean PbB concentrations across age groups for an example scenario in which children experience a single, non-recurring 4-month exposure at a site contaminated with a PbS of 2850 ppm. Residential sampling showed 200 ppm for the residential PbS, and a PbS_w of approximately 1000 ppm is assumed (based upon 70% of soil ingestion occurring at the residence [200 ppm] and 30% at the site due to site-specific conditions [2850 ppm]; this weighted concentration is not averaged over the entire year). Dirt (soil + dust) ingestion rates are also kept at model default values. For comparative purposes, the left portion of the table indicates P_{10} values calculated by the model under the more typical constant, or cumulative, type of scenario. This was done for PbS concentrations of 200 ppm (residential exposure only), 430 ppm (the PbS at which $P_{10}=5\%$ when all other model input parameters are at default levels), and 1000 ppm (the weighted average). The right portion of the table provides the model predictions resulting from the one-time exposures occurring singly in each of the six analyzed age ranges (no site exposure was assumed for the 6-11 month group). For each age group, the interval associated with the site exposure is underlined.

Table A-6. IEUBK Risk Estimates (P_{10} ; Percent of Population Exceeding 10 $\mu\text{g/dL}$) Corresponding to Varying Soil Exposures by Age. All the values have been updated with IEUBKwin (build 253).

Age group (months)	Constant (cumulative) exposure to lead in soil			One year exposure during underlined age range (in months) to 1000 ppm site soil lead, otherwise 200 ppm residential soil lead was used as the media concentration ⁵						
	200 ppm ¹	430 ppm ²	1000 ppm ³							
6-11 ⁴	2.9	8.6	30.0	2.9	2.9	2.9	2.9	2.9	2.9	
12-23	4.6	13.1	40.5	<i>34.5</i>	4.6	4.6	4.6	4.6	4.6	
24-35	3.4	10.3	35.3	<i>8.0</i>	<i>26.7</i>	3.4	3.4	3.4	3.4	
36-47	2.6	8.5	32.0	2.7	<i>7.4</i>	<i>22.1</i>	2.6	2.6	2.6	
48-59	1.1	4.0	19.6	<i>1.1</i>	<i>1.2</i>	<i>4.8</i>	<i>9.9</i>	1.1	1.1	
60-71	0.5	1.9	11.4	<i>0.5</i>	<i>0.5</i>	<i>0.6</i>	2.3	<i>5.0</i>	0.5	
72-84	0.3	1.1	7.4	<i>0.3</i>	<i>0.3</i>	<i>0.3</i>	<i>0.4</i>	<i>1.4</i>	<i>2.9</i>	
12-84	1.6	5.4	23.5							16.9

¹ 200 ppm is the residential PbS based on sampling.
² 430 ppm in soil is the concentration associated with a 5% risk of elevated PbB for children 12-84 months old, when all other IEUBK inputs are at default (dust lead=200 ppm, geometric mean PbB=4.7 $\mu\text{g/dL}$, GSD=1.6). This level of precision is reported only for completeness; in general, back-calculated IEUBK estimates of soil and dust lead concentrations should be rounded to the nearest 100 ppm, or 400 ppm in this case.
³ Weighted average of 70% at 200 ppm and 30% at 2850 ppm; default dirt ingestion rates were assumed.
⁴ Age group shown for baseline; no site exposure assumed; PbB concentrations were not included in overall means.
⁵ The predictions in italics correspond nominally to the children having no further access to the site.

The predictions in italics in Table A-6, which correspond nominally to the children having no further access to the site, suggest that it takes more than a year for the predicted annual average PbB concentrations to return to baseline (200 ppm column). Note: the IEUBK model was not validated to estimate elimination kinetics following a sharp change in exposure levels. Nevertheless, this example indicates the importance of evaluating the available information about exposure patterns at the site to assess how well the assessment assumptions are likely to approximate the actual exposure patterns that may be occurring at the site. Where there is uncertainty in choosing the most appropriate concentrations for these variables, the TRW generally recommends considering several possible alternative scenarios to address a range of plausible possibilities.

EXAMPLE 6: LAWN MAINTENANCE NEAR A RIVER

For a lead-contaminated site (mean soil lead concentration at the site is 2000 ppm) 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 x 4.3 weeks/month x 7 months) days and an averaging time (AT) of 211 (7 days/week x 4.3 weeks/month x 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 (3 months). 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-7):

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 NHANES III analysis to span the range from all races/ethnic groups in the U.S. to the Mexican American group in the U.S.

