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# TECHNICAL SUPPORT DOCUMENT: PARAMETERS AND EQUATIONS USED IN THE INTEGRATED EXPOSURE UPTAKE BIOKINETIC MODEL FOR LEAD IN CHILDREN (v0.99d)

Office of Solid Waste and Emergency Response
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# U.S. ENVIRONMENTAL PROTECTION AGENCY
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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 Emergency and Remedial Response (OSWER/OERR).

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# TECHNICAL SUPPORT DOCUMENT: PARAMETERS AND EQUATIONS USED IN THE INTEGRATED EXPOSURE UPTAKE BIOKINETIC (IEUBK) MODEL FOR LEAD IN CHILDREN (v 0.99d)

**Prepared by**

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**for**

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# PREFACE

The Technical Support Document describes in detail the basis for the parameters and equations that are used in the Integrated Exposure Uptake Biokinetic Model for Lead in Children, version 0.99d. It is a supplement to the Guidance Manual that was published in February, 1994, and is available from the National Technical Information Service as document PB93-963510. The IEUBK Model has been recommended as a risk assessment tool to support the implementation of the July 14, 1994 Office of Solid Waste and Emergency Response Interim Directive on Revised Soil Lead Guidance for CERCLA Sites and RCRA Facilities.

The development of the model has included the cooperative efforts of several EPA programs over nearly a decade. For the last four years, the development and documentation of the model have been coordinated by the Technical Review Workgroup for Lead, whose members are listed on page vi. This document was written by the Workgroup with extensive support from Dr. Steven W. Rust and Prithi Kumar of Battelle Columbus and Dr. Gary Diamond of Syracuse Research Corporation. It reflects the comments of peer reviewers from within and outside of EPA whose names and affiliations are listed on page vii.

Although this document details the selection of parameters and equations used in the IEUBK Model, it is not a line by line documentation of the source code. Equations and parameters presented in this document have been simplified for clarity. Comments on the technical content of this document or suggestions for its improvement may be brought to the attention of the Technical Review Workgroup for Lead.

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# 1.0 INTRODUCTION AND DOCUMENT OVERVIEW

The Integrated Exposure Uptake, and Biokinetic (IEUBK) Model for Lead in Children is a stand-alone PC-compatible software package consisting of several related computer programs. The IEUBK Model combines estimates of lead intake from lead in air, water, soil, dust, diet, and other ingested media, with an absorption model for the uptake of lead from the lung or gastrointestinal tract, and a biokinetic model of lead distribution, and elimination from a child's body, to predict the likely distribution of blood lead for children of ages six months through 84 months exposed to lead in these environmental media. Young children are particularly sensitive to adverse health effects from low-level lead exposures. The usual biomarker of lead exposure is the concentration of lead in the child's blood. Blood lead concentration is not only useful as an indicator of recent lead exposure and historical lead exposure, but is also the most widely used index of internal lead body burdens associated with potential adverse health effects. The IEUBK Model can be used to predict the probability that children exposed to lead in environmental media will have blood lead concentrations exceeding a health-based level of concern. These risk estimates can be useful in assessing the possible consequences of alternative lead exposure scenarios, including alternative models for intervention, abatement, or other remedial actions.

Initial development of a computer simulation model containing uptake and biokinetic components of a lead model was carried out by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (OAQPS) in 1985. This model estimated the effectiveness of alternative National Ambient Air Quality Standards for lead, particularly around point sources of air lead emissions such as smelters. The biokinetic component of the model was based on studies of lead metabolism in infant and juvenile baboons carried out at New York University by N. Harley, T. Kneip, and P. Mallon in the early 1980's (Mallon 1983; Harley and Kneip 1985). In the late 1980's, the exposure component of the IEUBK lead model was developed by the Environmental Criteria and Assessment Office at Research Triangle Park, NC (U.S. Environmental Protection Agency, 1989a; Cohen et al. 1990). The use of this early version of the IEUBK lead model for setting air lead standards was documented in a staff report in 1989,

and a subsequent staff paper in 1990 was reviewed and found acceptable by EPA's Clean Air Science Advisory Committee of the Science Advisory Board (U.S. Environmental Protection Agency, 1990a).

The air model was further developed to include enhancements in exposure, absorption and biokinetics. In November, 1991, the Indoor Air Quality and Total Human Exposure Committee of EPA's Science Advisory Board evaluated the newer version of the model for its use in assessing total lead exposures and in aiding the development of soil cleanup levels for lead at residential CERCLA and RCRA sites. The Committee concluded that while refinements in the detailed specification of the model would be needed, the approach followed in the development of the model was sound and the model could be applied effectively for many current needs even as it continued to be refined for additional applications based upon experience gained in its use. The Committee identified the need for guidance in some areas, such as the use of default parameters and the use of a geometric standard deviation to characterize inter-individual variability.

Documentation for the early development stages of the IEUBK lead model exists within two reports. Many of the initial model assumptions were documented in Appendix A of the OAQPS staff paper on exposure assessment and methodology validation (U.S. Environmental Protection Agency, 1989a). The 1990 Technical Support Document (U.S. Environmental Protection Agency, 1990b) extended the documented basis for some of the model parameters.

Since 1991, development of the IEUBK lead model has been coordinated by the Technical Review Workgroup (denoted TRW) for Lead whose members include scientists from EPA's Office of Research and Development, the Office of Emergency and Remedial Response, the Office of Pollution Prevention and Toxics, and from several EPA Regions. During this period, enhancements have been made to nearly every aspect of the model. In particular, the model has been implemented in a user-friendly software package (version 0.99d) that makes the model accessible to the regulatory and scientific community. To assist the user in providing appropriate input to the model, a Guidance Manual has been developed that describes the key features of the IEUBK Model, its evolution and development, its capabilities, and its limitations. The purpose of this report is to define the current stage of IEUBK lead model development, which was built on previous models. The result is a single report that documents all of the parameters and equations

employed in the IEUBK lead model, version 0.99d. Although this document describes in detail the parameters and equations used in the IEUBK Model, it is not a line by line documentation of the source code. Although most of the symbols and notation in this report are identical to the source code, some notations may differ, but they are mathematically equivalent.

A major portion of the documentation in this report is embedded in Appendices A and B. Appendix A, the equation dictionary, provides three tables that list the equations used in the IEUBK lead model. Exposure equations are listed in Table A-1. Table A-2 contains the equations relevant to the uptake component, while Table A-3 displays the biokinetic equations. Each of Tables A-1, A-2, and A-3 is structured as indicated in Table 1.

**TABLE 1. INFORMATION PROVIDED IN TABLES A-1, A-2, AND A-3**

| Column Heading | Description |
|---|---|
| Equation Group | Denotes a logical grouping of equations |
| Equation Number | Identifier for the individual equation. The equation number consists of:<br>! Component identifier<br>- E for Exposure<br>- U for Uptake<br>- B for Biokinetic<br>! Equation numeral - unique to each equation group<br>! Lower case letter - uniquely identifies each equation within an equation group. If there is only one equation in a group, then this letter is omitted. |
| Equation | Actual equation |

Within each table, the equation group clusters similar equations or equations that combine to achieve a common purpose. For instance, in Table A-1, the equation groups are defined by the different environmental media. The equation number provides a unique identifier for each equation.

Appendix B, the parameter dictionary, lists each parameter in the IEUBK lead model

alphabetically. As seen in Table 2, this appendix provides comprehensive information for each parameter.

**TABLE 2. INFORMATION PROVIDED IN TABLE B-1.**

| Column Heading | Description |
|---|---|
| Parameter Name | Unique name used to identify parameter. Time-dependent parameters are followed by "(t)" and may have a different value for each iteration period. Otherwise the parameter takes on a single value. |
| Description | Brief description of the parameter. |
| Default Values And/Or Defining Equation | |
| - Value and/or Equation Number | Lists the default value(s) for the parameter or the number of the equation which defines the parameter. |
| - Age (months) | Lists the age of the child for which the default value(s) or the equation are applicable. |
| I or E | Indicates whether the parameter is an internal (I) or external (E) parameter. 'I' implies the user cannot change the value of the parameter, while 'E' implies the user can change the value of the parameter. |
| Basis for Values/Equations | Description of the basis for the default values the parameter assumes or the equation which defines the parameter. |
| Units | Units of the parameter. |
| Parameter Use Equation | List of equation numbers in Appendix A for equations that employ the parameter. |

Section 2.0 provides a brief overview of the IEUBK lead model. In particular, the exposure, uptake, and biokinetic components of the model are described separately and interactions between the components are defined. Following this overview, the exposure, uptake, and biokinetic components of the model are discussed in detail in Sections 3.0, 4.0, and 5.0, respectively, describing the scientific basis for the equation structure and default parameter values in the IEUBK lead model.

## 2.0 MODEL OVERVIEW

As indicated above, the IEUBK lead model relates lead concentrations in various environmental media to the body burden of lead in children exposed to the environmental media. Since a child's blood lead level is the most common biomarker of lead exposure employed in practice, the IEUBK lead model emphasizes blood lead level in its output. Thus in simple terms, the IEUBK lead model translates environmental lead concentrations into predicted blood lead levels in children of different ages. In order to accomplish this, the IEUBK lead model has four distinct functional components that work together in series. The four model components are:

- Exposure Component
- Uptake Component
- Biokinetic Component
- Probability Distribution Component

Figures 1 and 2 illustrate the biological and mathematical structures, respectively, of the IEUBK lead model. The biological structure in Figure 1 places an emphasis on how lead can move from the environment of a hypothetical child into the child's blood, while the mathematical structure in Figure 2 emphasizes the parameters and calculations necessary to determine the child's blood lead concentration. In both figures, the first three model components are clearly delineated.

As indicated in Figure 1, the exposure component relates environmental lead concentrations to the intake rate at which lead enters the child's body via the gastrointestinal (GI) tract and lungs. The environmental media that act as lead sources for the child are air, which enters the body through the lungs, and diet, dust, paint, soil, water, and other sources which enter the body through the GI tract. As indicated in Figure 2, the exposure component converts media-specific consumption rates ($m^3$/day, g/day, or L/day) and media-specific lead concentrations ($\mu$g Pb/$m^3$, $\mu$g Pb/g, $\mu$g Pb/L), all of which are under the control of the user, to media specific lead intake rates ($\mu$g Pb/day). The general equation relating the consumption rates and lead concentrations to the lead intake rate is:

$$\text{Lead Intake Rate} = \text{Media Lead Concentration} * \text{Media Intake Rate}$$

In this manner, the exposure component models determines how much lead enters the child's body and captures that information in a set of media-specific lead intake rates.

As indicated in Figure 1, the uptake component relates lead intake into the lungs or GI tract to the uptake of lead from the exposed membrane into the child's blood, for children at each age. Lead that enters through the lungs is either absorbed into the blood plasma through the lungs, transferred to the gastrointestinal tract through the mucociliary escalator, or eliminated from the body via exhaled air. Very small particles (especially those 0.5 microns in diameter and smaller) may move directly into the blood plasma or may be eliminated from the body via exhaled air. Approximately 30-50% of particulate airborne lead is deposited in the deep parts of the adult lung, where it is almost totally absorbed. The rate may vary, depending on factors such as particle size and inhalation rate. The deposition rate of small particles in the child's lung may be 2-3 times greater. The bulk of the lead in the body enters via the GI tract, either through ingestion or by movement from the nose, throat or lung structures. Lead that enters the body via the GI tract is either absorbed into the blood plasma or eliminated from the gut via the feces. As indicated in Figure 2, the uptake component converts the media-specific lead intake rates produced by the exposure component into media-specific lead uptake rates ($\mu$g/day) for the blood plasma.

The total lead uptake ($\mu$g/day) from the gastrointestinal tract is estimated as the sum of two components, one passive (represented by a first order, linear relationship), the second active (represented by a saturable, nonlinear relationship). These two terms are intended to represent two different mechanisms of lead absorption, an approach that is in accord with limited available data in humans and animals and also by analogy with what is known about calcium uptake from the gut. First, the total lead "available" for gut uptake is defined as the sum, over all media, of the medium intake rate times the estimated low dose fractional absorption for that medium.

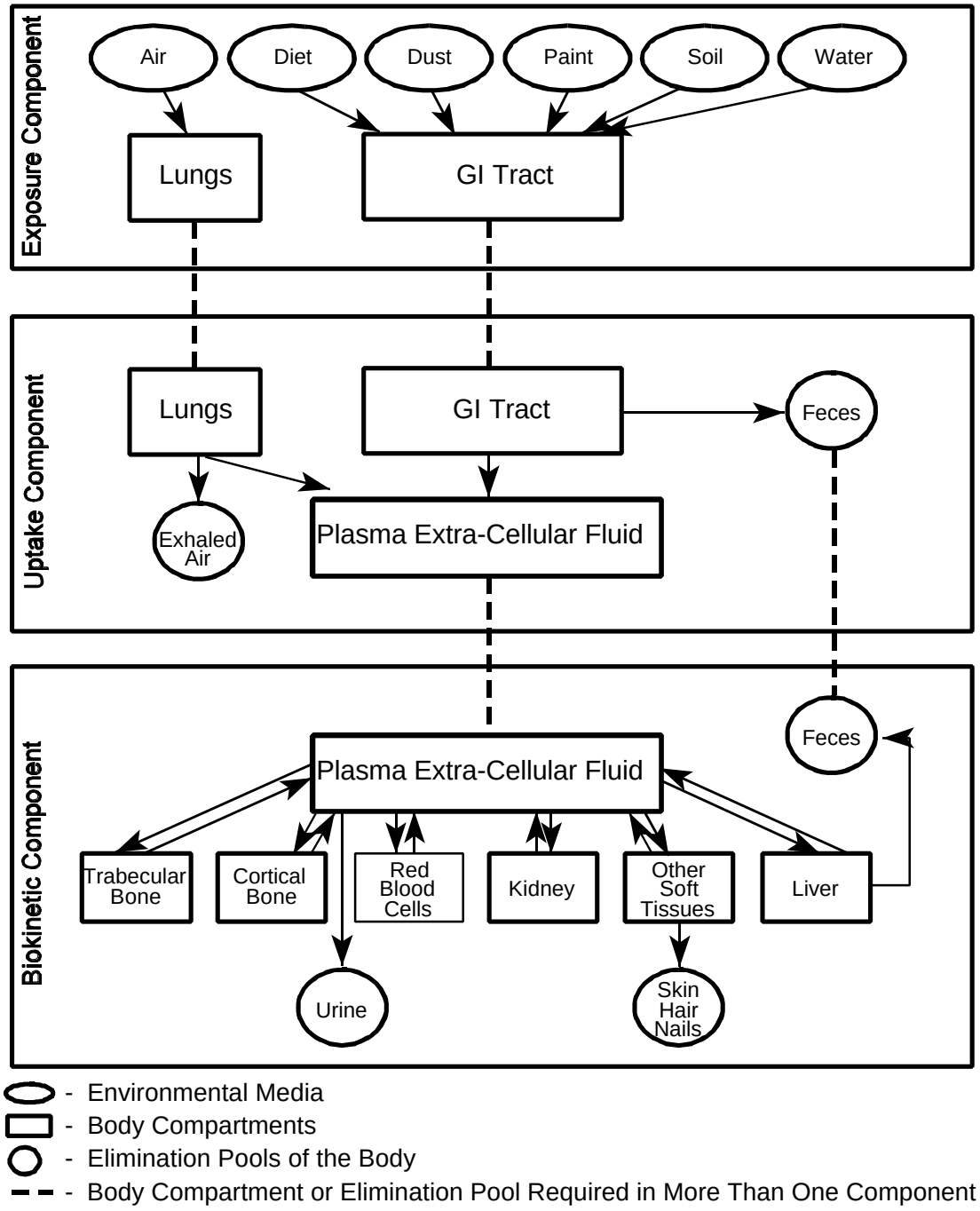



**FIGURE 1. Biological structure of the IEUBK Model for Lead in Children.**

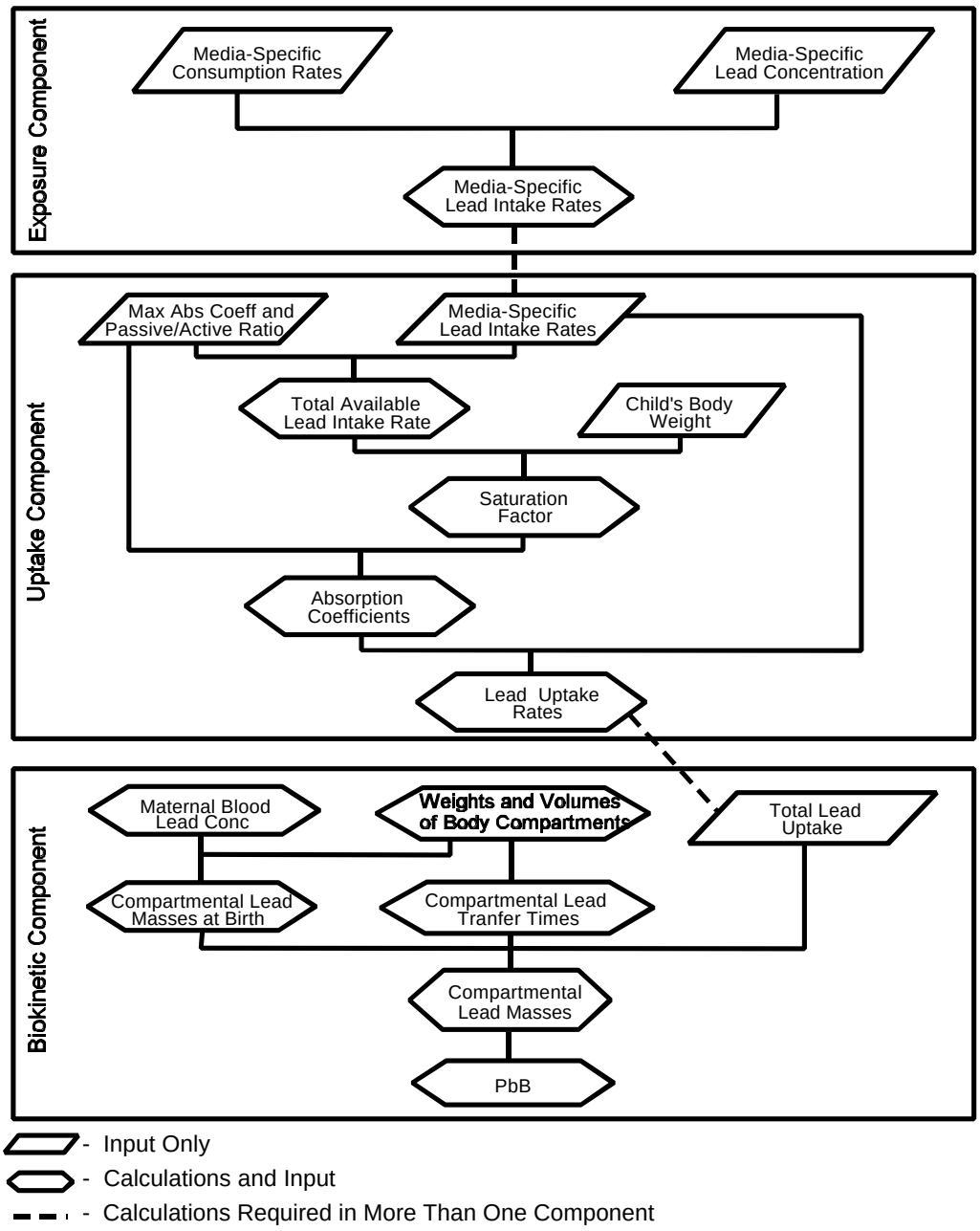



**FIGURE 2. Mathematical structure of the IEUBK Model for Lead in Children.**

A passive absorption coefficient defines the dose-independent fraction of the available lead that is absorbed by the passive absorption pathway, and allows calculation of the rate of absorption via that pathway. The rate of absorption of the remaining available lead by the active pathway is calculated using a non-linear relationship that allows for saturable absorption.

As indicated in Figure 1, the biokinetic component models the transfer of absorbed lead between blood and other body tissues, or elimination of lead from the body via urine, feces, skin, hair, and nails. The basic model that underlies the biokinetic component is a compartmental model whose pools have physiological properties, not just kinetic properties. The compartmental structure of the IEUBK Model was developed by identifying the anatomical components of the body critical to lead uptake, storage, and elimination, and the routes or pathways between these components. This compartmental scheme includes a central body compartment, six peripheral body compartments, and three elimination pools. The blood plasma is combined with the body's accessible extracellular fluid (ECF) to form the central plasma/ECF body compartment. Separate body compartments are used to model the trabecular bone, cortical bone, red blood cells, kidney, and liver. The cortical and trabecular bones can accumulate large quantities of lead, at least sixty percent of the total body burden in children and over ninety percent of body burden in adults with long exposure histories. Separate pools were used because of differences in cortical and trabecular bone kinetics in adults. The kidney and liver are important target sites of toxicity and some data are available from laboratory animal studies. Most of the lead in blood is in the red blood cells, which is modelled as a peripheral compartment exchanging with the plasma compartment. The remainder of the body tissues are included in the "other soft tissues" peripheral body compartment. Three elimination pathways are included in the biokinetic model: pathways from the central plasma/ECF compartment to the urinary pool, from the compartment for other soft tissues to skin, hair, and nails, and from the liver to the feces. The biological basis for this pathway is the excretion of bile by the liver into the GI tract where it is subject to the absorption processes of the uptake component. As indicated in Figure 2, the biokinetic component converts the total lead uptake rate produced by the uptake component into an input to the blood plasma/ECF. Transfer coefficients are used to model movement of lead between internal compartments and to the excretion pathway. These quantities are then combined with the total

lead uptake rate to determine lead masses in each of the body compartments. The lead in the plasma portion of the central plasma/ECF compartment is added to the lead in the red blood cells to determine the blood lead concentration (PbB).

The transfer coefficients used in the IEUBK Model are based on available data, including tissue concentrations in autopsy samples from human children (Barry, 1981); parameter estimates from experimental studies in primates comparable in age and developmental stage to human infants; and theoretical principles of allometric scaling that are widely applicable in biological models (Mordenti, 1986; Chappell and Mordenti, 1991).

The transfer coefficients in the IEUBK model are not directly related to blood flows, an approach that is used in many physiological based pharmacokinetic models. Where data to estimate transfer coefficients was sparse, the sensitivity of model predictions to changes in parameter values was examined. The model output was sensitive to the values of excretory parameters, for which data in human children was very limited. Final values of these parameters were selected with reference to comparison of model predictions to data from a community lead study where both blood lead and environmental lead levels were measured.

The iterative nature of the calculations in the biokinetic component is illustrated in Figure 3. The period of exposure, zero to 84 months, is divided into a number of equal time steps that are set by the user within the range 15 minutes to one month long. During each iteration, compartmental lead masses at the beginning of a time step are combined with the total lead uptake, inter-compartmental transfers, and quantities of excretion during the time step to estimate compartmental lead masses at the end of the time step. The compartmental lead transfer times during the time step are key parameters in these calculations. The compartmental lead masses at the end of the time step then become the compartmental lead masses at the beginning of the next time step and the iterative process continues. As indicated in Figure 2, the iterative process is initiated by determining the compartmental lead masses at birth from the maternal blood lead concentration and data on the relative concentrations of lead in different tissues of stillborn fetuses. The model calculates all of the compartmental contents from 0 to 84 months; it reports blood lead concentrations from 6 to 84 months.

The probability distribution component of the model estimates a plausible distribution of

blood lead concentrations centered on the geometric mean blood lead concentration for a hypothetical child or population of children. This distribution can be displayed graphically, or data can be loaded into a package for statistical analysis.

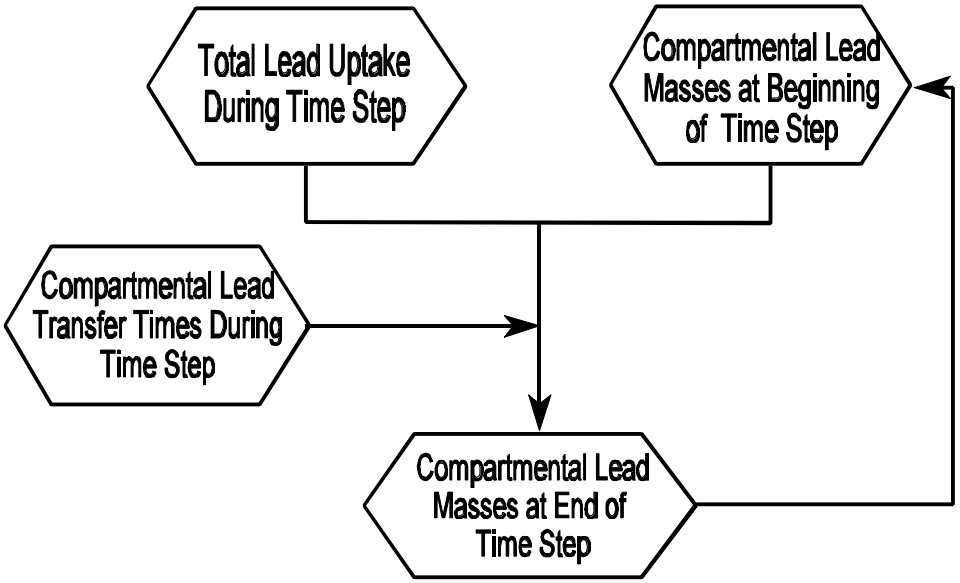



**FIGURE 3. Iterative procedure for determining compartmental lead masses in biokinetic component.**

# 3.0 EXPOSURE COMPONENT

The exposure component of the IEUBK model converts media-specific consumption rates and media-specific lead concentrations, both of which are under the control of the user, to media-specific lead intake rates. The equations that govern these model calculations are listed in Table A-1 of Appendix A. In these equations, the lead intake rates for air, diet, household dust, alternate source dust, soil, water, and other ingested media are denoted by EXAIR(t), INDIET(t), INDUST(t), INDUSTA(t), INSOIL(t), INWATER(t), and INOTHER(t), respectively. The notation "(t)" following each variable name indicates that these lead intake rates change with the age, t, of the child. All lead intake rates are in units of $\mu$g Pb/day. Once calculated, the media-specific lead intake rates serve as input to the uptake component. In the sections below, the calculations required to determine the lead intake rates are discussed by media. All referenced equation numbers can be found in the second column of Table A-1 of Appendix A.

Note that the IEUBK lead model does not include exposure from direct ingestion of paint chips because this exposure could not be adequately quantified, as discussed in Chapter 4 of the Guidance Manual (U.S. Environmental Protection Agency, 1994). An indirect exposure pathway in which lead-based paint contributes to dust lead exposure is included in the alternative dust model discussed in Section 3.1.5. The IEUBK Model does allow users to insert their own estimates of the daily intake rate of lead paint chips into the input parameter, INOTHER(t), which is independent of all other inputs.

## 3.1 Exposure Equations

### 3.1.1 Air Lead Exposure Model

The air lead exposure model considers both indoor and outdoor air lead exposure for determining the child's overall air lead exposure. The outdoor air lead concentration (air_concentration(t)) is specified by the user. The indoor air lead concentration (IndoorConc(t)) is determined according to Equation E-1 as a user-specified, constant percentage (indoorpercent) of the outdoor air lead concentration. A time-weighted average air lead concentration (TWA(t))

is determined according to Equation E-2 where the indoor and outdoor air lead concentrations are weighted by the user-specified, age-dependent number of hours per day that a child spends outdoors (time_out(t)). Finally, EXAIR(t) is calculated according to Equation E-3 as the product of the time-weighted air lead concentration and a user-specified, age-dependent ventilation rate (vent_rate(t)).

### 3.1.2 Dietary Lead Exposure Model

Dietary lead exposure is determined by one of two methods: (1) direct specification, or (2) alternative diet model. Under direct specification, as indicated in Equation E-4a, INDIET(t) is set equal to the a user-specified, age-dependent lead intake rate for diet (diet_intake(t)).

Under the alternative diet model, as indicated in Equation E-4b, INDIET(t) is calculated as the summation of the lead intake rates for meat, vegetables, fruit and other sources. The first three categories are sub-divided as follows.

- Meat
  - non-game animal (InMeat(t))
  - game animal (InGame(t))
  - fish (InFish(t))

- Vegetables
  - canned (InCanVeg(t))
  - fresh (InFrVeg(t))
  - home-grown (InHomeVeg(t))

- Fruit
  - canned (InCanFruit(t))
  - fresh (InFrFruit(t))
  - home-grown (InHomeFruit(t))

These are combined in Equation E-4b. The other dietary sources included in InOtherDiet(t) are dairy food, juice, nuts, beverages, pasta, bread, sauce, candy, and infant food and infant formula.

The terms on the right-hand side of Equation E-4b are defined in Equations E-5a through E-

5i, with the exception of InOtherDiet(t)[1], which can assume only default values. In these equations:

- The model allows the user to vary local dietary factors that may influence overall lead exposure.
- Specifically, the user may vary lead intake from home grown vegetables, fruits, game animals and fish.
- The user specifies the fraction of total food category consumption represented by the sources; the total quantity of food consumption from each category (meat, vegetables, fruit) is held constant.

The approach outlined here allows the user to input the lead content of locally produced foods, while still maintaining default assumptions about overall intake of lead from marketed foods. When greater flexibility is needed than is afforded by this method, the user should develop appropriate estimates for total dietary lead intake.

In Equations E-5a, through E-5e, the traditional supermarket portion of the dietary lead intake rate is calculated as the sum of the products of each consumption fraction and the specific lead intake for that category of food. The consumption fraction is calculated as a complement of the user defined nonsupermarket fraction (1-user defined nonsupermarket fraction). In Equations E-5f through E-5i, the lead intake rate is calculated as the product of the user-defined nonsupermarket consumption fraction, and a consumption rate for that category of food.

### 3.1.3 Water Lead Exposure Model

Water lead exposure is determined by one of two methods: (1) direct specification, or (2) an alternative water lead concentration model. Under direct specification, as indicated in Equation E-6a, INWATER(t) is calculated as the product of a user-specified, age-dependent water consumption rate (water_consumption(t)) and a user-specified, constant water lead concentration

[1]For the sake of simplification, the term InOtherDiet(t) is used in the text to represent components of the diet other than meat, fruit, vegetables, fish, or game. These other dietary components are modelled as InDairy, InJuice, InNuts, InBread, InPasta, InBeverage, InCandy, InSauce, InFormula, and InInfant and are not user-selectable.

(constant_water_conc).

Under the alternative water model, as indicated in Equation E-6b, INWATER(t) is calculated as the product of the same user-specified, age-dependent water consumption rate (water_consumption(t)) and a constant water lead concentration that is calculated as a weighted average of user-specified, constant water lead concentrations from the first-draw on a home faucet (FirstDrawConc), a flushed faucet at home (HomeFlushedConc), and a water fountain outside the home (FountainConc). These concentrations are weighted by user-specified, constant fractions of consumed water that are first-draw water (FirstDrawFraction), home flushed water (HomeFlushFraction), and fountain water (FountainFraction). As indicated in Equation E-7, HomeFlushedFraction is calculated by subtracting the other two fractions from one.

### 3.1.4 Soil Lead Exposure Model

As indicated in Equation E-8, INSOIL(t) is calculated using the user-specified soil lead concentration (constant_soil_conc(t)), the user-accessible age-dependent soil and dust ingestion rate (soil_ingest(t)), and a user-accessible constant fraction of soil and dust ingested that is soil (0.01 × weight_soil). Soil lead concentration can be specified in an age-dependent manner; the corresponding equations are not shown.

### 3.1.5 Dust Lead Exposure Model

Dust lead exposure is determined by one of two methods: (1) direct specification, or (2) an alternative dust model. Under direct specification, as indicated in Equation E-9a and E-9b, the baseline dust lead intake, INDUST(t), is calculated as the product of an age-dependent soil and dust ingestion rate (soil_ingested(t)), the fraction of soil and dust ingestion that is in the form of dust (1 - 0.01 × weight_soil), and a user-specified dust concentration (constant_dust_conc). Age-dependent dust lead concentrations (user_dust_conc(t)) can be specified but are not shown here. (When using the direct specification, the alternative source dust lead intake (INDUSTA(t), is set to zero).

The alternative dust sources model, as indicated in Equations E-9c and E-9d, has two alternative specifications:

- The indoor dust lead concentration is calculated as a sum of contributions from soil and air, either constant or age-dependent (not shown).

-OR-

- The indoor dust lead concentration is calculated as the sum of contributions from several additional sources, plus the household contribution estimated by one of the three approaches above. Only a fraction of dust lead exposure is assumed to come from residential dust. When data are available, the remainder is assumed to come from separately estimated dust sources including:

    - Secondary exposure to leaded dust carried home from workplace (OCCUP(t))
    - Leaded dust at school or pre-school (SCHOOL(t))
    - Leaded dust at other non-school daycare facilities (DAYCARE(t))
    - Leaded dust from secondary homes (e.g. grandparents) (SECHOME(t))
    - Leaded dust from deteriorating interior paint (PAINT(t))

As indicated in Equation E-9c, INDUST(t) is the product of the age-dependent dust ingestion rate (DustTotal(t)), an age-dependent indoor dust lead concentration (soil_indoor(t)), and the fraction of dust exposure that is from residential dust (HouseFraction). As indicated in Equation E-11, soil_ indoor(t) is calculated as a sum of contributions from soil and air. The contribution from soil is the product of a user-specified, constant ratio of dust to soil lead concentrations (0.01 × contrib_percent) and the user-specified, age-dependent soil lead concentration (user_soil(t)). Similarly, the contribution from air is the product of a user-specified, constant ratio of dust to air lead concentrations (multiply_factor) and the user-specified, (age-dependent) outdoor air concentration (air_concentration(t)).

As indicated in Equation E-9.5, HouseFraction is determined by subtracting from one, the total of the user-specified, constant fractions of dust ingested that come from the parent's occupation (OccupFraction), school (SchoolFraction), daycare (DaycareFraction), secondary homes (SecHomeFraction), and paint (PaintFraction). The sum of all source fractions entered

cannot exceed 1.0. As indicated in Equation E-9d, INDUSTA(t) is the sum of the lead intake rates from all five alternative sources where these individual lead intake rates are defined in Equations E-12a through E-12e. In these equations, the lead intake rate is the product of the age-dependent, dust ingestion rate (DustTotal(t)), the user-specified, constant fraction of dust ingested that comes from that source (OccupFraction, SchoolFraction, DaycareFraction, SecHomeFraction, or PaintFraction), and the user-specified, constant dust lead concentration for dust from that source (OccupConc, SchoolConc, DaycareConc, SecHomeConc, or PaintConc).

## 3.2 Default Values for Exposure Parameters

For diet, water and dust exposure, the user may choose from two or more methods of calculating exposure. Each of these exposure pathways has both concentration and intake parameter default values built into the model that can be used to calculate default exposure levels. Using the direct default specifications for lead exposure from diet, water, and dust, the resulting total lead intake rate for each age interval are: 23.40 (0-11 mo), 34.89 (12-23 mo), 35.76 (24-35 mo), 35.57 (36-47 mo), 28.42 (48-59 mo), 26.95 60-71 mo), and 26.65 (72-84 mo) $\mu$g Pb/day.[2] These are the total lead intake rates and are the summation of individual default rates for air, diet, water, soil, and dust. The following sections detail default values for selected calculated parameters associated each of these individual media. Default media concentration values, particularly those for soil and dust, are included for purposes of illustration of model behavior; assessment specific concentration data will be required for model applications.

### 3.2.1 Air Lead Parameter Values

The default values for indoorpercent, air_concentration(t), time_out(t), and vent_rate(t) result in the following default values for calculated parameters:

- Indoor air concentration (IndoorConc(t)) of 0.03 $\mu$g/m$^3$ for 0-84 months;
- Time weighted average air concentration (TWA(t) of 0.033, 0.036, 0.039,

[2]Here and elsewhere it should be noted that the model calculates the uptake and biokinetic distribution of lead for each iteration interval from 0 to 84 months. The model reports blood lead concentrations beginning with month six and accepts user selectable options for lead exposure for 6 months to 84 months. For the period 0 to 5 months, the model does not permit user selectable changes in exposure.

0.042, 0.042, 0.042, and 0.042 $\mu$g/m$^3$ for the seven age intervals, respectively;

- Lead intake rates from air (EXAIR(t)) of 0.07, 0.11, 0.19, 0.21, 0.21, 0.29, and 0.29 $\mu$g/day for the seven age intervals, respectively.

### 3.2.2 Dietary Lead Parameter Values

Under the default model specification, the lead intake rate from diet (INDIET(t)) assumes default values of 5.53, 5.78, 6.49, 6.24, 6.01, 6.34, and 7.00 $\mu$g/day for the seven age intervals (0-11, 12-23, 24-25, 36-47, 48-59, 60-71, and 72-84 months), respectively. Under the alternative diet specification, the model assumes no consumption of game animal meat, fish, home-grown vegetables, or home-grown fruit unless input by the user. Using default values for lead intake from non-game animal meat, canned and fresh vegetables, canned and fresh fruit, and other dietary sources, the lead intake rate from diet (INDIET(t)) assumes default values of 5.88, 5.92, 6.79, 6.57, 6.36, 6.75, and 7.48 $\mu$g/day for the seven age intervals, respectively.

### 3.2.3 Water Lead Parameter Values

Under the direct specification model, default values for water_consumption(t) and constant_water_conc result in the lead intake rate from water (INWATER(t)) assuming default values of 0.80, 2.00, 2.08, 2.12, 2.20, 2.32, and 2.36 $\mu$g/day for 0-11, 12-23, 24-25, 36-47, 48-59, 60-71, and 72-84 months, respectively. Under the alternative water model, default values for FirstDrawConc, HomeFlushedConc, FountainConc, FirstDrawFraction , and FountainFraction result in a composite water lead concentration of 3.85 $\mu$g/L, which in turn with default values of water_consumption(t) results in the lead intake rate from water (INWATER(t)) assuming default values of 0.77, 1.92, 2.00, 2.04, 2.12, 2.23, and 2.27 $\mu$g/day for the seven age intervals.

### 3.2.4 Soil Lead Parameter Values

Soil lead does not include the fraction of housedust that is derived from soil. This allows the estimation of soil lead concentration directly from soil measurements. Default values for constant_soil_conc(t), soil_ingest(t), and weight_soil result in the following default values for calculated intakes:

- Soil (excluding house dust) ingestion rates of 38.25, 60.75, 60.75, 60.75, 45.00, 40.50, and 38.25 mg/day for the seven age intervals (6-11, 12-23, 24-25, 36-47, 48-59, 60-71, and 72-84 months), respectively;

- Lead intake rates from soil (INSOIL(t)) of 7.65, 12.15, 12.15, 12.15, 9.00, 8.10, and 7.65 $\mu$g/day for the seven age intervals.

### 3.2.5 Dust Lead Parameter Values

Under the default model specification, values for soil_ingest(t), percent_soil, and user_dust_conc(t) result in the following default values for calculated parameters:

- House dust ingestion rates (DustTotal(t)) of 46.75, 74.25, 74.25, 74.25, 55.00, 49.5, 46.75 mg/day for (6-11, 12-23, 24-25, 36-47, 48-59, 60-71, and 72-84 months), respectively;

- Lead intake rates from household dust (INDUST(t)) of 9.35, 14.85, 14.85, 14.85, 11.00, 9.90, and 9.35 $\mu$g/day for the seven age intervals;

- Lead intake rate from alternative source dust (INDUSTA(t)) of zero $\mu$g/day.

Under the alternative dust model, default values for soil_ingest(t), weight_soil, contrib_percent, user_soil(t), multiply_factor, out_air_concentration(t), OccupFraction, SchoolFraction, DaycareFraction, SecHomeFraction, and PaintFraction result in the following default values for calculated parameters:

- House dust ingestion rates (dust_ingested(t)) of 46.75, 74.25, 74.25, 74.25, 55.00, 49.5, 46.75 mg/day for the seven age intervals, respectively; these rates are the same as for the default model specification discussed above;

- Indoor dust lead concentration (soil_indoor(t)) of 150 $\mu$g/g for all ages;

- Lead intake rates from household dust (INDUST(t)) of 8.42, 13.37, 13.37, 13.37, 9.90, 8.91, and 8.42 $\mu$g/day;

- Since the fraction of dust ingested that comes from each alternative dust source has a default value of zero, the lead intake rate from alternative dust sources (INDUSTA(t)) assumes a default value of zero $\mu$g/day.

# 4.0 UPTAKE COMPONENT

## 4.1 Overview

The uptake component models the manner in which lead intake (lead that has entered the child's body through ingestion or inhalation) is either transferred to the child's blood plasma or eliminated from the body. Uptake is the quantity of lead absorbed per unit time from portals of entry (gut, lung) into the systemic circulation of blood; that is, a rate at which lead from all media is taken up into the blood. Since most lead is taken into a child's body through the gastrointestinal (G.I.) tract, we will usually be discussing gut uptake. Only a fraction of the gut intake is actually absorbed into systemic circulation during any period of time. That is, the gut uptake rate in µg Pb/day is a fraction of the gut intake rate in µg Pb/day. This fraction is known as the absorption fraction and usually provides the most convenient parameterization of the uptake process.

In the IEUBK model, all lead uptake from the gut is treated as the sum of saturable and non-saturable components. This approach has been developed to address findings in studies in humans and experimental animals as well as our current (limited) understanding of the mechanisms of lead absorption in the gut. Human data suggest a curvilinear relationship between lead intake and lead absorption (Sherlock and Quinn, 1986; Ryu et al., 1983). Studies in non-human primates also suggest a nonlinear relationship between blood lead and lead intake (Mallon, 1981 and 1983). Additionally, *in vivo* experiments using the rat as a model show a concentration dependence between lead intake and blood lead (Freeman et al., 1992). We have interpreted the nonlinear relationship as representing lead absorption by at least two mechanisms (discussed below), based on the biological plausibility of the assumption of nonlinear absorption from other experimental studies (Aungst and Fung, 1981).

The physiological mechanisms that account for these observations of curvilinearity are not completely established. The absorption nonlinearity, assumed in the IEUBK Model at higher intake rates, is a plausible explanation for the nonlinear relationship observed between lead intake and blood lead. The nonlinear relationship can be observed when the GI component of lead intake exceeds 200 µg Pb/day for enough cases that the part of the relationship with lower absorption (usually blood lead above 25 or 30 µg/dL) can be clearly separated from the part of

the relationship with higher absorption at gut lead intake less than about 100 to 200 µg Pb/day. However, it should be noted that there are other nonlinear biokinetic factors that can influence the observed relationship between lead intake and blood lead. In particular, the binding of lead in red blood cells shows saturable behavior. The IEUBK model also incorporates a nonlinear relationship for the binding of lead in blood. However, available data are not yet sufficient to empirically resolve the contributions that these two nonlinear effects make to the observed relationship between lead intake and blood lead. The mathematical approach employed here is intended to allow plausible modeling of absorption phenomenon while important biochemical and biophysical research into the exact mechanisms of lead absorption proceeds.

Experimental studies of soil lead absorption using appropriate animal models and feeding patterns analogous to those of human children are being carried out by EPA. Preliminary results (Weis et al., 1994) are consistent with the assumptions used in the IEUBK Model, but require more complete analyses. The current parameters of the model are based on statistical analyses of some experimentally measurable quantities in these studies and in older studies in human children (Sherlock and Quinn, 1986).

In extending these results to a mixed multi-media gut intake scenario, we have assumed that linear absorption at low intake rates is the best characterization for the available lead. When doses are relatively low, human or experimental animal data may be applied to estimate the fractional absorption of lead. A fractional absorption estimate implicitly combines the elements of dissolution of solid particles such as particle size, chemical speciation, matrix embedding, and stomach pH at different times after meals, for which we have no comprehensive quantitative model at this time. While the characterization of gut uptake by a fractional absorption value is conceptually straightforward, it may not adequately characterize the complexity of the absorption processes. Absorption occurs in different segments of the gut, and lead concentrations in these segments will depend on acidity, binding of lead to total gut contents, including minerals and fibers, and other factors. We would not expect to have knowledge of all of these factors in any real-world childhood lead exposure scenario.