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 values ranged from 1729 ppm and for U.S. data for all races combined to 1092 ppm for Mexican-American population from all regions in the U.S. (see Table A-7). 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-7. 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	10	10
R _{fetal/maternal}	Fetal/maternal PbB ratio	--	0.9	0.9
BKSF	Biokinetic slope factor	µg/dL per µg/day	0.4	0.4
GSD _i	Geometric standard deviation PbB	--	2.1	2.3
PbB ₀	Baseline PbB	µg/dL	1.5	1.7
IR _s	Soil ingestion rate (including soil-derived indoor dust)	g/day	0.05	0.05
AF _{s, d}	Absorption fraction (same for soil and dust)	--	0.12	0.12
EF _{s, d}	Exposure frequency (same for soil and dust)	days/year	3	3
AT _{s, d}	Averaging time (same for soil and dust)	days/year	7	7
PRG	Preliminary Remediation Goal	ppm	1729	1092
<p>IR_s = Intake rate of soil, and outdoor soil derived dust.</p> <p>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 x 4.3 weeks/month x 7 months.</p> <p>AT_{s, d} = Averaging time; the total period during which soil contact may occur. Based on , based on 7 days/week x 4.3 weeks/month x 7 months.</p>				

REFERENCES

- Bornschein R.L., P. Succop, K.N. Dietrich, C.S. Clark, S. Que Hee, and P.B. Hammond. 1985. The influence of social and environmental factors on dust lead, hand lead, and blood lead levels in young children. *Environ. Res.* 38(1): 108-18.
- Hogan, K., A. Marcus, R. Smith, and P. White. 1998. Integrated Exposure, Uptake, Biokinetic Model for Lead in Children: Empirical Comparison with Epidemiologic Data. *Environ. Health Perspect.* 106 (S6): 1557-67.
- Matte, T.D., J.P. Figueroa, S. Ostrowski, G. Burr, L. Jackson-Hunt, and E.L. Baker. 1991. Lead Exposure from Conventional and Cottage Lead Smelting in Jamaica. *Arch. Environ. Contam. Toxicol.* 21: 65-71.
- U.S. EPA. 1994. *Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children*. Office of Emergency and Remedial Response. Washington, D.C., U.S. EPA 540/R-93/081, PB93-963510.
- U.S. EPA. 1995. *Seasonal Rhythms of Blood-Lead Levels: Boston, 1979-1983*. Washington, D.C., U.S. EPA 747-R-94-003.
- U.S. EPA. 1996a. *Urban Soil Lead Abatement Demonstration Project, Volume I: EPA Integrated Report*. Washington, DC, U.S. EPA 600/P-93/001aF.
- U.S. EPA. 1996b. *Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil*. Washington, DC, U.S. EPA Technical Review Workgroup for Lead (TRW) <http://www.epa.gov/superfund/programs/lead/products.htm#guidance>.
- U.S. EPA. 1997. *Exposure Factors Handbook (Final) Volumes I, II, III*. Washington, DC, U.S. National Center for Environmental Assessment. <http://www.epa.gov/ncea/exposfac.htm>.
- U.S. EPA. 1998. *Short Sheet: IEUBK Model Mass Fraction of Soil in Indoor Dust (MSD) Variable*. Washington, DC, U.S. EPA Technical Review Workgroup for Lead (TRW). EPA #540-F-00-008, OSWER #9285.7-34. <http://www.epa.gov/superfund/programs/lead/products.htm#short>.
- U.S. EPA. 1999a. *Frequently Asked Questions on the IEUBK Model: Description of Acute Exposures*; Washington, DC, U.S. EPA Technical Review Workgroup for Lead (TRW). <http://www.epa.gov/superfund/programs/lead/ieubkfaq.htm>.
- U.S. EPA. 1999b. *Short Sheet: IEUBK Model Soil/Dust Ingestion Rates*. Washington, DC, U.S. EPA Technical Review Workgroup for Lead (TRW). EPA 540-F-00-007, OSWER 9285.7-33. <http://www.epa.gov/superfund/programs/lead/products.htm#short>.
- U.S. EPA. 2001. *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (Peer Review Draft)*. Washington, DC, U.S. EPA Office of Solid Waste and Emergency Response. EPA 9355.4-24. <http://www.epa.gov/superfund/resources/soil/ssgmarch01.pdf>.
- White, P., P. Van Leeuwen, B. Davis, M. Maddaloni, K. Hogan, A. Marcus, and R. Elias. 1998. The Conceptual Structure of the Integrated Exposure, Uptake, Biokinetic Model for Lead in Children. *Environ. Health Perspect.* 106 (S6): 1513-30.