## 4.2 Parameterization of the Saturable and Non-Saturable Components of Absorption

The intake rates are calculated in the exposure component of the IEUBK Model, using the E-series equations in Table A-1, and are denoted EXAIR(t) for air lead, INDIET(t) for dietary lead, INDUST(t) for dust lead[3], INSOIL(t) for soil lead, INWATER(t) for lead in drinking water, and INOTHER(t)[4] for all other sources of ingested lead. Uptake rates are media-dependent and age-dependent. The media specific uptake rates are designated UPAIR(t) for air lead, UPDIET(t) for dietary lead, UPDUST(t) for dust lead, UPSOIL(t) for soil lead, UPWATER(t) for lead in drinking water, and UPOTHER(t) for all other sources of ingested lead. The IEUBK Model is parameterized such that, at typical blood lead levels of concern, media-specific absorption fractions are constant. The net absorption fractions used to characterize the IEUBK Model are denoted ABSF for dietary lead absorption, ABSD for dust lead absorption, ABSS for soil lead absorption, ABSW for drinking water lead absorption, and ABSO for absorption of lead from other intake sources. These parameters are accessible to the user. In the absence of saturation effects, total lead absorption is equal to the sum of media specific absorption values where absorption from each media is equal to the intake rate multiplied by the absorption fraction for that media. This quantity is denoted AVINTAKE.

$$\begin{aligned} \text{AVINTAKE} = {} & \text{ABSD} \times \text{INDUST}(t) \\ & + \text{ABSF} \times \text{INDIET}(t) \\ & + \text{ABSO} \times \text{INOTHER}(t) \\ & + \text{ABSS} \times \text{INSOIL}(t) \\ & + \text{ABSW} \times \text{INWATER}(t) \end{aligned}$$

As noted above, to more accurately model lead uptake at higher intake rates, the absorption fractions must be modified so as to separate their non-saturable and saturable components. At

[3] If the alternative dust intake options are used, then the alternative dust lead intake is denoted INDUST A(t) and the uptake UPDUSTA(t), and these replace the standard INDUST(t) and UPDUST(t) values.

[4] The contributors to INOTHER may include, for example, paint chips or medicines; however, the model user must determine appropriate intake rates.

doses where saturation of absorption is important, the actual uptake of lead will be less than AVINTAKE(t). Lead uptake by the passive pathway is assumed to be linearly proportional to intake at all dose levels. The user parameter PAF is the fraction of the total net absorption at low intake rates that is attributable to non-saturable processes. Specifically, the lead uptake by the passive pathway is equal to

$$PAF \times AVINTAKE(t).$$

We have assumed that the fraction of absorbed lead intake that is absorbed by non-saturable processes is the same for all media.

At low doses, the quantity of lead absorbed by the saturable pathway is:

$$(1\text{-}PAF) \times AVINTAKE(t).$$

However, at higher doses, only a certain fraction of this amount will be absorbed. The equation for a rectangular hyperbola (familiar from biochemistry as the functional form applied with Michaelis Menton enzyme kinetics) is used to represent saturable pathway absorption. The key parameter in this relationship is SATINTAKE(t), which represents the level of available intake (AVINTAKE) at which the saturable pathway uptake reaches half of its maximum value. This half-saturation parameter depends on the age t of the children. The user has access to the value of SATINTAKE(t) at age t = 24 months, denoted SATINTAKE2, through the gut absorption parameter menu in the Model. From SATINTAKE2, the model calculates SATINTAKE(t) for all ages.

The fraction of potential saturable pathway uptake that is actually absorbed is given by:

$$1/(1 + [AVINTAKE(t)/SATINTAKE(t)].$$

Thus, the amount of lead that is absorbed by saturable processes is calculated as:

$$(1\text{-}PAF) \times AVINTAKE(t)/[1+ (AVINTAKE(t)/SATINTAKE(t)].^{5}$$

Total lead uptake is given by the sum of the active and passive components of uptake. Media specific uptake rates are calculated using the same proportionalities as total intake for example, the non-saturable uptake component for soil is given by:

$$PAF \times UPSOIL(t)$$

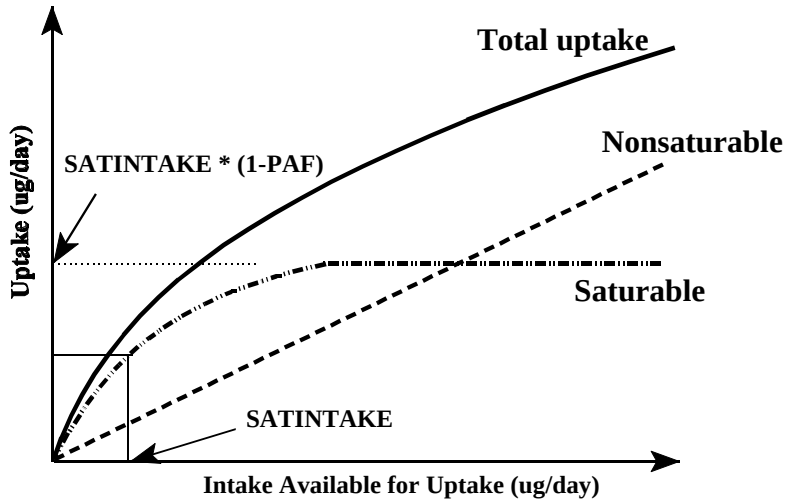
While the saturable uptake component for soil is:

$$(1\text{-}PAF) \times UPSOIL(t)/[1+ (AVINTAKE(t)/SATINTAKE(t)].$$

Uptake rates for other media are calculated analogously, and the reader may verify that the sum of media specific rates gives the values for total uptake shown above.

Figure 4 illustrates the functional relationships between intake of lead and the components of lead uptake. The conceptual relationship between saturable and non-saturable pathways are shown in Figure 5. The partitioning of gut lead uptake is shown in Table 3.

[5]Note that with a different choice of constant parameters, this term may be rearranged as (a*AVINTAKE)/(b+AVINTAKE), a form that may be more familiar to many readers.




**Where:**

**SATINTAKE=100**
**PAF = 20**

**Figure 4: The mathematical treatment of lead absorption in the IEUBK model comprised of saturable and non-saturable components [figure not to scale].**

**Table 3. PARTITIONING OF TOTAL GUT LEAD INTAKE BY PROCESS.**

| FATE | PROCESS | GUT INTAKE COMPONENT |
|---|---|---|
| Absorbed | Non-saturable | PAF × AVINTAKE(t) |
| | Saturable absorbed | (1-PAF) × AVINTAKE(t)/ [1+AVINTAKE(t)/SATINTAKE(t)] |
| Excreted | Non-available | (1-ABSD) × INDUST(t) + (1-ABSF) × INDIET(t) + (1-ABSO) × INOTHER(t) + (1-ABSS) × INSOIL(t) + (1-ABSW) × INWATER(t) |
| | Saturable non-absorbed | (1-PAF) × AVINTAKE(t)$^2$ /(AVINTAKE(t) + SATINTAKE(t)) |

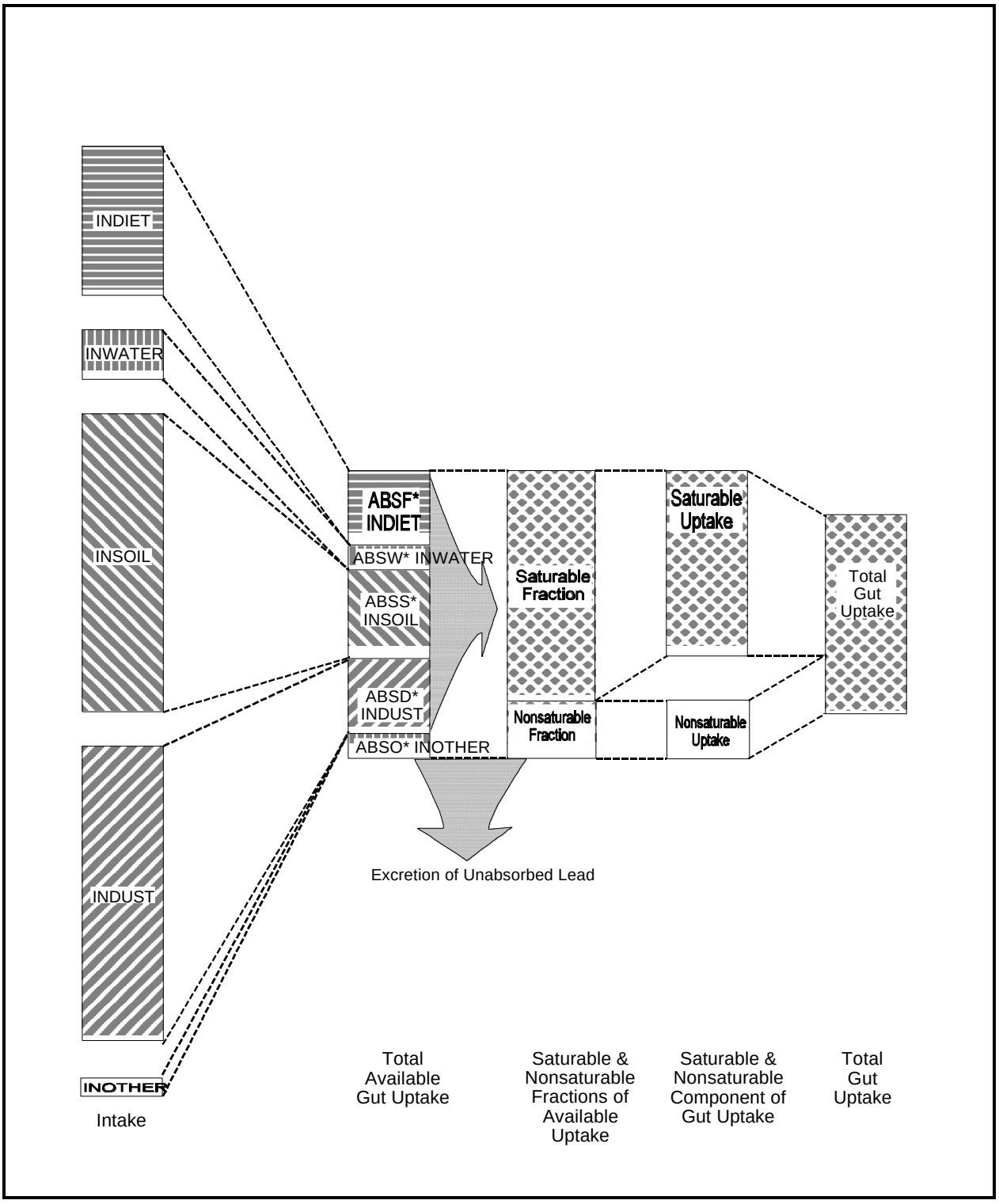



**Figure 5. Conceptual model of gastrointestinal lead absorption.**

## 4.3 Other Uptake Pathways

The multi-media nature of a child's lead exposure requires a detailed examination of the mechanisms of absorption of lead through the portals of entry: skin, lungs, and GI tract. While dermal absorption may be a significant route of entry for organolead compounds, such as tetraethyl lead used as an additive to leaded gasoline, it is not considered a significant pathway for inorganic lead and is not included in the IEUBK model.

The lung absorption model employed in the IEUBK Model is discussed in detail in the OAQPS Staff Paper (U.S. Environmental Protection Agency, (1989a). This model assumes that a fixed proportion of the lead taken into the lungs via inhaled air is transferred to the child's blood plasma. Much of the lead that enters the lungs is probably removed by the action of the mucociliary escalator and ultimately finds its way into the GI tract. Very small particles (especially those 0.5 microns in diameter and smaller) may move directly into the blood plasma or may be eliminated from the body via exhaled air. Lead that becomes entrained on the mucociliary escalator and is subsequently swallowed is not modelled separately from the inhalation fraction.

# 5.0 BIOKINETIC COMPONENT

The biokinetic component of the IEUBK model calculates age-dependent lead masses in each of the body compartments (plasma-extra-cellular fluid, liver, kidney, trabecular bone, cortical bone, and other soft tissue) based on the total lead uptake rate (UPTAKE(t)). The concentration of lead in blood is then calculated by dividing mass of lead in the blood plasma and red blood cells by the volume of blood. The equations that govern the biokinetic model calculations are listed in Table A-3 of Appendix A. In this table there are equations for compartmental lead transfer times, blood to plasma-ECF lead mass ratio, tissue to blood lead concentration ratios, fluid volumes and organ weights, compartmental lead masses, blood lead concentration at birth, and blood lead concentration. A description of the biokinetic parameters can be found in Table B-1. The notation (t) indicates that the parameter value is adjusted for the child's age.

The calculations in the biokinetic model begin by determining the volumes and weights of specific compartments in a child's body, as a function of age. Next, the transfer times of lead between the compartments and through elimination pathways are estimated. Initial compartmental lead masses and an initial blood lead level are calculated for a newborn child. Then successive values are calculated for the compartmental lead masses and blood lead concentration of a child at each iteration time. These calculations are performed for a child from birth to age 84 months.

In developing estimates of parameter values, primary emphasis was placed on applying information from studies with human children. When data for children were not available, data on human adults were sought, with consideration for appropriate allometric scaling. Data from primate studies were also helpful in defining plausible ranges of parameter values for human children. However, baboon and monkey data were not used as the primary basis for any parameters in the IEUBK Model. Where there was considerable uncertainty in parameter values (specifically for excretory parameters), model predictions for a range of plausible parameter values were compared to data from epidemiological studies of blood lead in children from communities with measured environmental lead levels. The results of these comparisons were used in the selection of specified parameter values within the varied ranges. The following steps

were applied in estimation of specific parameter values:

1. Tissue/blood concentration ratios were established.

   Tissue/blood concentrations were based primarily on autopsy samples from children that were reported by Barry (1981). We assumed that near steady-state conditions existed for most of these children corresponding to long periods of exposure to environmental concentrations that were constant over time. For cortical bone/blood, trabecular bone/blood, kidney/blood, liver/blood, and combined other soft tissues/blood, tissue/blood concentrations were calculated using mean concentration values, because individual data were not available.

2. The compartmental concentration ratio estimates were converted into the ratio of masses of lead using compartmental size (mass or volume). These ratios were then used to relate transfer times to and from model compartments.

   A fundamental requirement for the IEUBK model is that a mass balance of lead be maintained. When applied to the special case of near steady-state conditions, the mass balance requirement implies that the ratio of the quantity of lead in a tissue to the quantity of lead in the central plasma-ECF compartment equals the ratio of the transfer time from tissue to the central compartment to the transfer time from central compartment to tissue.

   Concentration ratio data do not, by themselves, allow separate estimates of transfer times into and out from compartments. Kinetic data to allow separate estimates of the transfer in and out from specific compartments are scarce. Therefore, for most compartments, the estimated ratio of transfer times is more strongly founded than the individual transfer rates, and the exercise of judgment was necessary in assigning specific values for transfer times from blood to the peripheral compartments.

However, once the ratios of times were specified, the model predictions were found to be quite insensitive to the specific values selected for these transfer times.

3. The relationship between blood and plasma was established, and the ratio of transfer times from red blood cells to plasma and from plasma to red blood cells was estimated.

   To estimate transfer times from red blood cells to plasma and from plasma to red blood cells, adult data (deSilva, 1981a,b; Cavalieri et al., 1978a,b, 1981, 1984) were applied, assuming that transfer times in adults and children are similar.

   This assumption is consistent with general allometric considerations. However, there could be biochemical differences between adults and children that could affect the partitioning of lead between blood and urine.

   To maintain mass balance in near steady-state conditions, the ratio of the quantity of lead in the tissue to the quantity of lead in the central plasma-ECF compartment equals the ratio of transfer time from tissue to the central compartment to transfer time from central compartment to tissue. This relationship was inverted by fixing the ratio of masses to correspond to the tissue/blood concentration ratios of Barry (1981), the ratio of blood/plasma, and the weight of the tissues and volume of the plasma-ECF pool. Data did not allow separate estimates of transfer times into and out of most compartments. Rather, only the ratio of transfer times could be determined from data for most compartments.

4. After these parameters were fixed, the additional modifying terms or urinary, fecal, and soft tissue elimination times were considered.

   Because of the long time needed to achieve steady-state in bone, i.e., the long transfer time from bone to blood, the blood to bone transfer time was also considered as an

adjusted parameter. Transfer coefficients for urinary excretion of lead by adults were reviewed and used as a starting point for estimation of urinary excretion by children.

The ratio of endogenous fecal to urinary elimination was calculated based on statistical reanalysis of data on children (Zeigler et al., 1978; Ryu et al., 1983), supported by information in Alexander (1974). To determine reasonable bounds on parameters, data from adult studies measuring relative amounts of lead eliminated by urinary, fecal, and other paths of excretion were also examined (Rabinowitz et al., 1976). For each of the excretory terms (urinary, fecal, other soft tissue elimination) as well as blood to bone transfer, (which, conceptually, may act similarly to an excretory pathway in removing lead from blood), a grid of biologically plausible values was constructed and an iterative optimization procedure established for comparing model predictions to a data set from a field study that collected both detailed environmental data and blood data. In this process, the model was run repeatedly in batch mode and the rate of observed to predicted blood lead levels was examined. The bone parameters were adjusted first, followed by the urinary elimination rate, the ratio of endogenous fecal to urinary elimination rates, and then other soft tissue values. The elimination parameters were varied in this order because of the greater certainty about the urinary rate and the virtual lack of information about other soft tissue routes of elimination in children.

Using the results of these comparisons, values for the four parameters, within the varied ranges, were established. with these parameter values, model predictions were consistent with the geometric mean and blood lead distribution in the field study data. Test simulations were also made with different hypothetical exposure scenarios and the bone to blood concentration ratio from the simulation output was checked to insure that the values produced were concordant with ratios based on data from Barry (1981).

Finally, model predictions were then compared with observed blood and environmental lead data at a second field study. Further parameter adjustments were judged unnecessary. Other specifications for the relative magnitudes of the three excretory pathways could produce equivalent rates of total lead excretion and, thus, equivalent model blood lead predictions.

It is also important to note that the selected model parameters set excretory rates for the

three pathways to levels that are at the high end of values deemed plausible. If changes were made for the intake or absorption values used in the analysis of the community lead data, different values for the excretory parameters may have been supported. As the excretory parameters have substantial impact on model predictions and, as very little data for human children were available to directly support the selection of these values, generation of better excretory data for human children is a priority for further research.

The sections that follow provide descriptions of the calculations involved in the biokinetic model. Since this model requires many equations, the descriptions are brief and are meant as a general overview of the calculations. All referenced equation numbers can be found in the second column of Table A-3 in Appendix A.

## 5.1 Basis for the Biokinetic Compartmental Structure

### 5.1.1 Postulates for the Compartmental Structure

The differential equations of the biokinetic model component are a consequence of the compartmental structure assumed for the model. Compartments in the model are identified as specific physiological or anatomical compartments with the exception of a residual soft tissue compartment designated as OTHER. The biokinetic components were chosen for several reasons: the importance of some tissues as target sites of toxicity, such as liver or kidney; the large potential lead burden of tissues , such as bone; the conventional definition of certain compartments in many pharmacokinetic models; that availability of data describing the concentrations of lead found in these tissues; and the need for a system that would require little additional expansion for future applications. Those compartments that have not been characterized are lumped together as other soft tissues. We chose to extend the compartmental structure of the biokinetic model for several purposes, looking ahead to the need for a system that would require these additional components in future applications. The most important features and assumptions include:

(1) Blood is divided into plasma and red blood cell compartments;

(2) The plasma compartment is extended to include the extracellular fluid that

exchanges rapidly with plasma, but is not accessible in usual blood sampling methods, and may account responsible for the volume of distribution of blood lead being about 1.7 times larger than the blood volume; The larger volume of distribution includes possible larger physical space as well as other factors such as increases resulting from protein binding.

(3) Lead from entry portals in lung and gut is taken up directly into the plasma-extracellular fluid pool, not into the red blood cells;

(4) The uptake of lead from the gut into the plasma-extracellular fluid pool is rate-limited by the lead concentration in the gut, but does not depend on the plasma lead concentration, so that uptake is independent of the internal biokinetics;

(5) The transfer of lead from plasma to red blood cells is partially limited by the finite capacity of the red cells to bind and retain lead, so that the whole blood lead concentration is not directly proportional to the lead uptake rate, especially at high levels of exposure;

(6) Transfer times among compartments may be scaled for children of different ages by means of body weight according to an allometric scaling that approximates whole body surface area;

(7) Transfer between plasma and red cells shows little age dependence;

(8) The kidney should be used as a separate compartment because data on kidney lead levels are available in both animal experiments and human autopsy data, because it is an important target site of lead toxicity, and because predicted kidney lead burdens may be of use in estimating the increased risk of hypertension or other adverse renal effects of lead exposure;

(9) The liver should be used as a separate compartment because data on liver lead levels are available in both animal experiments and human autopsy data, and because the liver is a possible target site of lead toxicity at elevated exposure levels;

(10) Separate compartments for cortical and trabecular bone were included, although transfer times for younger children are the same in these two compartments of the model. In older children large lead burdens in these tissues might reflect differences in transfer times and potential ease of mobilization of lead burdens in these tissues.

(11) Other soft tissue target sites of toxicity may be needed for future uses of the IEUBK model, such as the bone marrow for hematopoietic toxicity, or certain brain or central nervous system sites for neurotoxicity, these sites are biokinetically

"small" but toxicologically significant.

### 5.1.2 Division of the Whole Blood Pool

It has been known for some time that red blood cells carry the majority of lead in blood. Accordingly, a number of authors have inferred that it is necessary to subdivide the blood compartment and model separately the toxicologically active fraction of the blood lead in the plasma. References in Marcus (1985a,b) include McRoberts (1973), Baloh et al. (1974), Cavalleri et al. (1978a,b), deSilva (1981a,b), Everson and Patterson (1980), and Manton and Malloy (1983). Other studies on plasma lead include Chamberlain et al. (1978), Campbell et al. (1984), Cavalleri et al. (1981, 1984), Cavalleri and Minola (1987), Manton and Cook (1984), O'Flaherty (1992), Ong et al. (1986), and Simons et al. (1991). An age-dependent model for lead and other metals, using plasma as the central pool, was presented by Cristy et al. (1986), and expanded by Leggett (1993). The use of the whole blood lead concentrations rather than the plasma lead concentrations is traditional, based on the relative ease of accurate blood lead measurement and the relative difficulty measuring plasma lead.

The earliest version of the IEUBK Model used the approach of Harley and Kneip (1985), who assert that "While it is probably the plasma which provides the exchangeable fraction for the various organs, since cells and plasma remain in a constant ratio, the blood is treated as a single compartment since no benefit is obtained by using two compartments." However, in order to better represent the biological system, the IEUBK Model now treats red blood cells as a compartment separate from plasma. With the parameter values that are employed, the present approach does imply that the plasma and red blood cell lead concentrations achieve near-equilibrium level for most purposes.

The division of the whole blood pool into one or more plasma and erythrocyte pools in a compartmental model is described by Cavalleri et al. (1981), Marcus (1985a,b), and O'Flaherty (1992). The plasma pool probably consists of both a filterable or diffusible component, and a non-diffusible protein-bound component. Cavalleri et al. (1981) estimate about 4 µg Pb in the plasma-diffusible compartment, about 45 µg Pb in the plasma protein-bound compartment, and about 1850 µg Pb in the erythrocytes in the adult subjects in the Rabinowitz et al (1976) stable

isotope studies. We have chosen to combine the two plasma compartments, which are probably in a very rapid kinetic quasi-equilibrium. Attempts to model the kinetics of the plasma and extracellular fluid pools separately (Marcus 1985a,b) were not very successful. More importantly, we are not aware of any significant kinetic non-linearities for lead transfer between plasma compartments or plasma-ECF fractions that would affect the interpretation of blood lead vs. lead uptake relationships.

There is a large amount of conflicting literature on the quantitative relationship between plasma lead concentration and either the whole blood lead concentration or the red blood cell lead concentration. Some authors report that no predictive relationship is observed between plasma lead concentration and blood lead concentration (Rosen et al. 1974) or a weak and statistically non-significant relationship (Ong et al. 1986). However, most recent studies have found that there is a statistically significant relationship, whether estimated from a linear statistical model (Cavalleri et al. 1978a; DeSilva 1981a,b) or a non-linear statistical model (Manton and Cook 1984; Marcus 1985a). The non-linear models provide a far better fit to the data than do the linear models.

The ratio of plasma lead concentration to blood lead concentration is roughly constant at low concentrations (below 40-60 $\mu$g/dL) based on deSilva (1981a,b) as described and reanalyzed in Marcus (1985c). The ratio is variously estimated as 0.014 (deSilva, 1981a,b) or 0.028 (Cavalleri et al., 1978a) in adults, compared to an estimate of 0.06 (Ong and Lee, 1980 a,b). Concentrations are converted to mass by multiplying by compartmental volume. More recent assessments (Diamond and O'Flaherty, 1992a,b) suggest a much lower value, in the range of 0.2 to 2 percent. However, it is likely that the regression slopes have been seriously attenuated by the classic "error-in-variables" bias in least-squares regression models. This bias arises because the blood lead concentration, which is the predictor variable, is measured with some analytical uncertainty even if no systematic biases occur. It can be proven that the estimated regression slope of plasma lead concentration vs blood lead concentration will be closer to 0 (on an average) than the true value, and consequently the apparent value of the intercept will be higher than the true value. We are not aware of any analyses in which the estimate has been adjusted for measurement error bias. It is likely that the true value of the ratio of plasma lead concentration to

blood lead concentration is larger than 2 percent in these studies.

The IEUBK model includes a parameter that places an upper limit on red-cell lead binding capacity. *In vivo* and *in vitro* studies of blood lead kinetics and partitioning show evidence of saturable binding of lead to red blood cells at relatively high lead concentrations for adults. In the parameterization of this model, a high upper limit on binding is set, consistent with available observations. Accordingly this phenomenon has little effect of predictions of children's blood lead at normally anticipated levels of environmental exposure. However, as noted in the discussion of lead uptake above, there are significant nonlinearities in the empirical relationship between lead intake and observed blood lead. While this nonlinearity is currently attributed to saturation of lead uptake from the gut, it is possible that nonlinear binding in red cells may also play a role in explaining these observations.

It is known that lead is bound to two or more distinct fractions of the erythrocyte, as cited in (Marcus 1985a): (Bruenger et al. 1973; Clarkson and Kench, 1958; Ong and Lee 1980c; Stover 1959). This is in part attributable to the presence of lead-binding proteins in different parts of the erythrocyte (Raghavan and Gonick 1977; Raghavan et al. 1980, 1981; Gonick et al. 1981; Church et al. 1991). While limited lead-binding capacity in the erythrocyte is known from in-vitro studies (Barton 1989), it appears to be far more dependent on lead concentration in-vivo. The limited lead-binding capacity of the erythrocyte appears to be highly related to the toxicity of lead (Raghavan and Gonick 1977; Marcus and Schwartz 1987; Mushak 1991; Church et al. 1991). Workers and children in which lead was largely bound to the erythrocytes showed less frank toxicity and lower levels of biomarkers such as erythrocyte protoporphyrin.

An analysis by Marcus and Schwartz (1987) suggests that the blood lead concentrations at which one could infer significant saturation of red-cell lead binding were relatively low in children with iron deficiency (about 26 µg/dL), and higher ( > 33 µg/dL) in iron-replete or iron-abundant children. It is not clear whether differences in lead-binding among erythrocyte fractions are due to genetic polymorphism or to environmental differences such as vitamin and trace mineral nutritional status, nor do we understand the extent to which these lead-binding proteins may be induced by elevated lead exposure.

### 5.1.3 Plasma-Extracellular Fluid Compartment

Stable lead isotope studies allow estimation of the total blood lead volume of distribution (Rabinowitz et al. 1976). This volume is much larger than the volume of blood, averaging about 9.7 kg in a sample of five adult men whose average estimated blood volume was about 5.7 kg. The average ratio of volume of distribution to blood lead was about 1.7. The average residence time in blood was about 30 days. This suggests that the extra volume of distribution was due at least in part to distribution in a larger fluid volume. It is plausible to assign this to lead in extracellular fluids (denoted ECF) that exchange rapidly with plasma lead at the time scales of interest, a few hours to a day, but are not accessible with ordinary blood sampling intervals of six weeks or more. Support for the existence of an ECF pool that is kinetically indistinguishable from plasma at intervals longer than a few minutes is provided by several authors. Chamberlain et al. (1978), using lead radioisotopes, have argued for rapid transfer of lead into some readily accessible ECF. The existence of an intermediate ECF pool is sketched by Cavalleri et al. (1981), and is hinted at by Mallon (1983) and by Harley and Kneip (1985) in their discussion of a delay compartment they call "ECS [extracellular space]- gut".

Therefore, in the IEUBK Model, we have chosen to combine the plasma pool with the kinetically similar ECF as the central compartment.

## 5.2 Compartmental Specification for Model

The biokinetic component of the IEUBK model is structured as a compartmental model with transfer times between compartments as basic model building elements. The compartments are:

- Plasma-extracellular fluid (ECF)
- Red blood cells
- Liver
- Kidney
- Trabecular (spongy) bone
- Cortical (compact) bone

- Other soft tissues

The whole blood consists of the plasma portion of the plasma/ECF pool along with the red blood cells. The IEUBK model assumes that lead is transported between the central plasma-ECF compartment and most of the other compartments by a first-order kinetic process whose rate coefficients are independent of the compartment lead concentrations. The only rate coefficient that is concentration-dependent is the plasma/ECF to red blood cell coefficient, which assumes that the lead holding capacity of the red blood cells is saturable. Here, a maximum lead holding capacity of 1200 µg/dL is assumed for the red blood cells, based on Marcus (1993) reanalysis of data from Mallon (1983).

The above assumptions concerning the model structure and the nature of the kinetic transfer of lead between compartments result in the biokinetic component of the IEUBK model being governed by Equations B-6a through B-6i. This set of first-order differential equations governs the age-dependent accumulation of lead masses in the various body compartments. The basic tenet underlying the formulation of the differential equations is mass-balance.

### 5.2.1 Fluid Volumes and Organ Weights

As mentioned earlier in this document, many of the biokinetic calculations require body fluid volumes and organ weights as a function of the age of the child. The growth equations were fitted using a double logistic model (El Lozy, 1978, Karlberg, 1987), where the data sets for organ volume or weight were composites of childhood growth data from several handbooks (Altman and Ditmer, 1973; Spector, 1956; Silve et al., 1987). The fluid volumes calculated in Equations B-5a through B-5d are for blood (VOLBLOOD(t)), red blood cells (VOLRBC(t)), plasma (VOLPLASM(t)), and ECF (VOLECF(t)). All fluid volumes are in deciliters (dL). The weights calculated in Equations B-5e through B-5m are of the child's extra-cellular fluid (WTECF(t)), body (WTBODY(t)), bone (WTBONE(t)), trabecular bone (WTTRAB(t)), cortical bone (WTCORT(t)), kidney (WTKIDNEY(t)), liver (WTLIVER(t)), other soft tissue (WTOTHER(t)), and blood (WTBLOOD(t)). All weights are in kilograms (kg).

As indicated in Equation B-5d, the ECF volume is assumed to be 73% of the blood volume

based on Rabinowitz et al. (1976). This is the difference between the volume of distribution and the blood volume, which is assumed to be an actual physical volume. Other interpretations are possible. Rabinowitz measured the volumes in adults. These were proportionally adjusted on an age-relative basis for use in the model. Equations B-5e through B-5l are for organ weights and body weight. The divisor of 10 in Equation B-5e and B-5m converts deciliters of blood to liters of blood. The density of the ECF is assumed to be similar to water, one kg/L.

As indicated in Equation B-5g, for a child older than 12 months, WTBONE(t) is assumed to be a linear function of age. The slope and intercept parameters were estimated by fitting a simple linear regression model to data from Harley and Kneip (1985). Since little bone information was available for children less than one year of age, the weight of the bone is assumed to be a constant percentage of the weight of the body up to one year of age. As indicated in Equations B-5h and B-5i, trabecular and cortical bone are assumed to account for 20% and 80%, respectively, of the total bone weight (Leggett et al., 1982). As indicated in Equation B-5m, the density of blood is assumed to be 1.056 kg/L. Finally, as indicated in Equation B-5l, the weight of the other soft tissues is determined by subtracting the weight of all other body compartments from the weight of the body.

### 5.2.2 Compartmental Lead Transfer Times

The biokinetic model determines the compartmental lead transfer times as a function of tissue to blood lead concentration ratios. The ratios of lead concentration in the kidney (CRKIDBL(t)), liver (CRLIVBL(t)), bone (CRBONEBL(t)), and other soft tissue (CROTHBL(t)) (equations B-4a to 4d) to blood concentration are calculated based solely on the age of the child. The ratio of the lead mass in blood to the lead mass in plasma-ECF (RATBLPL) is assigned a value of 100 (equation B-3).

The compartmental lead transfer time equations (Equations B-1, B-2) model the movement of lead between the plasma-ECF and the red blood cells, the liver, the kidney, bone (trabecular and cortical), and other soft tissue, and the elimination pathways of skin, hair, and feces (See Figure 1). The rates at which the lead moves between the compartments are based on WTBODY(t) (equation B-5f), WTKIDNEY(t) (B-5j), WTLIVER(t)(B-5k), WTBONE(t)(B-5g),

WTTRAB(t)(B-5i), WTCORT(t)(B-5h), WTOTHER(t)(B-5l), VOLBLOOD(t)(B-5a), CRKIDBL(t)(B-2h), CRLIVBL(t)(B-2e, B-2f), CRBONEBL(t)(B-1h), CROTHBL(t)(B-2n, B-2o), and RATBLPL(B-3).

First, the lead transfer times (Equations B-1, B-2) from blood to urine (TBLUR(t))(B-5c), the liver (TBLLIV(t))(B-5b), the kidney (TBLKID(t))(B-5d), bone (TBLBONE(t))(B-5e), and other soft tissues (TBLOTH(t))(B-5c) are estimated. The transfer times are allometrically scaled by the ratio of WTBODY(t)(B-5f) to the weight of a child at 24 months (12.3 kg) raised to the 1/3 power. That is, multiplying the transfer times TBLUR(24), TBLLIV(24), TBLKID(24), TBLBONE(24), and TBLOTH(24) by the 1/3 power of the ratio of WTBODY(t) to WTBODY(24), $\left[\frac{\text{WTBODY(t)}}{\text{WTBODY(24)}}\right]^{0.33}$, yields TBLUR(t), TBLLIV(t), TBLKID(t), TBLBONE(t), and TBLOTH(t), respectively. The 1/3 power scaling exponent for transfer times (-1/3 power for transfer rates) corresponds to surface area scaling for growing children. That is, the surface area of the organ increased in proportion to the 2/3 power of child's increase in weight, and this increase in weight is a function of the child's age. For some applications, the empirical value of 0.26 fits better than 0.33 (Mordenti, 1986), but the difference is numerically unimportant in this application because the child grows only from 3.4 kg to 20 kg in this age range. In earlier versions of the model, scaling was based on organ weight or volume of fluid pool. For this version, all scaling is based on body weight to the 1/3 power, which is roughly the equivalent of body surface area scaling rather than organ surface area scaling. This simpler approach was adopted because of the uncertainties about other developmental changes in tissues that might affect age-dependent biokinetics, so that the more complicated earlier scaling approximation was not justified at this time.

Next, the lead transfer time from blood through the bile duct to feces (TBLFEC(t)) is the product of TBLUR(t) and the ratio of the urinary lead elimination rate to the endogenous fecal lead elimination rate (i.e., the ratio of endogenous fecal lead transfer time to urinary transfer time, denoted RATFECUR). TBLOUT(t), the lead transfer time from blood to the elimination pool via the soft tissue is TBLFEC(t) times the ratio of the endogenous fecal lead elimination rate to the elimination rate via soft tissue (RATOUTFEC). The lead transfer time from bone to blood (TBONEBL(t)) is the product of CRBONEBL(t), TBLBONE(t), and the ratio of the weight of

the bone (WTTRAB(t) plus WTCORT(t)) to VOLBLOOD(t) divided by 10.

At low concentrations when the red blood cell is nearly unsaturated, the ratio of lead mass in blood to lead mass in plasma-ECF (RATBLPL) is set to 100 (Equation B-3). The plasma-ECF to red blood cell lead transfer time (TPLRBC) is directly assigned a nominal value of 0.1 days. This value was chosen from a plausible range of values (0.02 to 0.25) based on several studies that examined the fate of injected, ingested, or inhaled lead over very short time intervals (Hursh and Suomela, 1968, Chamberlain et al., 1978, deSilva, 1981a,b, Campbell et al., 1984). The selection of 0.1 days represents our best judgment on the appropriate time scales for the composite process of the transfer of lead through the red blood cell membrane to the various lead-binding components of the red blood cell. An adjustment to the transfer time from plasma to red blood cells must then be made in the general case where the red blood cell is partially saturated (TBLRBC2). Our model assumption is that the transfer time from plasma to red blood cells increases with increasing saturation (Equation B-2.5). Transfer between plasma and red blood cells is assumed to show little age dependence apart from dependence on concentration.

Fixing the value of RATBLPL also affects the relationship of TBLUR to TPLUR and that of TBLBONE to TPLBONE. TRBCPL, the red blood cell to plasma-ECF lead transfer time, is the product of TPLRBC and RATBLPL minus a constant. The transfer of lead from plasma to red blood cells is partially limited by the finite capacity of the red cells to bind and retain lead. The whole blood lead concentration is therefore not directly proportional to lead uptake rates, especially at high levels of exposure. At high levels of exposure, the plasma lead concentration will increase in proportion to the uptake rate, but red blood cells that are partially saturated will increase with increasing uptake much more slowly, eventually approaching a maximum concentration, CONRBC. Therefore, the whole blood (weighted sum of lead concentration in plasma and lead concentration in red blood cells) will contain an increasingly larger fraction of the lead in plasma as uptake rates increase. The calculated blood lead concentration shows little dependence on TPLRBC for a wide range of values, once RATBLPL is specified (Equation B-2b).

The lead transfer times from plasma to urine (TPLUR(t)), the liver (TPLLIV(t)), the kidney (TPLKID(t)), and other soft tissue (TPLOTH(t)) are the ratios of TBLUR(t), TBLLIV(t),

TBLKID(t), and TBLOTH(t) to RATBLPL, respectively. The transfer time from blood to urine (TBLUR, days) is estimated by the blood lead mass (µg) divided by the rate (µg/day) at which lead is eliminated from the blood through the urine. A literature review revealed 17 adult studies for evaluating TBLUR (See Table B-1). The adult value of TBLUR was allometrically scaled to the range 0 to 84 months based on the proportionality between the blood volume (VOLBLOOD, dL) and the glomerular filtration rate (GFR, dL/day) for that age group. No direct data on the ratio VOLBLOOD/GFR was available; therefore, since GFR is proportional to body surface area for infants (10-20 weeks) and toddlers (24 months) (West, 1948) and for ages ≥ 24 months (Weil, 1955), scaling by surface area is equivalent to scaling by GFR.

TLIVFEC(t), TKIDPL(t), and TOTHOUT(t), the lead transfer times from the liver to the feces, the kidney to the plasma-ECF, and the other soft tissue to the elimination pool are the products of the concentration ratios of lead in the tissues to blood (CRLIVBL(t), CRKIDBL(t), and CROTHBL(t)), the transfer times from blood to the tissue of elimination pool (TBLFEC(t), TBLKID(t), and TBLOUT(t)), and a ratio of the weight of the tissue (WTLIVER(t), WTKIDNEY(t), and WTOTHER(t)) to VOLBLOOD(t). The lead transfer times from the liver to the plasma-ECF (TLIVPL(t)) and the other soft tissue to the plasma-ECF (TOTHPL(t)) are similarly calculated. The distinction is the transfer time term. TLIVPL(t) replaces TBLFEC(t) by a term involving TBLLIV(t) and TBLFEC(t), while TOTHPL(t) replaces TBLOUT(t) with a term involving TBLOTH(t) and TBLOUT(t).

While we recognize the complexity of bone kinetics, the Technical Review Workgroup for Lead concluded that a simplified approximation of bone lead kinetics would be adequate for modeling the relationship between bone and blood in young children. The primary purpose of the cortical and trabecular compartments in the IEUBK model is to provide the potential for long-term retention and storage of lead as an endogenous or internal source. Several more complicated models for bone lead kinetics have been developed (Marcus, 1985c,d; O'Flaherty, 1992; Leggett, 1993).

The kinetics of lead in bone can be extremely complicated. Bone is conventionally divided into two ty cortical (compact or dense bone material) and trabecular (cancellous or spongy bone, often plate-like structur Andriot and O'Flaherty (1993) have shown that bulk physical properties of cortical and trabecular bone in yo

mammals may be very similar. In view of the similar concentration ratios between lead in different bones an blood lead that may be calculated for children based on autopsy data (Barry 1981), we concluded that the bio properties of cortical and trabecular bone may also be rather similar for children less than 84 months.

In a detailed examination, skeletal tissue cannot be regarded as a single well-mixed fluid-like compartm Various models for lead transport in bone have been proposed, including non-first-order spatial diffusion mo (Marcus 1983, 1985c), first-order models with a series of radial concentric rings (O'Flaherty 1992) based on models for other bone-seeking elements (Marshall and Onckelinx 1968; Marshall 1969), and as a series of bo compartments that may be characterized as surface, shallow, or deep slow-turnover pools (Cristy 1986; Legg 1993). Marcus (1985c,d) showed that a compartmental approximation to bone lead diffusion was possible, w time scale for the longest-term retention depended on diffusion parameters. The most appropriate compartm model depends on the intended purpose of the model. The IEUBK model uses a single compartment for eac cortical and trabecular bone tissue, with a long retention time.

Isotopic tracer studies in adults do not usually allow detection of longer-lived plasma lead kinetic comp For example, in a three compartment first-order pharmacokinetic system, the elimination of lead from a sing intravenous injection can be described as the sum of three exponential terms (Gibaldi, 1982). In the central compartment (either plasma or whole blood, depending on the model) the lead concentration can be written a of three exponentially decreasing functions of time. The "fast" component goes to zero very quickly with in time from injection, and the "slow" component goes to zero only over a relatively long period of time. The I Model was designed for application to exposure scenarios in which there are long periods of relatively steady exposure, not to acute or relatively rapid sub-chronic exposure scenarios, so that only the slowest transfer com affect kinetics on the time scales of interest. In essence, the equivalent model is plasma exchange with the lo lead-binding constituents of the skeleton.

Both the lead transfer times from the trabecular bone and cortical bone to the plasma-ECF (TTRABPL(t), TCORTPL(t)), are assigned TBONEBL(t). TPLTRAB(t) and TPLCORT(t), the lead transfer times from the plasma-ECF to the trabecular and cortical bones are calculated as the ratio of TBLBONE(t) to a percentage of RATBLPL. TPLTRAB(t) uses 20% of RATBLPL in the denominator, while TPLCORT(t) uses 80% of RATBLPL.

Finally, TPLRBC2(t), the scaled lead transfer time from the plasma-ECF to the red blood cells, is calculated as the ratio of TPLRBC to a term involving MRBC, VOLRBC, and the maximum lead concentration capacity of red blood cells (CONRBC). CONRBC is assigned a

value of 1,200 µg/dL, based on estimates for adults (Marcus, 1985a), and infant baboons using data in Mallon (1983).

### 5.2.3 Tissue Lead Masses at Birth

The iterative nature of the biokinetic solution algorithm requires that compartmental lead masses be determined for a newborn child to begin the solution process. As indicated in Equation B-7a, the blood lead concentration of a newborn child (PBBLD0) is assumed to be 85% of the user-specified mother's blood lead concentration (PBBLDMAT). This relationship is discussed in U.S. Environmental Protection Agency, (1989a, pp.C-15 to C-18) and is based on data from the sources referred to in that document. Bioconcentration ratios in newborn children, using data in Barry (1981) were used to calculate tissue lead burdens at birth.

### 5.2.4 Compartmental Lead Masses and Blood Lead Concentration

The differential equations corresponding to the compartmental structure discussed in Section 5.1.1 represent the continuous lead kinetics in a child's body. From a computational viewpoint, however, the change in time does not occur continuously, but in discrete timesteps. Therefore, for the purpose of calculations, the differential equations labeled Equations B-6a through B-6i are represented by difference equations labeled Equations B-6.5a through B-6.5i. For instance, the differential Equation B-6d

$$\frac{dMRBC(t)}{dt} = \frac{MPLECF(t)}{TPLRBC2(t)} - \frac{MRBC(t)}{TRBCPL}$$

is represented by the difference Equation B-6.5d

$$\frac{MRBC(t) - MRBC(t - TimeStep)}{TimeStep} = \frac{MPLECF(t)}{TPLRBC2(t)} - \frac{MRBC(t)}{TRBCPL}.$$

The backward Euler solution algorithm solves the difference equations for the compartmental lead masses at the end of the iteration time "t". These compartmental lead masses are then used to determine the child's blood lead concentration at time "t". Details of the difference equations and

the solution algorithm are provided below.

The difference equations are structured to represent the lead masses, transfer rates, and elimination rates at the beginning and end of a time interval. The argument "t-TimeStep" denotes lead masses and transfer rates at the beginning of the time interval, while the argument "t" represents these quantities at the end of the interval. The length of the interval is denoted by the user-specified variable, TimeStep. The backward Euler solution algorithm solves these difference equations so that the child's compartmental lead masses and blood lead concentration at the end of the iteration may be determined.

The backward Euler solution algorithm is a stable, time-efficient numerical algorithm. The stability of the algorithm allows larger timesteps to be employed, thus reducing the required computational time. The basic premise of the solution algorithm is that the increase in a compartmental lead mass over an interval divided by the length of the interval is equal to the total lead inflow rate minus the total lead outflow rate at the end of the interval. The solution to the difference equations over a specified interval gives the compartmental lead masses at the end of the interval as a function of the inflow and outflow rates at the end of the interval. Equating the unknown changes in the compartmental lead mass over the interval to the difference between the unknown lead inflow and outflow rates at the end of the interval yields a solution. That is, the equation for the compartmental lead masses at the end of the interval can be solved in terms of the compartmental lead masses at the beginning of the interval. The equations employed by the backward Euler solution algorithm are presented as Equations B-9a through B-9i.

The compartmental lead masses for a newborn child discussed in Section 5.2.3 (MPLECF(0), MRBC(0), MPLASM(0), MCORT(0), MKIDNEY(0), MLIVER(0), MOTHER(0), and MTRAB(0)) are used as initial values to begin the iterative biokinetic solution algorithm. Given these parameters, the lead masses for the red blood cells (MRBC(t)), liver (MLIVER(t)), kidney (MKIDNEY(t)), trabecular and cortical bone (MTRAB(t), MCORT(t)), plasma-ECF (MPLASM(t)), and other soft tissue (MOTHER(t)) are calculated. Each of these parameters are calculated at each iteration through age 84 months. As indicated in Equations B-10a and B-10b, the child's blood lead concentration (PBBLD(t)) is calculated as an average monthly value over the number of time intervals in the month.

# 6.0 PROBABILITY DISTRIBUTION COMPONENT

The fourth component of the IEUBK model estimates, for a hypothetical child or population of children, a plausible distribution of blood lead concentrations centered on the geometric mean blood lead concentration predicted by the model from available information about children's exposure to lead. From this distribution, the model calculates the probability that children's blood lead concentrations will exceed the user-selected level of concern.

Risk estimation and plotting of probability distributions requires the selection of two parameters, the blood lead level of concern or cutoff level and the Geometric Standard Deviation (GSD). A value of 10 $\mu$g/dL is generally used as the blood lead level of concern, but other values can be selected by the user.

The GSD is a measure of the relative variability in the blood lead of a child of a specified age, or of children from a hypothetical population, whose lead exposures in a specified dwelling are known. Many factors can cause children in environments with similar environmental lead concentrations to have different blood lead concentrations. These include biological and behavioral variability, measurement variability from repeat sampling, sample location variability, and analytical error. In the model, the GSD is intended to reflect only individual blood lead variability, not variability in blood lead concentrations where different individuals are exposed to substantially different media concentrations of lead.

The determination of the GSD and its use in risk estimation are discussed in detail in the Guidance Manual. The Guidance Manual describes the selection of the GSD value of 1.6, based on calculations of GSDs from a number of specific sites. The manual emphasizes that the GSD values should be similar at all sites and site-specific values should not be needed unless there are great differences in child behavior and lead biokinetics among different sites. It also describes how to estimate a site-specific, inter-individual GSD when necessary.

# 7.0 USER CONTROL WITHIN THE IEUBK MODEL

The purpose of this section is to explicitly outline the choices a user of the IEUBK lead model may make in estimating a child's blood lead concentration. Throughout Sections 3 through 5, references have been made to "user- specified" parameters or decisions. Two flow-charts are provided to illustrate where the user-specified parameters or decisions occur and exactly which parameters are affected. Parameter names are listed in each flow-chart. Table B-1 provides an index of all the parameters a user may access.

Figure 6 describes the overall structure of the IEUBK lead model emphasizing the decisions and input parameters a user may control. From the Main Menu and the Parameter Entry Submenu, the user may make several decisions on the sources of lead intake. These decisions and the associated user specified parameters are shown in Figure 6. Turning to Figure 7, the user may provide the outdoor air lead concentration (out_air_concentration), the percentage of outdoor air lead that becomes indoor air lead (indoorpercent), the time a child spends outdoors (time_out(t)), and the ventilation rate for a child (vent_rate(t)).

The diet model component requires the user to decide if the dietary lead intake should be calculated from individual dietary sources. The user may choose to enter the dietary lead intake directly (user_diet_intake(t)). Otherwise, individual sources of dietary lead are considered. The user may enter the lead concentration for fish (UserFishConc), game animal meat (UserGameConc), home grown fruits (UserFruitConc), and home grown vegetables (UserVegConc) and the fraction of meat consumed as fish or game animal meat (userFishFraction, userGameFraction), fruit consumed as home grown fruit (userFruitFraction), and vegetables consumed as home grown vegetables (userVegFraction).

For the water lead model, the user may first enter the child's water consumption (water_consumption(t)). Next, the user decides which of the two model options to use to determine the water lead intake. Either the user can assume a constant water lead concentration, by entering values for constant_water_conc, or the user may calculate the water lead concentration by considering several sources of water. If several sources of water are to be considered, the user would enter the fraction of total water consumed as first draw water (FirstDrawFraction) and fountain water (FountainFraction) with the remainder being the amount

of water consumed as HomeFlushed. The lead concentration in first draw water (FirstDrawConc), fountain water (FountainConc), and a flushed faucet at home (HomeFlushedConc) are also entered.

In the soil and dust lead model option, the user may first enter the lead concentration in soil (soil_concentration(t)). The user may then decide if the household dust lead concentration is to be calculated. The user may enter the indoor household dust lead concentration (user_dust_conc(t)) directly. This choice is used when household dust is a measured source of dust exposure for the child.

If the user chooses to calculate the dust lead concentration, then the user may enter the percentage of soil lead concentration that characterizes the soil contribution to indoor household

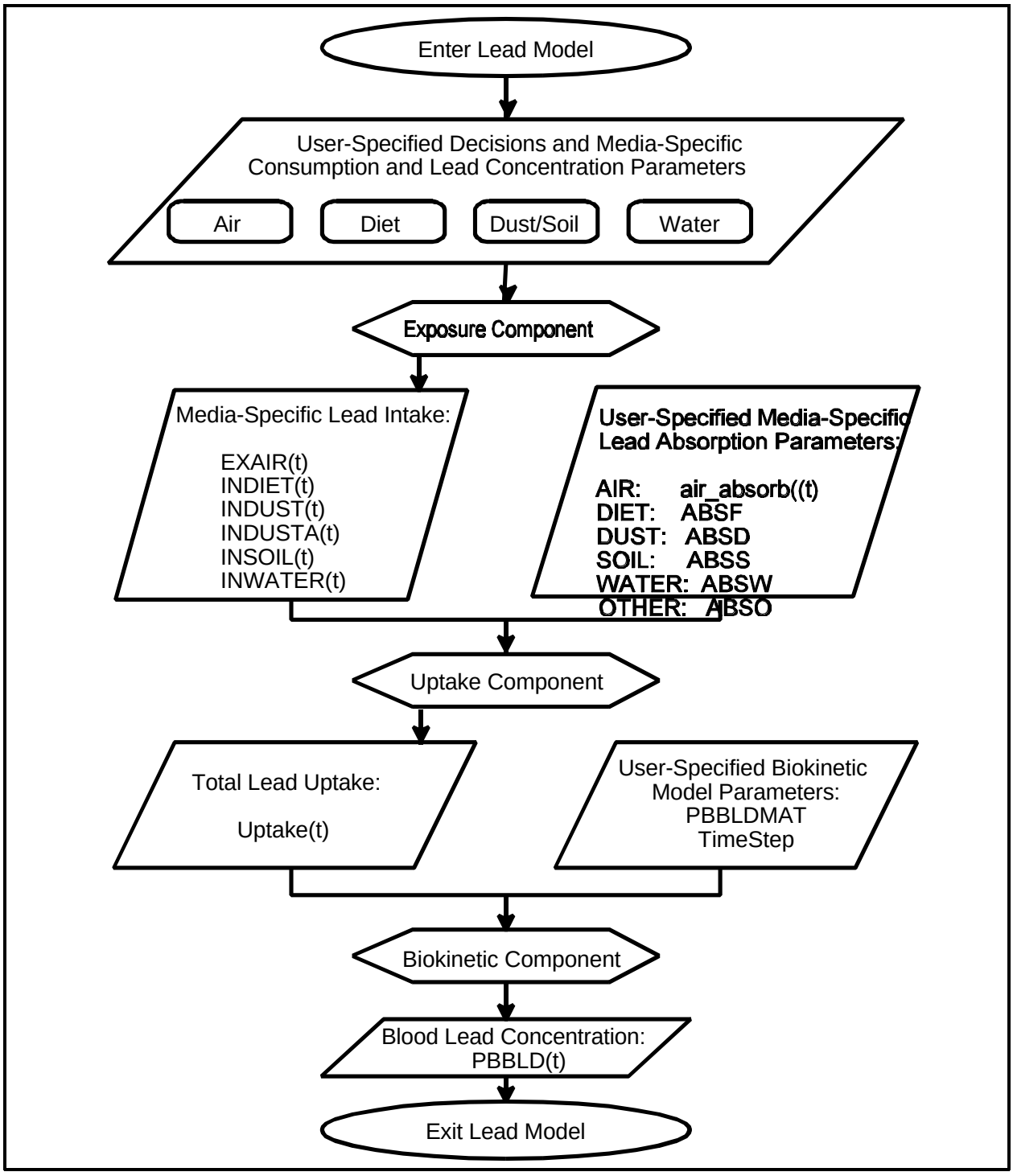



**Figure 6. Structure of the IEUBK model with emphasis on the user control of input parameters and decisions.**

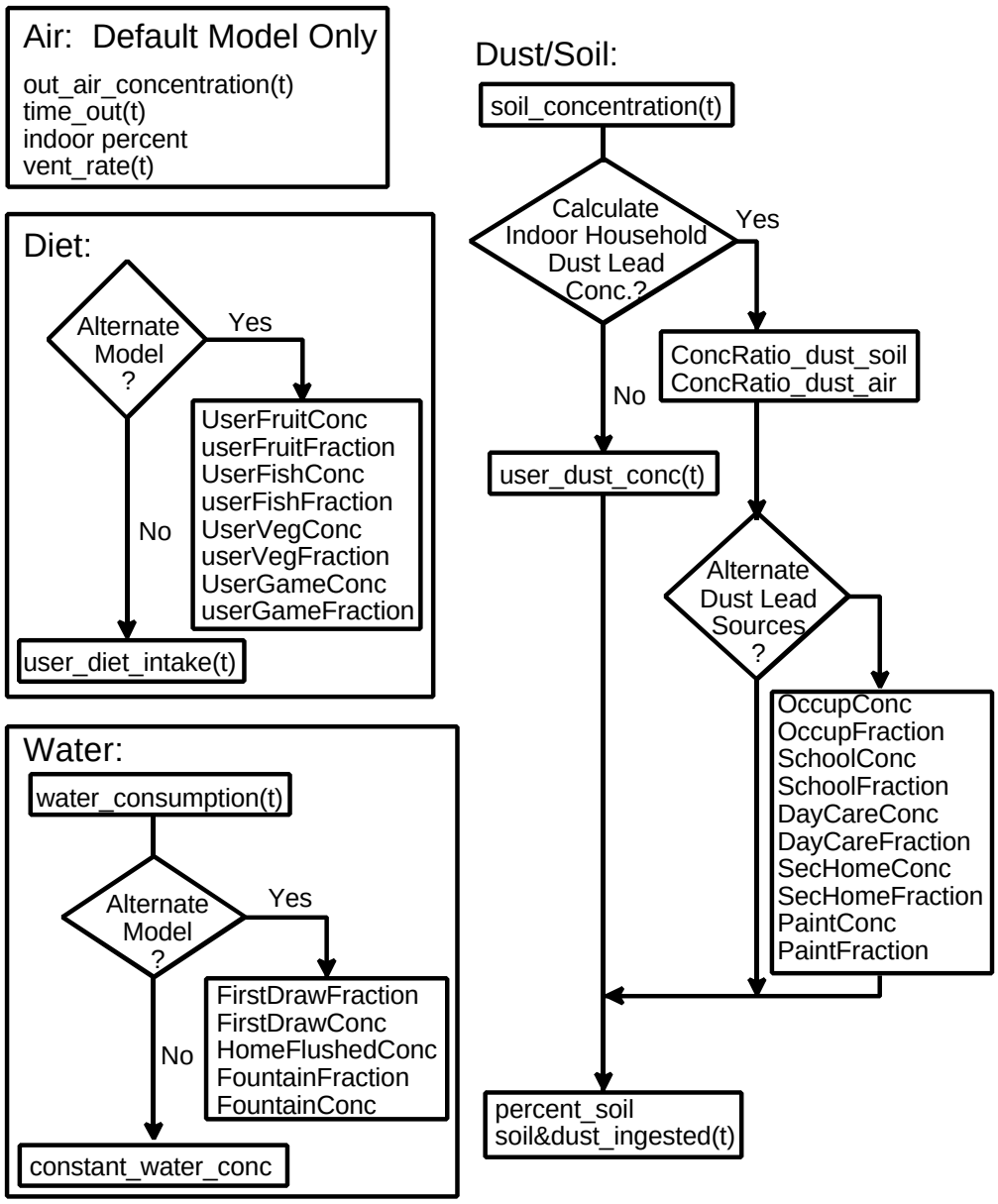



**Figure 7. User specified decisions and parameters that determine the media-specific consumption and lead concentration parameters.**

dust lead (contrib_percent); the user may also enter a factor that relates the air lead contribution to house dust lead concentration (multiply_factor). Once these have been entered, the user may decide that alternate sources of dust lead should be considered. The user may enter values for the fraction of total dust ingested as dust from any of the following: the parents occupation (OccupFraction), school (SchoolFraction), daycare (DaycareFraction), secondary home (SecHomeFraction), and paint (PaintFraction), and the corresponding dust lead concentration from the parents occupation (OccupConc), school (SchoolConc), daycare (DaycareConc), secondary home (SecHomeConc), or paint (PaintConc).

Finally, for all dust model options, the user may enter the values for the percentage of dust and soil ingested as soil (weight_soil) and the amount of soil and dust ingested (soil_ingested).

Returning to Figure 6, once the decisions have been made and the parameter values entered for the media-specific consumption and lead concentrations, the calculations for the exposure component are performed. The output from this component are the media-specific lead intakes, EXAIR(t), INDIET(t), INDUST(t), INDUSTA(t), INSOIL(t), INWATER(t), and INOTHER(t). These values are used as input into the uptake component.

The user may then enter the media-specific lead absorption parameters. These parameters are the passive absorption fraction at low doses (PAF), the net absorption coefficient for air lead (air_absorb(t)), and the total absorption coefficient for dietary lead at low doses (ABSF), dust lead (ABSD), soil lead (ABSS), and water lead (ABSW), and other ingested lead sources (ABSO). UPTAKE(t), the child's total lead uptake, is calculated by combining all of the user-provided default parameters in the exposure and uptake components of the model.

The final set of parameters the user may specify are the maternal blood lead concentration (PBBLDMAT) and the length of the time-step to be used in the solution algorithm (TimeStep). PBBLDMAT and TimeStep serve as input to the biokinetic component, where the child's blood lead concentration (PBBLOODEND(t), averaged across each month, is calculated.

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# APPENDIX A: EQUATIONS AND PARAMETERS IN THE IEUBK LEAD MODEL

**TABLE A-1. EQUATIONS OF THE EXPOSURE MODEL COMPONENT**

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Air Lead | E-1 | IndoorConc(t) = 0.01 * indoorpercent * air_concentration(t) |
| | E-2 | $TWA(t) = \frac{[time\_out(t) * but\_air\_concentration(t)] + [(24 - time\_out(t)) * IndoorConc(t)]}{24}$ |
| | E-3 | **EXAIR(t) = TWA(t) * vent_rate(t)** |
| Dietary Lead | E-4a<br><br>E-4b | **INDIET(t) = diet_intake(t)**<br>***or***<br>**INDIET(t) = DietTotal(t) = *InOtherDiet(t)*+ InMeat(t) + InGame(t) + InFish(t) + InCanVeg(t) + InFrVeg(t) + InHomeVeg(t) + InCanFruit(t) + InFrFruit(t) + InHomeFruit(t)** |

Note: Italicized variables are not parameters in the model. These variables are only intermediate variables.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| | E-5a | **InMeat(t) = (1 - userFishFraction - userGameFraction) * meat(t)** |
| | E-5b | **InCanVeg(t) = (1 - userVegFraction) * can_veg(t)** |
| | E-5c | **InFrVeg(t) = (1 - userVegFraction) * f_veg(t)** |
| | E-5d | **InCanFruit(t) = (1 - userFruitFraction) * can_fruit(t)** |
| | E-5e | **InFrFruit(t) = (1 - userFruitFraction) * f_fruit(t)** |
| | E-5f | **InHomeFruit(t) = userFruitFraction * fruit_all(t) * UserFruitConc** |
| | E-5g | **InHomeVeg(t) = userVegFraction * veg_all(t) * UserVegConc** |
| | E-5h | **InFish(t) = userFishFraction * fish(t) * UserFishConc** |
| | E-5i | **InGame(t) = userGameFraction * game(t) * UserGameConc** |
| Water Lead | E-6a<br>E-6b | INWATER(t) = water_consumption(t) * constant_water_conc<br>*or*<br>INWATER(t) =water_consumption(t) * (HomeFlushedConc * HomeFlushedFraction + FirstDrawConc * FirstDrawFraction + FountainConc * FountainFraction) |
| | E-7 | HomeFlushedFraction = 1 - FirstDrawFraction - FountainFraction |
| Soil Lead | E-8 | INSOIL(t) = constant_soil_conc * soil_ingested(t) * (0.01 * weight_soil) |

Note: Italicized variables are not parameters in the model. These variables are only intermediate variables.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Dust Lead | E-9a | INDUST(t) = constant_dust_conc * soil_ingested(t) * (1- 0.01 * weight_soil) |
| | E-9b | INDUSTA(t) = 0; for all t |
| | E-9c | INDUST(t) = DustTotal(t) * soil_indoor(t) * HouseFraction |
| | E-9d | INDUSTA(t) = OCCUP(t) + SCHOOL(t) + DAYCARE(t) + SECHOME(t) + PAINT(t) |
| | E-9.5 | HouseFraction = 1 - OccupFraction - SchoolFraction - DaycareFraction - SecHomeFraction - PaintFraction |
| | E-10 | DustTotal(t) = soil_ingested(t) * (0.01 * (100 - weight_soil)) |
| | E-11 | soil_indoor(t) = (contrib_percent * constant_soil_conc(t) + (multiply_factor * air_concentration(t))* |
| | E12a | OCCUP(t) = DustTotal(t) * OccupFraction * OccupConc |
| | E12b | SCHOOL(t) = DustTotal(t) * SchoolFraction * SchoolConc |
| | E-12c | DAYCARE(t) = DustTotal(t) * DaycareFraction * DaycareConc |
| | E-12d | SECHOME(t) = DustTotal(t) * SecHomeFraction * SecHomeConc |
| | E-12e | PAINT(t) = DustTotal(t) * PaintFraction * PaintConc |

* Age dependent

Note: Italicized variables are not parameters in the model. These variables are only intermediate variables.

## TABLE A-2. EQUATIONS OF THE UPTAKE MODEL COMPONENT

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Absorption Coefficients | U-1a | $UPDIET(t) = INDIET(t) * ABSF * AVF * \left[ PAF + \frac{1 - PAF}{1 + \frac{AVINTAKE}{SATINTAKE(t)}} \right]$ |
| | U-1b | $UPWATER(t) = INWATER(t) * ABSW * AVW * \left[ PAF + \frac{1 - PAF}{1 + \frac{AVINTAKE}{SATINTAKE(t)}} \right]$ |
| | U-1c | $UPDUST(t) = INDUST(t) * ABSD * AVD * \left[ PAF + \frac{1 - PAF}{1 + \frac{AVINTAKE}{SATINTAKE(t)}} \right]$ |
| | U-1d | $UPOTHER(t) = INOTHER(t) * ABSO * AVO * \left[ PAF + \frac{1 - PAF}{1 + \frac{AVINTAKE}{SATINTAKE(t)}} \right]$ |
| | U-1e | $UPSOIL(t) = INSOIL(t) * ABSS * AVS * \left[ PAF + \frac{1 - PAF}{1 + \frac{AVINTAKE}{SATINTAKE(t)}} \right]$ |
| | U-1f | $UPDUSTA(t) = INDUSTA(t) * ABSD * AVD * \left[ PAF + \frac{1 - PAF}{1 + \frac{AVINTAKE}{SATINTAKE(t)}} \right]$ |
| | U-1g | $UPGUT(t) = UPDIET(t) + UPWATER(t) + UPDUST(t) + UPOTHER(t) + UPSOIL(t) + UPDUSTA(t)$ |
| Absorption Coefficients | U-2 | $AVINTAKE = ABSD * INDUST(t) + ABSD * INDUSTA(t) + ABSS * INSOIL(t) + ABSF * INDIET(t) + ABSO * INOTHER(t) + ABSW * INWATER(t)$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate variables.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Absorption Coefficients | U-3 | $SATINTAKE(t) = SATINTAKE24 * \left[ \frac{WTBODY(t)}{WTBODY(24)} \right]$ |
| Total LeadUptake | U-4 | UPAIR(t) = air_absorb(t)*0.01*EXAIR(t) |
| | U-5 | UPTAKE(t) = 30*{(UPDIET(t) + UPWATER(t) + UPDUST(t) + UPSOIL(t) + UPDUSTA(t) + UPOTHER(t) + UPAIR(t)} |

Note: Italicized variables are not parameters in the model. These variables are only intermediate variables.

## TABLE A-3. EQUATIONS OF THE BIOKINETIC MODEL COMPONENT

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Transfer Times | B-1a | $TBLUR(t) = TBLUR(24) * \left( \frac{WTBODY(t)}{WTBODY(24)} \right)^{0.33}$ |
| | B-1b | |
| | B-1c | |
| | B-1d | $TBLOTH(t) = TBLOTH(24) * \left( \frac{WTBODY(t)}{WTBODY(24)} \right)^{0.33}$ |
| | B-1e | $TBLKID(t) = TBLKID(24) * \left( \frac{WTBODY(t)}{WTBODY(24)} \right)^{0.33}$ |
| | B-1f | $TBLBONE(t) = TBLBONE(24) * \left( \frac{WTBODY(t)}{WTBODY(24)} \right)^{0.33}$ |
| | B-1g | $TBLFEC(t) = RATFECUR * TBLUR(t)$ |
| | B-1h | $TBLOUT(t) = RATOUTFEC * TBLFEC(t)$ |
| | | $TBONEBL(t) = CRBONEBL(t) * TBLBONE(t) * \left[ \frac{\{WTTRAB(t) + WTCORT(t)\}}{\left( \frac{VOLBLOOD(t)}{10} \right)} \right]$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Transfer Times (continued) | B-2a | $TPLRBC = 0.1$ |
| | B-2b | $TPLUR(t) = TPLRBC \times \left[ \frac{TBLUR(t)}{RATBLPL} - \frac{0.55}{(0.55+0.73)} \right]$ |
| | B-2c | $TPLLIV(t) = \frac{TBLLIV(t)}{RATBLPL}$ |
| | B-2d | $TLIVPL(t) = CRLIVBL(t) * \left[ \frac{TBLLIV(t)}{\left(1 - \frac{TBLLIV(t)}{TBLFEC(t)}\right)} \right] * \left[ \frac{WTLIVER(t)}{\left(\frac{VOLBLOOD(t)}{10}\right)} \right]$ |
| | B-2e | $TLIVFEC(t) = CRLIVBL(t) * TBLFEC(t) * \left[ \frac{WTLIVER(t)}{\left(\frac{VOLBLOOD(t)}{10}\right)} \right]$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Transfer Times (continued) | B-2g | $TPLKID(t) = \frac{TBLKID(t)}{RATBLPL}$ |
| | B-2h | $TKIDPL(t) = CRKIDBL(t) * TBLKID(t) * \left[ \frac{WTKIDNEY(t)}{\left( \frac{VOLBLOOD(t)}{10} \right)} \right]$ |
| | B-2i | $TPLTRAB(t) = \frac{TBLBONE(t)}{(0.2 * RATBLPL)}$ |
| | B-2j | $TTRABPL(t) = TBONEBL(t)$ |
| | B-2k | $TPLCORT(t) = \frac{TBLBONE(t)}{(0.8 * RATBLPL)}$ |
| | B-2l | **TCORTPL(t) = TBONEBL(T)** |
| | B-2m | $TPLOTH(t) = \frac{TBLOTH(t)}{RATBLPL}$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Transfer Times (continued) | B-2n | $TOTHPL(t) = CROTHBL(t) * \left[\frac{TBLOTH(t)}{\left(1 - \frac{TBLOTH(t)}{TBLOUT(t)}\right)}\right] * \left[\frac{WTOTHER(t)}{\left(\frac{VOLBLOOD(t)}{10}\right)}\right]$ |
| | B-2o | $TOTHOUT(t) = CROTHBL(t) * TBLOUT(t) * \left[\frac{WTOTHER(t)}{\left(\frac{VOLBLOOD(t)}{10}\right)}\right]$ |
| | B-2.5 | $TPLRBC2(t) = \frac{TPLRBC}{\left[1 - \frac{MRBC(t)}{(VOLRBC(t-1) * CONRBC)}\right]}$ |
| Blood to Plasma-ECF Lead Mass Ratio | B-3 | $RATBLPL = 100$ |
| Fluid Volumes and Organ Weights | B-4a | $CRKIDBL(t) = 0.777 + [2.35 * \{1 - \exp(-0.0468*t)\}]$ |
| | B-4b | $CRLIVBL(t) = 1.1 + [3.5 * \{1 - \exp(-0.0462*t)\}]$ |
| | B-4c | $CRBONEBL(t) = 6.0 + [215.0 * \{1 - \exp(-0.000942*t)\}]$ |
| | B-4d | $CROTHBL(t) = 0.931 + [0.437 * \{1 - \exp(-0.00749*t)\}]$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Fluid Volumes and Organ Weights (continued) | B-5a | $VOLBLOOD(t) = \left[\frac{10.67}{1 + \exp\left\{-\frac{(t-6.87)}{7.09}\right\}}\right] + \left[\frac{21.86}{1 + \exp\left\{-\frac{(t-88.15)}{26.73}\right\}}\right]$ |
| | B-5b | $VOLRBC(t) = \left[\frac{4.31}{1 + \exp\left\{-\frac{(t-6.45)}{10.0}\right\}}\right] + \left[\frac{26.47}{1 + \exp\left\{-\frac{(t-129.61)}{25.98}\right\}}\right]$ |
| | B-5c | $VOLPLASM(t) = \left[\frac{6.46}{1 + \exp\left\{-\frac{(t-6.81)}{5.74}\right\}}\right] + \left[\frac{8.83}{1 + \exp\left\{-\frac{(t-65.66)}{23.62}\right\}}\right]$ |
| | B-5d | **VOLECF(t) = 0.73 * VOLBLOOD(t)** |
| | B-5e | $WTECF(t) = 0.73 * \frac{VOLBLOOD(t)}{10}$ |
| | B-5f | $WTBODY(t) = \left[\frac{8.375}{1 + \exp\left\{-\frac{(t-3.80)}{3.60}\right\}}\right] + \left[\frac{17.261}{1 + \exp\left\{-\frac{(t-48.76)}{20.63}\right\}}\right]$ |
| | B-5g | **WTBONE(t) = 0.111 * WTBODY(t)  $t \leq$ 12 months**<br>**= 0.838 + 0.02 * t  t > 12 months** |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| | B-5h | WTCORT = 0.8*WTBONE |
| | B-5i | WTRAB = 0.2*WTBONE |
| | B-5j | $WTKIDNEY(t) = \left[\frac{0.050}{1 + \exp\left\{-\frac{(t-5.24)}{4.24}\right\}}\right] + \left[\frac{0.106}{1 + \exp\left\{-\frac{(t-65.67)}{34.11}\right\}}\right]$ |
| | B-5k | $WTLIVER(t) = \left[\frac{0.261}{1 + \exp\left\{-\frac{(t-9.82)}{3.67}\right\}}\right] + \left[\frac{0.584}{1 + \exp\left\{-\frac{(t-55.65)}{37.64}\right\}}\right]$ |
| | B-5l | WTOTHER(t) = WTBODY(t) - WTKIDNEY(t) - WTLIVER(t) - WTTRAB(t) - WTCORT(t) - WTBLOOD(t) - WTECF(t) |
| | B-5m | $WTBLOOD(t) = 1.056 * \frac{VOLBLOOD(t)}{10}$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Masses (Differential Equations) | | **NOTE: The following equations (B-6a to B-6i) represent the correct mathematical specification. These differential equations are translated into difference equations employing the forward Euler solution in the series B-6.5a to B-6.5i, then to the solution algorithm for differential equations using the backward Euler method, or alternate difference equation scheme.** |
| | B-6a | **dMPLECF(t)/dt = UPTAKE(t) + INFLOW(t) - OUTFLOW(t)** |
| | B-6b | $INFLOW(t) = \frac{MLIVER(t)}{TLIVPL(t)} + \frac{MKIDNEY(t)}{TKIDPL(t)} + \frac{MOTHER(t)}{TOTHPL(t)} + \frac{MTRAB(t)}{TTRABPL(t)} + \frac{MCORT(t)}{TCORTPL(t)} + \frac{MRBC(t)}{TRBCPL(t)}$ |
| | B-6c | $OUTFLOW(t) = MPLECF * \left[\frac{1}{TPLUR(t)} + \frac{1}{TPLLIV(t)} + \frac{1}{TPLKID(t)} + \frac{1}{TPLOTH(t)} + \frac{1}{TPLTRAB(t)} + \frac{1}{TPLCORT(t)} + \frac{1}{TPLRBC2(t)}\right]$ |
| | B-6d | $\frac{dMRBC(t)}{dt} = \frac{MPLECF(t)}{TPLRBC2(t)} - \frac{MRBC(t)}{TRBCPL(t)}$ |
| | B-6e | $\frac{dMLIVER(t)}{dt} = \frac{MPLECF(t)}{TPLLIV(t)} - MLIVER(t) * \left[\frac{1}{TLIVPL(t)} + \frac{1}{TLIVFEC(t)}\right]$ |
| | B-6f | $\frac{dMKIDNEY(t)}{dt} = \frac{MPLECF(t)}{TPLKID(t)} - \frac{MKIDNEY}{TKIDPL}$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Masses (Differential Equations) (continued) | B-6g | $\frac{dMOTHER(t)}{dt} = \frac{MPLECF(t)}{TPLOTH(t)} - MOTHER(t) * \left[\frac{1}{TOTHPL(t)} + \frac{1}{TOTHOUT(t)}\right]$ |
| | B-6h | $\frac{dMTRAB(t)}{dt} = \frac{MPLECF(t)}{TPLTRAB(t)} - \frac{MTRAB(t)}{TTRABPL(t)}$ |
| | B-6i | $\frac{dMCORT(t)}{dt} = \frac{MPLECF(t)}{TPLCORT(t)} - \frac{MCORT(t)}{TCORTPL(t)}$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Masses (Difference Equations) | B-6.5a | $\frac{MPLECF(t) - MPLECF(t-TimeStep)}{TimeStep} = UPTAKE(t) + INFLOW(t) - OUTFLOW(t)$ |
| | B-6.5b | $INFLOW(t) = \frac{MLIVER(t)}{TLIVPL(t)} + \frac{MKIDNEY(t)}{TKIDPL(t)} + \frac{MOTHER(t)}{TOTHPL(t)} + \frac{MTRAB(t)}{TTRABPL(t)} + \frac{MCORT(t)}{TCORTPL(t)} + \frac{MRBC(t)}{TRBCPL}$ |
| | B-6.5c | $OUTFLOW(t) = MPLECF * \left[\frac{1}{TPLUR(t)} + \frac{1}{TPLLIV(t)} + \frac{1}{TPLKID(t)} + \frac{1}{TPLOTH(t)} + \frac{1}{TPLTRAB(t)} + \frac{1}{TPLCORT(t)} + \frac{1}{TPLRBC2(t)}\right]$ |
| | B-6.5d | $\frac{MRBC(t) - MRBC(t-TimeStep)}{TimeStep} = \frac{MPLECF(t)}{TPLRBC2(t)} - \frac{MRBC(t)}{TRBCPL}$ |
| | B-6.5e | $\frac{MLIVER(t) - MLIVER(t-TimeStep)}{TimeStep} = \frac{MPLECF(t)}{TPLLIV(t)} - MLIVER(t) * \left[\frac{1}{TLIVPL(t)} + \frac{1}{TLIVFEC(t)}\right]$ |
| | B-6.5f | $\frac{MKIDNEY(t) - MKIDNEY(t-TimeStep)}{TimeStep} = \frac{MPLECF(t)}{TPLKID(t)} - \frac{MKIDNEY(t)}{TKIDPL(t)}$ |
| | B-6.5g | $\frac{MOTHER(t) - MOTHER(t-TimeStep)}{TimeStep} = \frac{MPLECF(t)}{TPLOTH(t)} - MOTHER(t) * \left[\frac{1}{TOTHPL(t)} + \frac{1}{TOTHOUT(t)}\right]$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Compartmental Lead Masses (Difference Equations) (continued) | B-6.5h | $\frac{MTRAB(t) - MTRAB(t-TimeStep)}{TimeStep} = \frac{MPLECF(t)}{TPLTRAB(t)} - \frac{MTRAB(t)}{TTRABPL(t)}$ |
| | B-6.5i | $\frac{MCORT(t) - MCORT(t-TimeStep)}{TimeStep} = \frac{MPLECF(t)}{TPLCORT(t)} - \frac{MCORT(t)}{TCORTPL(t)}$ |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| Tissue Lead Masses and Blood Lead Concentration at Birth | B-7a | PBBLD0 = 0.85 * PBBLDMAT |
| | B-7b | $$MPLECF(0) = \frac{PBBLD0 * (VOLPLASM(0) + VOLRBC(0)) * \left(\frac{TPLRBC}{TimeStep}\right) * (1.7 - HCT0)}{\left(\frac{TRBCPL(0)}{TimeStep} + \frac{TPLRBC}{TimeStep}\right)}$$ |
| | B-7c | $$MRBC(0) = \frac{PBBLD0 * (VOLPLASM(0) + VOLRBC(0)) * \left(\frac{TRBCPL(0)}{TimeStep}\right)}{\left(\frac{TRBCPL(0)}{TimeStep} + \frac{TPLRBC}{TimeStep}\right)}$$ |
| | B-7d | $$MPLASM(0) = \frac{MPLECF(0)}{(1.7 - HCT0)}$$ |
| | | NOTE: Equations B-7b, B-7c, and B-7d represent the distribuition of fetal blood lead, derived from the mother's blood lead, at birth. In this simplified form, these equations are numerically equivalent to the following equations that more precisely represent the distribution of lead at birth. The difference in these two sets of equations is insignificant after 2-3 iteration steps. |
| | | $$MPLECF(0) = \frac{PBBLD0 * (VOLPLASM(0) + VOLRBC(0)) * \left(\frac{TPLRBC}{TimeStep}\right)}{\left(\frac{TRBCPL(0)}{TimeStep}\right)}$$ |
| | | $$MRBC(0) = PBBLD0 * (VOLPLASM(0) + VOLRBC(0)) * \left[1 - 0.416\left(\frac{TPLRBC(0)}{TRBCPL(0)}\right)\right]$$ |
| | | $$MPLASM(0) = \frac{MPLECF(0)}{0.416}$$ |

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| **Tissue Lead Masses and Blood Lead Concentration at Birth** | **B-7e** | MCORT(0) = 78.9 *** PBBLD0 * WTCORT(0) |
| | **B-7f** | MKIDNEY(0) = 10.6 * PBBLD0 * WTKIDNEY(0) |
| | **B-7g** | MLIVER(0) = 13.0 * PBBLD0 * WTLIVER(0) |
| | **B-7h** | MOTHER(0) = 16.0 * PBBLD0 * WTOTHER(0) |
| | **B-7I** | MTRAB(0) = 51.2 * PBBLD0 * WTTRAB(0) |

Note: Italicized variables are not parameters in the model. These variables are only intermediate values.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| **Compartmental Lead Masses (Solution Algorithm)** | **B-8a** | $$MPLECF(t) = \frac{\left[MPLECF(t-TimeStep) + \left(UPTAKE(t) * \frac{TimeStep}{30}\right) + SUM3(t)\right]}{[1 + \{TimeStep * SUM1(t)\} - \{TimeStep * SUM2(t)\}]}$$ |
| | **B-8b** | $$SUM1(t) = \frac{1}{TPLUR(t)} + \frac{1}{TPLRBC2(t)} + \frac{1}{TPLLIV(t)} + \frac{1}{TPLKID(t)} + \frac{1}{TPLOTH(t)} + \frac{1}{TPLTRAB(t)} + \frac{1}{TPLCORT(t)}$$ |
| | **B-8c** | $$SUM2(t) = \frac{1}{TPLRBC2(t) * \left(\frac{TRBCPL}{TimeStep} + 1\right)} + \frac{1}{TPLLIV(t) * \left(\frac{TLIVPL(t)}{TimeStep} + \frac{TLIVPL(t)}{TLIVALL(t)} + 1\right)} + \frac{1}{TPLKID(t) * \left(\frac{TKIDPL(t)}{TimeStep} + 1\right)} + \frac{1}{\left(\frac{TOTHPL(t)}{TimeStep} + \frac{TOTHPL(t)}{TOTHALL(t)} + 1\right)} + \frac{1}{TPLTRAB(t) * \left(\frac{TTRABPL(t)}{TimeStep} + 1\right)} + \frac{1}{TPLCORT(t) * \left(\frac{TCORTPL(t)}{TimeStep} + 1\right)}$$ |
| | **B-8d** | $$SUM3(t) = \frac{MRBC(t-TimeStep)}{\left(\frac{TRBCPL}{TimeStep} + 1\right)} + \frac{MLIVER(t-TimeStep)}{\left(\frac{TLIVPL(t)}{TimeStep} + \frac{TLIVPL(t)}{TLIVALL(t)} + 1\right)} + \frac{MKIDNEY(t-TimeStep)}{\left(\frac{TKIDPL(t)}{TimeStep} + 1\right)} + \frac{MOTHER(t-TimeStep)}{\left(\frac{TOTHPL(t)}{TimeStep} + \frac{TOTHPL(t)}{TOTHALL(t)} + 1\right)} + \frac{MTRAB(t-TimeStep)}{\left(\frac{TTRABPL(t)}{TimeStep} + 1\right)} + \frac{MCORT(t-TimeStep)}{\left(\frac{TCORTPL(t)}{TimeStep} + 1\right)}$$ |

Note: In the solution algorithm (Equations B-8a - B-10c), we have chosen for clarity to distinguish the subscript (i) as denoting parameter values that change each month, whereas the subscript (t) indicates values that change with each iteration interval. The source code uses a different notation.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| **Compartmental Lead Masss (Solution Algorithm) (continued)** | **B-9a** | $$MRBC(t) = \frac{MRBC(t-TimeStep) + \left[MPLECF(t) * \left(\frac{TimeStep}{TPLRBC2(t)}\right)\right]}{\left[1 + \frac{TimeStep}{TRBCPL}\right]}$$ |
| | **B-9b** | $$MLIVER\ (t) = \frac{MLIVER\ (t-TimeStep) + \left[MPLECF\ (t) * \left(\frac{TimeStep}{TPLLIV\ (t)}\right)\right]}{\left[1 + \frac{TimeStep}{TLIVALL\ (t)}\right]}$$ |
| | **B-9c** | |
| | **B-9d** | $$MOTHER\ (t) = \frac{MOTHER\ (t-TimeStep) + \left[MPLECF\ (t) * \left(\frac{TimeStep}{TPLOTH\ (t)}\right)\right]}{\left[1 + \frac{TimeStep}{TOTHALL\ (t)}\right]}$$ |
| | **B-9e** | |

Note: In the solution algorithm (Equations B-8a - B-10c), we have chosen for clarity to distinguish the subscript (i) as denoting parameter values that change each month, whereas the subscript (t) indicates values that change with each iteration interval. The source code uses a different notation.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| **Compartmental Lead Masses (Solution Algorithm) (continued)** | **B-9f** | $$MCORT(t) = \frac{MCORT(t-TimeStep) + \left[MPLECF(t) * \left(\frac{TimeStep}{TPLCORT(t)}\right)\right]}{\left[1 + \frac{TimeStep}{TCORTPL(t)}\right]}$$ |
| | **B-9g** | $$MPLASM(t) = \frac{MPLECF(t) * VOLPLASM(t)}{VOLECF(t) + VOLPLASM(t)}$$ |
| | **B-9h** | $$TOTHALL(t) = \frac{1}{\left[\frac{1}{TOTHPL(t)} + \frac{1}{TOTHOUT(t)}\right]}$$ |
| | **B-9i** | $$TLIVALL(t) = \frac{1}{\left[\frac{1}{TLIVPL(t)} + \frac{1}{TLIVFEC(t)}\right]}$$ |

Note: In the solution algorithm (Equations B-8a - B-10c), we have chosen for clarity to distinguish the subscript (i) as denoting parameter values that change each month, whereas the subscript (t) indicates values that change with each iteration interval. The source code uses a different notation.

| EQUATION GROUP | EQUATION NUMBER | EQUATION |
|---|---|---|
| **Blood Lead Concentration** | | **NOTE: Equation B-10a is computed by a cumulative loop** |
| | **B-10a** | $$BLOOD(t) = \sum_{t=1}^{STEPS} \frac{MRBC(t) + MPLASM(t)}{VOLBLOOD(i-1)}$$ |
| | **B-10b** | **TimeStep = 1/iterations per day** |
| | | **STEPS = 30 / TimeStep = iterations per month** |
| | **B-10c** | **PBBLOODEND(i) = BLOOD(t)/STEPS** |

Note: In the solution algorithm (Equations B-8a - B-10c), we have chosen for clarity to distinguish the subscript (i) as denoting parameter values that change each month, whereas the subscript (t) indicates values that change with each iteration interval. The source code uses a different notation.

# APPENDIX B: DESCRIPTION OF PARAMETERS IN THE IEUBK LEAD MODEL

# TABLE B-1. DESCRIPTION OF PARAMETERS IN THE IEUBK LEAD MODEL

| PARAMETER NAME | DESCRIPTION | DEFAULT VALUE OR EQN. NO. | AGE RANGE (mo) | I or E | BASIS FOR VALUES/EQUATIONS | UNITS | EQUATION WHERE USED |
|---|---|---|---|---|---|---|---|
| ABSD | Total absorption for dust at low saturation | 0.3 | 0-84 | E | Based on US EPA (1989a). | unitless | U-1c, U-2 |
| ABSF | Total absorption for food at low saturation | 0.5 | 0-84 | E | Based on US EPA (1989a). | unitless | U-1a,U-2 |
| ABSO | Total absorption for other ingested lead at low saturation | 0.0 | 0-84 | E | Based on the default condition that there is no other source of lead ingestion in the household. | unitless | U-1d,U-2 |
| ABSS | Total absorption for soil at low saturation | 0.3 | 0-84 | E | Based on US EPA (1989a). | unitless | U-1e,U-2 |
| ABSW | Total absorption for water at low saturation | 0.5 | 0-84 | E | Based on US EPA (1989a). | unitless | U-1b,U-2 |
| air_absorb(t) | Net percentage absorption of air lead | 32<br>32<br>32<br>32<br>32<br>32<br>32 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Deposition efficiencies of airborne lead particles were estimated by U S EPA (1989a). A respiratory deposition/absorption rate of 25% to 45% is reported for young children living in non-point source areas while a rate of 42% is calculated for those living near point sources. An intermediate value of 32% was chosen. | % | U-4 |
| air_concentration(t) | Outdoor air lead concentration | 0.1<br>0.1<br>0.1<br>0.1<br>0.1<br>0.1<br>0.1 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Based on the lower end of the range 0.1 - 0.3 µg Pb/$m^3$ that is reported for outdoor air lead concentration in U.S. cities without lead point sources (US EPA 1989) | µg/$m^3$ | E-1,2,11 |

NOTE: I = interior parameter, E = Exterior, user selectable parameter

| PARAMETER NAME | DESCRIPTION | DEFAULT VALUE OR EQN. NO. | AGE RANGE (mo) | I or E | BASIS FOR VALUES/EQUATIONS | UNITS | EQUATION WHERE USED |
|---|---|---|---|---|---|---|---|
| AVF, AVW, AVD, AVO, AVS | Bioavailability | 1 | 0-84 | I | Parameter added for later flexibility in describing the absorption process; has no effect in current algorithm. | unitless | U-1a-U-1e |
| AVINTAKE | Available intake | U-2 | 0-84 | I | The amount of Pb that is available for intake | µg | U-1a,b,c,d,e |
| can_fruit(t) | Lead intake from canned fruit when fruit is consumed only in canned form | 1.811<br>1.063<br>1.058<br>0.999<br>0.940<br>0.969<br>1.027 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | µg/day | E-5d |
| can_veg(t) | Lead intake from canned vegetables when vegetable is consumed only in canned form | 0.074<br>0.252<br>0.284<br>0.295<br>0.307<br>0.291<br>0.261 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | µg/day | E-5b |
| contrib_percent | Ratio of indoor dust lead concentration to soil lead concentration | 0.70 | 0-84 | E | Analysis of soil and dust data from 1983 East Helena study (US EPA, 1989) | Fg/g per Fg/g | E-11 |
| CONRBC | Maximum lead concentration capacity of red blood cells | 1200 | 0-84 | I | Based on Marcus (1983) reanalysis of infant baboon data from Mallon (1983). See Marcus (1985a) for assessment of form of relationship and estimates from data on human adults [data from deSilva (1981a,b), Manton and Malloy (1983), and Manton and Cook (1984)] and infant and juvenile baboons (Mallon, 1983). | µg/dL | B-2.5 |
| constant_soil_conc(t) | Soil lead concentration | 200<br>200<br>200<br>200<br>200<br>200<br>200 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Air Quality Criteria Document for Lead. (US EPA, 1986) | µg/g | E-8 |

NOTE: I = interior parameter, E = Exterior, user selectable parameter

| PARAMETER NAME | DESCRIPTION | DEFAULT VALUE OR EQN. NO. | AGE RANGE (mo) | I or E | BASIS FOR VALUES/EQUATIONS | UNITS | EQUATION WHERE USED |
|---|---|---|---|---|---|---|---|
| constant_water_conc | Water lead concentration | 4.0 | 0-84 | E | Based on analysis of data from the American Water Works Service Co. (Marcus, 1989) | µg/L | E-6a |
| CRBONEBL(t) | Ratio of lead concentration (µg/kg) in bone to blood lead concentration (µg/L) | B-4c | 0-84 | I | Data in Barry (1981) were used.<br><br>Bone lead concentration was calculated as an arithmetic average of the concentrations in the rib, tibia, and calvaria. The blood lead concentrations were taken directly from the study.<br><br>Concentrations in each of the following eight age groups were considered: stillbirths, 0-12 days, 1-11 mos, 1-5 yrs, 6-9 yrs, 11-16 yrs, adult (men), and adult (women). Ages 0 and 40 yrs were assumed for stillbirths and adults, respectively. | L/kg | B-1h |
| CRKIDBL(t) | Ratio of lead concentration (µg/kg) in kidney to blood lead concentration (µgL) | B-4a | 0-84 | I | Data in Barry (1981) were used.<br><br>Lead concentrations in kidney (combined values for cortex and medulla) and blood were taken directly from the study.<br><br>Concentrations in each of the following eight age groups were considered: stillbirths, 0-12 days, 1-11 mos, 1-5 yrs, 6-9 yrs, 11-16 yrs, adult (men), and adult (women). Ages 0 and 40 yrs were assumed for stillbirths and adults, respectively. | L/kg | B-2h |
| CRLIVBL(t) | Ratio of lead concentration (µg/kg) in liver to blood lead concentration (µg/l) | B-4b | 0-84 | I | Data in Barry (1981) were used.<br><br>Lead concentrations in liver and blood were taken directly from the study.<br><br>Concentrations in each of the following eight age groups were considered: stillbirths, 0-12 days, 1-11 mos, 1-5 yrs, 6-9 yrs, 11-16 yrs, adult (men), and adult (women). Ages 0 and 40 yrs were assumed for stillbirths and adults, respectively. | L/kg | B-2e,2f |

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|---|---|---|---|---|---|---|---|
| CROTHBL(t) | Ratio of lead concentration (µg/kg) in other soft tissue to blood lead concentration (µg/L) | B-4d | 0-84 | I | Data in Barry (1981) were used.<br><br>Lead concentration ratio for soft tissues was calculated as a weighted arithmetic average of concentration ratios for muscle (53.8%), fat (24.0%), skin (9.4%), dense connective tissue (4.4%), brain (2.7%), GI tract (2.3%), lung (1.9%), heart (0.7%), spleen (0.3%), pancreas (0.2%), and aorta (0.2%), where the weights applied are given in parentheses. The weight associated with each soft tissue component was equal to the weight of the component (kg) divided by weight of all soft tissues (kg). These weights were estimated from Schroeder and Tipton (1968) and are assumed to apply in the range 0-84 months of age.<br><br>Concentrations in each of the following eight age groups were considered: stillbirths, 0-12 days, 1-11 mos, 1-5 yrs, 6-9 yrs, 11-16 yrs, adult (men), and adult (women). Ages 0 and 40 yrs were assumed for stillbirths and adults, respectively. | L/kg | B-2n,2o |
| DAYCARE(t) | Dust lead intake at daycare | E-12c | 0-84 | I | Simple combination of the total amount of dust ingested daily, fraction of total dust ingested as daycare dust, and dust lead concentration at daycare. | µg/day | E-9d |
| DaycareConc | Dust lead concentration at daycare | 200 | 0-84 | E | Based on the assumption that default daycare dust concentrations are the same as default residence dust concentrations. | µg/g | E-12c |
| DaycareFraction | Fraction of total dust ingested daily as daycare dust | 0 | 0-84 | E | Based on the default assumption that the child does not attend daycare. | unitless | E-9.5,12c |
| diet_intake(t) | User-specified diet lead intake | 5.53<br>5.78<br>6.49<br>6.24<br>6.01<br>6.34<br>7.00 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | µg/day | E-4a |
| DietTotal(t) | Total Dietary Intake | E-4b | 0.84 | I | Summation of all dietary sources; same as INDIET(t) | µg/day | E-4b |
| DustTotal(t) | Daily amount of dust ingested | E-10 | 0-84 | I | Simple combination of total amount soil and dust ingested daily and fraction of this combined ingestion that is dust alone. | g/day | E-9c,12a-12e |

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|---|---|---|---|---|---|---|---|
| EXAIR(t) | Air lead intake | E-3 | 0-84 | I | Simple combination of average air lead concentration and ventilation rate. | µg/day | U-4 |
| f_fruit(t) | Lead intake from fresh fruit if no home-grown fruit is consumed | 0.039<br>0.196<br>0.175<br>0.175<br>0.179<br>0.203<br>0.251 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | µg/day | E-5e |
| f_veg(t) | Lead intake from fresh vegetables if no home-grown vegetables are consumed | 0.148<br>0.269<br>0.475<br>0.466<br>0.456<br>0.492<br>0.563 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | µg/day | E-5c |
| FirstDrawConc | First Draw water lead concentration | 4.0 | 0-84 | E | Based on analysis of data from the American Water Works Service Co. (Marcus, 1989) | µg/L | E-6b |
| FirstDrawFraction | Fraction of total water consumed daily as first draw | 0.5 | 0-84 | E | In the absence of appropriate data, a conservative value corresponding to consumption largely after four fours stagnation time was used, e.g. early morning or late afternoon. | unitless | E-6b,7 |
| FountainConc | Fountain water lead concentration | 10 | 0-84 | E | Default assumption is that the drinking fountain has a lead-lined reservoir, but that consumption is not always first draw. Therefore, a value was selected from the range of 5-25 Fg/L. | µg/L | E-6b |
| FountainFraction | Fraction of total water consumed daily from fountains | 0.15 | 0-84 | E | A default value was based on 4-6 trips to the water fountain at 40-50 ml per trip. | none | E-6b,7 |
| fruit_all(t) | Daily amount of all frults consumed | 38.481<br>169.000<br>63.166<br>61.672<br>61.848<br>67.907<br>80.024 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | g/day | E-5f |

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|---|---|---|---|---|---|---|---|
| HomeFlushedConc | Home flushed water lead concentration | 1.0 | 0-84 | E | Based on analysis of data from the American Water Works Service Co. (Marcus, 1989) | µg/L | E-6b |
| HCT0 | Hematocrit at birth | 0.45 | 0 | I | Data from Silve et al. (1987); also Spector (1956) and Altman and Ditmer (1973) | decimal percent | B-7b,d |
| InCanFruit(t) | Lead intake from canned fruit | E-5d | 0-84 | I | Simple combination of the fraction of non-home grown fruits consumed daily, and lead intake from canned fruits when fruits are consumed only in canned form. | µg/day | E-4b |
| InCanVeg(t) | Lead intake from canned vegetables | E-5b | 0-84 | I | Simple combination of the fraction of vegetables consumed daily as non-home grown, and lead intake from canned vegetables when vegetables are consumed only in canned form. | µg/day | E-4b |
| INDIET(t) | Diet lead intake | E-4a *or* E-4b | 0-84 | I | Two options are provided.<br><br>Default option - Considers composite diet lead intake.<br><br>Alternate option - Combines lead intake from several individual components of diet. | µg/day | U-1a, U-2 |
| IndoorConc(t) | Indoor air lead concentration | E-1 | 0-84 | I | Algebraic expression of relationship | $\mu g/m^3$ | E-2 |
| indoorpercent | Ratio of indoor dust lead concentration to corresponding outdoor concentration | 30 | 0-84 | E | Based on homes near lead point sources. The default value is reported in OAQPS (USEPA 1989, pp A-1) and is estimated by Cohen and Cohen (1980). | % | E-1 |
| INDUST(t) | Household dust lead intake | E-9a *or* E-9c | 0-84 | I | Two options are provided.<br><br>Default option - Assumes that all dust lead exposure is from the household.<br><br>Alternate option - Considers dust lead exposure from several alternative sources as well. | µg/day | U-1-c, U-2 |

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| PARAMETER NAME | DESCRIPTION | DEFAULT VALUE OR EQN. NO. | AGE RANGE (mo) | I or E | BASIS FOR VALUES/EQUATIONS | UNITS | EQUATION WHERE USED |
|---|---|---|---|---|---|---|---|
| INDUSTA(t) | Lead intake from alternate dust sources | E-9b<br>*or*<br>E-9d | 0-84 | I | Two options are provided.<br><br>Default option - Assumes that lead intake from alternate sources is zero.<br><br>Alternate option - Combines lead intake from several alternate sources. | µg/day | U-1.5c, U-2 |
| InFish(t) | Lead intake from fish | E-5h | 0-84 | I | Simple combination of total meat consumed daily, fraction of meat consumed as fish, and lead concentration in fish. | µg/day | E-4b |
| InFrFruit(t) | Lead intake from non-home grown fresh fruits | E-5e | 0-84 | I | Simple combination of the fraction of fruits consumed daily as non-home grown and lead intake from fresh fruits. | µg/day | E-4b |
| InFrVeg(t) | Lead intake from non-home grown fresh vegetables | E-5c | 0-84 | I | Simple combination of the fraction of vegetables consumed daily as non-home grown and lead intake from fresh vegetables. | µg/day | E-4b |
| InGame(t) | Lead intake from game animal meat | E-5i | 0-84 | I | Simple combination of total meat consumed daily, fraction of meat consumed as game animal meat, and lead concentration in game animal meat. | µg/day | E-4b |
| InHomeFruit(t) | Lead intake from home grown fruits | E-5f | 0-84 | I | Simple combination of total amount of fruit consumed daily, fraction of fruit consumed as home grown, and lead concentration in home grown fruit. | µg/day | E-4b |
| InHomeVeg(t) | Lead intake from home grown vegetables | E-5g | 0-84 | I | Simple combination of total amount of vegetable consumed daily, fraction of vegetables consumed as home grown, and lead concentration in home grown vegetables. | µg/day | E-4b |
| InMeat(t) | Lead intake from non-game and non-fish meat | E-5a | 0-84 | I | Simple combination of total amount of meat consumed daily, fraction of meat consumed as non-game and non-fish meat, and lead concentration in non-game and non-fish meat. | µg/day | E-4b |
| InOtherDiet(t) | Combined lead intake from dairy food, juice, nuts, beverage, pasta, bread, sauce, candy, infant and formula food | 3.578<br>3.506<br>3.990<br>3.765<br>3.545<br>3.784<br>4.215 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Sum of the amounts of lead ingested in food items not substituted by the calculation of exposure to lead in home grown fruits and vegetables, wild game or fish. Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | µg/day | E-4b, E-4c |

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|---|---|---|---|---|---|---|---|
| INOTHER(t) | Combined other sources of ingested lead, such as paint chips, ethnic medicines, etc. | 0 | 0-84 | E | Assumes no other sources of ingested lead | Fg/day | U-1d, U-2 |
| INSOIL(t) | Soil lead intake | E-8 | 0-84 | I | Simple combination of total amount of soil and dust ingested daily, fraction of this combined ingestion that is soil alone, and lead concentration in soil. | µg/day | U-1e,U-2 |
| INWATER(t) | Water lead intake | E-6a *or* E-6b | 0-84 | I | Two options are provided.<br><br>Default option - Simple combination of water consumed daily and a constant water lead concentration.<br><br>Alternate option - Water lead concentration depends on contribution from several individual sources of water. | µg/day | U-1b, U-2 |
| MCORT(t) | Mass of lead in cortical bone | B-7e *and* B-9f | 0 *and* 0-84 | I | 0 months - Simple combination of an assumed bone to blood lead concentration ratio, blood lead concentration, and weight of cortical bone. Basis for value of bone to blood lead concentration ratio was human autopsy data (Barry, 1981).<br><br>0-84 months - Application of the Backward Euler solution algorithm to the system of differential equations (B-6a-B-6i in Table A-3).<br><br>Both cases above assume that the cortical bone to blood lead concentration ratio is equal to the bone (composite) to blood lead concentration ratio. | µg | B-6b,6i,6.5b, 6.5i,8a,9f |
| meat_all(t) | Daily amount of meat (including fish and game) consumed | 29.551<br>87.477<br>95.700<br>101.570<br>107.441<br>111.948<br>120.961 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | g/day | E-5h |

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|---|---|---|---|---|---|---|---|
| meat(t) | Lead intake from meat if no game meat or fish is consumed | 0.226<br>0.630<br>0.811<br>0.871<br>0.931<br>1.008<br>1.161 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | µg /day | E-5a |
| MKIDNEY(t) | Mass of lead in kidney | B-7f<br>*and*<br>B-9c | 0<br>*and*<br>0-84 | I | 0 months - Simple combination of an assumed kidney to blood lead concentration ratio, blood lead concentration, and weight of kidney. Basis for the value of the kidney to blood lead concentration ratio was human autopsy data (Barry, 1981).<br><br>0-84 months - Application of the Backward Euler solution algorithm to the system of differential equations (B-6a-B-6i in Table A-3). | µg | B-6b,6f,6.5b,6.5f,8d,9c |
| MLIVER(t) | Mass of lead in liver | B-7g<br>*and*<br>B-9b | 0<br>*and*<br>0-84 | I | 0 months - Simple combination of an assumed liver to blood lead concentration ratio, blood lead concentration, and weight of the liver. Basis for the value of the liver to blood lead concentration ratio was human autopsy data (Barry, 1981).<br><br>0-84 months - Application of the Backward Euler solution algorithm to the system of differential equations (B-6a-B-6i in Table A-3). | µg | B-6b,6e,6.5b,6.5e,8d,9b |
| MOTHER(t) | Mass of lead in soft tissues | B-7h<br>*and*<br>B-9d | 0<br>*and*<br>0-84 | I | 0 months - Simple combination of an assumed soft tissue to blood lead concentration ratio, blood lead concentration, and weight of the soft tissues at birth. Basis for the value of soft tissue to blood lead concentration ratio was human autopsy data (Barry et al., 1981), using total lead and total weight of other tissue.<br><br>0-84 months - Application of the Backward Euler solution algorithm to the system of differential equations (B-6a-B-6i in Table A-3). | µg | B-6b,6g,6.5b,6.5g,8d,9d |
| MPLASM(t) | Mass of lead in plasma pool | B-7d<br>*and*<br>B-9g | 0<br>*and*<br>0-84 | I | 0 months - Simple combination of the mass of lead in blood and red blood cells.<br><br>0-84 months - Based on the assumption that the lead concentration in plasma-ECF is equal to the lead concentration in the plasma. | µg | B-10a |

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|---|---|---|---|---|---|---|---|
| MPLECF(t) | Mass of lead in plasma-extra-cellular fluid (plasma-ECF) | B-7b *and* B-8a | 0 *and* 0-84 | I | 0 months - Based on two assumptions.<br><br>(1) masses of lead in plasma-ECF and red blood cells are in kinetic quasi-equilibrium, and<br>(2) lead concentration in the plasma-ECF is equal to lead concentration in the plasma.<br><br>0-84 months - Application of the Backward Euler solution algorithm to the system of differential equations (B-6a-B-6i in Table A-3). | µg | B-6a,6c-6i,6.5a, 6.5c-6.5i,8a,9a-9g |
| MRBC(t) | Mass of lead in red blood cells | B-7c *and* B-9a | 0 *and* 0-84 | I | 0 months - Based on the assumption that the masses of lead in plasma-ECF and red blood cells are in kinetic quasi-equilibrium.<br><br>0-84 months - Application of the Backward Euler solution algorithm to the system of differential equations (B-6a-B-6i in Table A-3). | µg | B-6a,6d,6.5a,6.5d,8d,9a,10a |
| MTRAB(t) | Mass of lead in trabecular bone | B-7i *and* B-9e | 0 *and* 0-84 | I | 0 months - Simple combination of an assumed bone to blood lead concentration ratio, blood lead concentration, and weight of trabecular bone. Basis for the value of bone to blood lead concentration ratio was human autopsy data (Barry, 1981).<br><br>0-84 months - Application of the Backward Euler solution algorithm to the system of differential equations (B-6a-B-6i in Table A-3).<br><br>Both cases above assume that trabecular bone to blood lead concentration ratio is equal to bone (composite) to blood lead concentration ratio. | µg | B-6b,6h,6.5b,6.5h,8d,9e |
| multiply_factor | Ratio of indoor dust lead concentration to air lead concentration | 100 | 0-84 | E | Analyses of the 1983 East Helena study in (USEPA 1989, Appendix B-8) suggest about 267 µg/g increment of lead in dust for each µg /m³. lead in air. A much smaller factor of 100 µg/g PbD per µg/m³ is assumed for non-smelter community exposure. | µg /g per µg/m$^3$ | E-11 |
| OCCUP(t) | Dust lead intake from secondary occupation | E-12a | 0-84 | I | Simple combination of amount of dust ingested, fraction of the total dust ingested as secondary occupational dust, and lead concentration in secondary occupational dust | µg/day | E-9d |
| OccupConc | Secondary occupational dust lead concentration | 1200 | 0-84 | E | Air Quality Criteria Document for Lead. (US EPA, 1986) | µg/g | E-12a |

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|---|---|---|---|---|---|---|---|
| OccupFraction | Fraction of total dust ingested as secondary occupation dust | 0 | 0-84 | E | The default condition is that there is no adult in the residence who works at a lead-related job. | unitless | E-9.5,12a |
| PAINT(t) | Dust lead intake from lead based home paint | E-12e | 0-84 | I | Simple combination of amount of dust ingested daily, fraction of the total dust ingested as lead-based home paint, and lead concentration in lead-based home paint. | µg/day | E-9d |
| PaintConc | Leadconcentration in housedust containing lead based paint | 1200 | 0-84 | E | Air Quality Criteria Document for Lead. (US EPA, 1986) | µg/g | E-12e |
| PAF | Fraction of total absorption as passive absorption at low dose | 0.20 | 0-84 | E | Based on in vitro everted rat intestine data (Aungst and Fung, 1981), reanalyses (Marcus, 1994) of infant baboon data (Mallon, 1983) and infant duplicate diet study (Sherlock and Quinn, 1986) | unitless | U-1a thru U-1f |
| PaintFraction | Fraction of total dust ingested that results from lead based home paint | 0 | 0-84 | E | The default is that there is no lead-based paint in the home. | unitless | E-12e |
| PBBLDMAT | Maternal blood lead concentration | 2.5 | adult | E | Based in part on Midvale 1989 study. The default value of 2.5 Fg/dL has little influence of the early post natal exposure of the child. | µg/dL | B-7a |
| PBBLD0 | Lead concen-tration in blood | B-7a | 0 | I | Based on 85% of maternal blood lead concentration (US EPA 1989) | µg/dL | B-7b, 7c, 7e-7i |
| PBBLOODEND(t) | Lead concen-tration in blood | B-10a | 0-84 | I | Simple combination of the blood lead concentrations determined in each iteration in the solution algorithm between the previous month and that month. | µg/dL | B-10c |
| RATBLPL | Ratio of lead mass in blood to lead mass in plasma-ECF | 100 | 0-84 | I | Based on the lower end of the 50-500 range for the red cell/plasma lead concentration ratio recommended in Diamond and O'Flaherty (1992a). | unitless | B-2b-2d,2g,2i,2k,2m |

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|---|---|---|---|---|---|---|---|
| RATFECUR | Ratio of endogenous fecal lead elimination rate to urinary lead elimination rate | 0.75 | 0-84 | I | Assume child ratio is larger than the adult ratio; values derived from a reanalysis of data from Ziegler et al. (1978) and Rabinowitz and Wetherill (1973). | unitless | B-1f |
| RATOUTFEC | Ratio of elimination rate via soft tissues to endogenous fecal lead elimination rate | 0.75 | 0-84 | I | Within the range of values derived from a reanalysis of data from Ziegler et al. (1978) and Rabinowitz and Wetherill (1973). | unitless | B-1g |
| SATINTAKE(t) | Half saturation absorbable lead intake | U-3 | 0-84 | I | Assumed proportional to the weight of body . The coefficient of proportionality is assumed to depend on the estimate of the parameter for a 24 month old and the corresponding body weight. | µg/day | U-1a thru U-1e |
| SATINTAKE24 | Half saturation absorbable lead intake for a 24 month old | 100 | 0-84 | E | Extrapolated from reanalysis of human infant data (Sherlock and Quinn, 1986) and infant baboon data (Mallon, 1983) | µg/day | U-3 |
| SCHOOL(t) | Dust lead intake from school | E-12b | 0-84 | I | Simple combination of amount of dust ingested daily, the fraction of total dust ingested daily as school dust, and lead concentration in dust at school | µg/day | E-9d |
| SchoolConc | Dust lead concentration at school | 200 | 0-84 | E | By default, this dust lead concentration is set to the same as the residential dust lead concentration. | µg/g | E-12b |
| SchoolFraction | Fraction of total dust ingested daily as school dust | 0 | 0-84 | E | Based on the default assumption that children are not in school. | unitless | E-9c,E-9.5,12b |
| SECHOME(t) | Dust lead intake at secondary home | E-12d | 0-84 | I | Simple combination of amount of dust ingested daily, fraction of dust ingested daily as secondary home dust, and lead concentration in dust at the secondary home. | µg/day | E-9d |
| SecHomeConc | Secondary home dust lead concentration | 200 | 0-84 | E | Based on the assumption that dust lead concentration in a secondary home is the same as the default dust lead concentration in the primary home. | µg/g | E-12d |

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|---|---|---|---|---|---|---|---|
| SecHomeFraction | Fraction of total dust ingested daily as secondary home dust | 0 | 0-84 | E | Based on the default assumption that the child does not spend a significant amount of time in a secondary home. | unitless | E-9b,12d |
| soil_indoor(t) | Indoor household dust lead concentration | E-11 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Under alternate dust sources model, based on assumption that both soil and outdoor air contribute to indoor dust lead. | µg/g | E-9c |
| soil_ingested(t) | Soil and dust (combined) consumption | 0.085<br>0.135<br>0.135<br>0.135<br>0.100<br>0.090<br>0.085 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Based on values reported in OAQPS report (USEPA 1989, pp. A-16). The values reported were estimated for children, ages 12-48 mos, by several authors such as Binder et al. (1986) and Clausing et al. (1987). Sedman (1987) extrapolated these estimates to those for children, ages 0-84 mos. | g/day | E-8-9a,10 |
| TBLBONE(t) | Lead transfer time from blood to bone | 1<br>*and*<br>B-1e | 24<br>*and*<br>0-84 | I | 24 months - Initialization is keyed to the two year old child, based in part on information from Heard and Chamberlain, (1982) for adults, and O'Flaherty (1992). Once the concentration ratios are fixed, the exact value of this parameter, within a wide range of possible values, has little effect on the blood lead value.<br><br>0-84 months - Assumed proportional body surface area. The coefficient of proportionality is assumed to depend on an estimate of the parameter for a 24 month old and the corresponding body surface area. Also, it is assumed that body surface area varies as 1/3 power of the weight of body based on Mordenti (1986). | days | B-1h,2i,2k |
| TBLFEC(t) | Lead transfer time from blood to feces | B-1f | 0-84 | I | Simple combination of an assumed ratio of urinary lead elimination rate to endogenous fecal lead elimination rate, and lead transfer time from blood to urine (See RATFECUR).<br><br>The ratio of of elimination rates was estimated for adults using Chamberlain et al. (1978), and Chamberlain (1985) and is assumed to apply to ages 0-84 months. | days | B-1g,2e,2f |

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| PARAMETER NAME | DESCRIPTION | DEFAULT VALUE OR EQN. NO. | AGE RANGE (mo) | I or E | BASIS FOR VALUES/EQUATIONS | UNITS | EQUATION WHERE USED |
|---|---|---|---|---|---|---|---|
| TBLKID(t) | Lead transfer time from blood to kidney | 10 *and* B-1d | 24 *and* 0-84 | I | 24 months - Initialization is keyed to the two year old child, based in part on information from Heard and Chamberlain, (1982) for adults, and O'Flaherty (1992). Once the concentration ratios are fixed, the exact value of this parameter, within a wide range of possible values, has little effect on the blood lead value.<br><br>0-84 months - Assumed proportional body surface area. The coefficient of proportionality is assumed to depend on an estimate of the parameter for a 24 month old and the corresponding body surface area. Also, it is assumed that body surface area varies as 1/3 power of the weight of body based on (Mordenti, 1986). | days | B-2g,2h |
| TBLLIV(t) | Lead transfer time from blood to liver | 10 *and* B-1b | 24 *and* 0-84 | I | 24 months - Initialization is keyed to the two year old child, based in part on information from Heard and Chamberlain, (1982) for adults, and O'Flaherty (1992). Once the concentration ratios are fixed, the exact value of this parameter, within a wide range of possible values, has little effect on the blood lead value.<br><br>0-84 months - Assumed proportional body surface area. The coefficient of proportionality is assumed to depend on an estimate of the parameter for a 24 month old and the corresponding body surface area. Also, it is assumed that body surface area varies as 1/3 power of the weight of body based on (Mordenti, 1986). | days | B-2d,2e |
| TBLOTH(t) | Lead transfer time from blood to other soft tissue | 10 *and* B-1c | 24 *and* 0-84 | I | 24 months - Initialization is keyed to the two year old child, based in part on information from Heard and Chamberlain, (1982) for adults, and O'Flaherty (1992). Once the concentration ratios are fixed, the exact value of this parameter, within a wide range of possible values, has little effect on the blood lead value.<br><br>0-84 months - Assumed proportional body surface area. The coefficient of proportionality is assumed to depend on an estimate of the parameter for a 24 month old and the corresponding body surface area. Also, it is assumed that body surface area varies as 1/3 power of the weight of body based on (Mordenti, 1986). | days | B-2m,2n |
| TBLOUT(t) | Lead transfer time from blood to elimination pool via soft tissue | B-1g | 0-84 | I | Simple combination of an assumed ratio of elimintion rate via soft tissues to endogenous fecal lead elimination rate, times the lead transfer time from blood to feces (See RATOUTFEC). | days | B-2n,2o |

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|---|---|---|---|---|---|---|---|
| TBLUR(t) | Lead transfer time from blood to urine | 20 *and* B-1a | 24 *and* 0-84 | I | 24 months - Assumed proportional to body surface area. The coefficient of proportionality is assumed to depend on an adult estimate for the parameter and the corresponding body surface area. The adult estimate of 39 days was obtained using Araki et al (1986a, 1986b, 1987), Assenato et al (1986), Campbell et al (1981), Carton et al (1987), Chamberlain et al. (1978), Folashade et al (1991), Heard and Chamberlain (1981), He et al (1988), Kawaii et al (1983), Kehoe (1961), Koster et al (1989), Manton and Malloy (1983), Rabinowitz and Wetherill (1973), Rabinowitz et al (1976), and Yokoyama et al (1985).<br><br>0-84 months - Assumed proportional body surface area. The coefficient of proportionality is assumed to depend on an estimate of the parameter for a 24 month old and the corresponding body surface area.<br><br>Both cases above assume that (a) body surface area varies as 1/3 power of weight of body based on (Mordenti, 1986) and (b) respectively, 70 kg and 12.3 kg are standard adult and 2 year old body weights based on Spector (1956).<br><br>Since glomerular filtration rate (GFR) is proportional to body surface area for ages $ 24 months based on (Weil, 1955), surface area scaling is equivalent to scaling by GFR for ages $ 24 months. | days | B-1f,2c |
| TBONEBL(t) | Lead transfer time from bone to blood | B-1h | 0-84 | I | Based on the assumption that masses of lead in bone and blood are in kinetic quasi-equilibrium. | days | B-2j,2l |
| TCORTPL(t) | Lead transfer time from cortical bone to plasma-ECF | B-2l | 0-84 | I | Based on the assumption that the cortical and trabecular bone pools have similar lead kineticsfor children younger than 84 months. | days | B-6b,6i,6.5b, 6.5i,8d,9f |
| time_out(t) | Time spent outdoors | 1<br>2<br>3<br>4<br>4<br>4<br>4 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Values are reported in the OAQPS staff report (USEPA 1989, pp. A-2) and the TSD (USEPA 1990a). The values have been derived from a literature review (Pope, 1985). | hrs/day | E-2 |

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|---|---|---|---|---|---|---|---|
| TimeStep | Length of time-step in solution algorithm | 1/6 | 0-84 | E | This user-selectable parameter is available mainly for adjusting the model run time to the speed of the computer. Newer, faster computers can run the model at the shortest TimeStep (15 min) in less than one minute. The default value, 4 hours, is based on a tradeoff between numerical accuracy of results and computer run-time. Except in the case of extreme exposure scenarios, there is no difference in the numerical accuracy at any user selectable value for TimeStep. | day | B-6.5a,6.5d-6.5i,7b,7c, 8a,d,9a-9f,10a-10b |
| TKIDPL(t) | Lead transfer time from kidney to plasma-ECF | B-2h | 0-84 | I | Based on the assumption that the lead transfer time from kidney to blood is equal to the lead transfer time from kidney to plasma-ECF. | days | B-6b,6f,6.5b,6.5f,8d,9c |
| TLIVFEC(t) | Lead transfer time from liver to feces | B-2f | 0-84 | I | Based on the assumption that the masses of lead in liver and blood are in kinetic quasi-equilibrium. | days | B-6e,6.5e, 8c,d,9b |
| TLIVPL(t) | Lead transfer time from liver to plasma-ECF | B-2e | 0-84 | I | Based on the assumption that the lead transfer time from liver to blood is equal to the lead transfer time from liver to plasma-ECF. | days | B-6b,6e,6.5b,6.5e,8c,d, 9b |
| TOTHOUT(t) | Lead transfer time from soft tissues to elimination pool | B-2o | 0-84 | I | Based on the assumption that the masses of lead in soft tissues and blood are in kinetic quasi-equilibrium. | days | B-6g,6.5g, 8c,d,9h |
| TOTHPL(t) | Lead transfer time from soft tissues to plasma-ECF | B-2n | 0-84 | I | Based on the assumption that the lead transfer time from soft tissues to blood is equal to the lead transfer time from soft tissues to plasma-ECF. | days | B-6c,6g,6.5c,6.5g,8c,d, 9h |
| TPLCORT(t) | Lead transfer time from plasma-ECF to cortical bone | B-2k | 0-84 | I | Based on the following assumptions:<br><br>The rate at which lead leaves the plasma-ECF to reach the bone is proportional to the rate which lead leaves the blood to reach the same pool.<br><br>The cortical and trabecular bone pools have similar lead kinetics for children younger than 84 months.<br><br>The cortical bone is 80% of the weight of bone based on Leggett et al. (1982). | days | B-6c,6i,6.5c, 6.5i,8b,c,9f |

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|---|---|---|---|---|---|---|---|
| TPLKID(t) | Lead transfer time from plasma-ECF to kidney | B-2g | 0-84 | I | Based on the assumption that the rate at which lead leaves the plasma-ECF to reach the kidney is proportional to the rate at which lead leaves the blood to reach the same pool. | days | B-6c,6f,6.5c,6.5f,8b,c,9c |
| TPLLIV(t) | Lead transfer time from plasma-ECF to liver | B-2d | 0-84 | I | Based on the assumption that the rate at which lead leaves the plasma-ECF to reach the liver is proportional to the rate at which lead leaves the blood to reach the same pool. | days | B-6c,6e,6.5c,6.5e,8b,c,9b |
| TPLOTH(t) | Lead transfer time from plasma-ECF to soft tissues | B-2m | 0-84 | I | Based on the assumption that the rate at which lead leaves the plasma-ECF to reach the soft tissues is proportional to the rate which lead leaves the blood to reach the same pool. | days | B-6c,6g,6.5c,6.5g,8b,c,9d |
| TPLRBC | Lead transfer time from plasma-ECF to red blood cells | 0.1 | 0-84 | I | Initialization value of 0.1 was assigned as plausible nominal value reflecting best professional judgement on appropriate time scale for composite process of transfer of lead through the red blood cell membrane to lead binding components. | days | B-2b,2.5,7b,7c |
| TPLRBC2(t) | Lead transfer time from plasma-ECF to red blood cells constrained by the maximum capacity of red blood cell lead concentration | B-2.5 | 0-84 | I | Simple combination of the lead transfer time from plasma-ECF to red blood cells, and the ratio of red blood cell lead concentration to the corresponding maximum concentration. Based on Marcus (1985a) and reanalysis of infant baboon data. | days | B-6a,6d,6.5a,6.5d,8b,9a |
| TPLTRAB(t) | Lead transfer time from plasma-ECF to trabecular bone | B-2i | 0-84 | I | Based on the following assumptions:<br><br>The rate at which lead leaves the plasma-ECF to reach the bone is proportional to the rate which lead leaves the blood to reach the same pool.<br><br>The cortical and trabecular bone pools have similar lead kinetics.<br><br>The trabecular bone is 20% of the weight of bone based on Leggett et al. (1982). | days | B-6c,6h,6.5c,6.5h,8b,c,9e |
| TPLUR(t) | Lead transfer time from plasma-ECF to urine | B-2c | 0-84 | I | Based on the assumption that the rate at which lead leaves the plasma-extra-cellular fluid to reach the urine pool is proportional to the rate at which lead leaves the blood to reach the same pool. | days | B-6c,6.5c,8a |

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|---|---|---|---|---|---|---|---|
| TRBCPL | Lead transfer time from red blood cells to plasma-ECF | B-2b | 0-84 | I | Based on the assumption that the transfer time out of RBC is similar at all ages, since mean red cell value is similar. | days | B-6b,6d,6.5b,6.5d,7b,7c,8c,d,9a |
| TTRABPL(t) | Lead transfer time from trabecular bone to plasma-extra-cellular fluid | B-2j | 0-84 | I | Based on the assumption that the cortical and trabecular bone pools have similar lead kinetics for children younger than 84 months. | days | B-6b,6h,6.5b,6.5h,8c,d,9e |
| TWA(t) | Time weighted average air lead concentration | E-2 | 0-84 | I | Simple combination of outdoor and indoor air lead concentrations and the number of hours spent outdoors. | $\mu g/m^3$ | E-3 |
| UPAIR(t) | Air lead uptake | U-4 | 0-84 | I | Simple combination of media-specific lead intake and the corresponding net absorption coefficient. | µg/day | U-5 |
| UPDIET(t) | Diet lead uptake | U-1a | 0-84 | I | Simple combination of media-specific lead intake and the corresponding net absorption coefficient. | µg/day | U-1f |
| UPDUST(t) | Dust lead uptake | U-1c | 0-84 | I | Simple combination of media-specific lead intake and the corresponding net absorption coefficient. | µg/day | U-1f |
| UPDUSTA(t) | Dust lead uptake rate from alternate sources | U-1.5c | 0-84 | I | Simple combination of media-specific lead intake and the corresponding net absorption coefficient. | µg/day | U-1f |
| UPGUT(t) | Total gut uptake | U-1f | 0-84 | I | Sum of all gastrointestinal uptake. | µg/day | U-5 |
| UPOTHER(t) | Uptake of other ingested lead | U-1d | 0-84 | I | Assumes no other gut lead intake | µg/day | U-1f |
| UPSOIL(t) | Soil lead uptake | U-1e | 0-84 | I | Simple combination of media-specific lead intake and the corresponding net absorption coefficient. | µg/day | U-1f |
| UPTAKE(t) | Total lead uptake | U-5 | 0-84 | I | Simple combination of the media-specific daily lead uptake rates, translated to a monthly rate. | µg/mo | B-6a,6.5a,8a |
| UPWATER(t) | Water lead uptake | U-1b | 0-84 | I | Simple combination of media-specific lead intake and the corresponding net absorption coefficient. | µg/day | U-1f |

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|---|---|---|---|---|---|---|---|
| UserFishConc | Lead concentration in fish | 0 | 0-84 | E | Based on the assumption that only commercially available fish are consumed. | µg/g | E-5h |
| userFishFraction | Fraction of total meat consumed as fish | 0 | 0-84 | E | Based on the assumption that only commercially available fish are consumed. | unitless | E-5a,5h |
| UserFruitConc | Lead concentration in home grown fruits | 0 | 0-84 | E | Based on the assumption that only commercially available fruits are consumed. | µg/g | E-5f |
| userFruitFraction | Fraction of total fruits consumed as home grown fruits | 0 | 0-84 | E | Based on the assumption that only commercially available fruits are consumed. | unitless | E-5d,5e,5f |
| UserGameConc | Lead concentration in game animal meat | 0 | 0-84 | E | Based on the assumption that only commercially available meat is consumed. | µg/g | E-5i |
| userGameFraction | Fraction of total meat consumed as game animal meat excluding fish | 0 | 0-84 | E | Based on the assumption that only commercially available meat is consumed. | unitless | E-5a,5i |
| UserVegConc | Lead concentration in home grown vegetables | 0 | 0-84 | E | Based on the assumption that only commercially available vegetables are consumed. | µg/g | E-5g |
| userVegFraction | Fraction of total vegetables consumed as home grown vegetables | 0 | 0-84 | E | Based on the assumption that only commercially available vegetables are consumed. | unitless | E-5b,5c,5g |

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|---|---|---|---|---|---|---|---|
| veg_all(t) | Daily amount of all vegetables consumed | 56.84<br>106.50<br>155.75<br>157.34<br>158.93<br>172.50<br>199.65 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | I | Pb concentration from data provided to EPA by FDA (US EPA (1986). Quantity consumed from Pennington (1983). | g/day | E-5g |
| vent_rate(t) | Ventilation rate | 2<br>3<br>5<br>5<br>5<br>7<br>7 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Values are reported in the OAQPS report (USEPA 1989, pp. A-3) and the TSD (USEPA 1990a). These estimates are based on body size in combination with smoothed data from Phalen et al., (1985). | $m^3$/day | E-3 |
| VOLBLOOD(t) | Volume of blood | B-5a | 0-84 | I | Statistical fitting of data from Silve et al (1987); also Spector (1956) and Altman and Ditmer (1973) | µg/dL | B-1h,2e,2f,2h,2n,2o,5d,5e,5m,10a |
| VOLECF(t) | Volume of extra-cellular fluid (ECF) | B-5d | 0-84 | I | The volume of extracellular fluid that exchanges rapidly with plasma is estimated 73% of the blood volume based on Rabinowitz (1976). This additional volume of distribution is assumed to be the volume the extra-cellular fluid pool, which is the difference between the volume of the distribution and the blood volume. | dL | B-9g |
| VOLPLASM(t) | Volume of plasma | B-5c | 0-84 | I | Statistical fit to VOLBLOOD(t) - VOLRBC(t) | dL | B-7b,7c,9g |
| VOLRBC(t) | Volume of red blood cells | B-5b | 0-84 | I | Statistical fit to hematocrit × blood volume | dL | B-2.5 |
| water_consumption(t) | Daily amount of water consumed | 0.20<br>0.50<br>0.52<br>0.53<br>0.55<br>0.58<br>0.59 | 0-11<br>12-23<br>24-35<br>36-47<br>48-59<br>60-71<br>72-84 | E | Exposure Factors Handbook (US EPA, 1989b) | L/day | E-6a,6b |

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|---|---|---|---|---|---|---|---|
| weight_soil | Percentage of total soil and dust ingestion that is soil | 45 | 0-84 | E | Guidance Manual, Section 2.3 (US EPA, 1994) | % | E-8,10 |
| WTBLOOD(t) | Weight of blood | B-5m | 0-84 | I | Based on an blood density of 1.056 kg/l (Spector 1956). | kg | B-5l |
| WTBODY(t) | Weight of body | B-5f | 0-84 | I | Statistical fitting of data from Silve et al. (1987); also Spector (1956) and Altman and Ditmer (1973). Also, body weight of 24 month old is assumed to be 12.3 kg (Spector 1956). | kg | B-1a-1e,5f,5g,5l |
| WTBONE(t) | Weight of bone | B-5g | 0-84 | I | 12-84 months - Based on child skeletal ash data in Harley and Kneip (1984) and the following assumptions.<br><br>$WTBONE = (WTBONE_{ADULT} / WTSKEL\_ASH_{ADULT}) * WTSKEL\_ASH$<br><br>where<br><br>$WTBONE_{ADULT} = 10$ kg<br>$WTSKEL\_ASH_{ADULT} = 2.91$ kg<br><br>0-12 months - Assumed to be 11% of the weight of the body. The ratio of weight of bone to weight of body (11%) is based on the 12-month estimate for WTBONE from the above equation, and an estimate for WTBODY at the same age. | kg | B-5h,5i |
| WTCORT(t) | Weight of cortical bone | B-5i | 0-84 | I | Assumed to be 80% of the weight of the bone based on Leggett et al. (1982). | kg | B-1h,5l,7e |
| WTECF(t) | Weight of extra-cellular fluid (ECF) | B-5e | 0-84 | I | Based on an assumed ECF density approximately the same as water, of 1.0 kg/L. | kg | B-5l |
| WTKIDNEY(t) | Weight of kidney | B-5j | 0-84 | I | Statistical fitting of data from Silve et al. (1987); also Spector (1956) and Altman and Ditmer (1973). Also, body weight of 24 month old is assumed to be 12.3 kg (Spector 1956). | kg | B-5j,5l,7f |
| WTLIVER(t) | Weight of liver | B-5k | 0-84 | I | Statistical fitting of data from Silve et al. (1987); also Spector (1956) and Altman and Ditmer (1973). Also, body weight of 24 month old is assumed to be 12.3 kg (Spector 1956). | kg | B-2e,2f,5l,7g |
| WTOTHER(t) | Weight of soft tissues | B-5l | 0-84 | I | Simple combination of the weight of body and the weights of kidney, liver, bone, blood and extra-cellular fluid. | kg | B-2n,2o,7h |

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|---|---|---|---|---|---|---|---|
| WTTRAB(t) | Weight of trabecular bone | B-5h | 0-84 | I | Assumed to be 20% of the weight of the bone based on Leggett et al. (1982). | kg | B-1h, 5l,7i |