ESTIMATION OF INHALATION RATES FOR U.S. CHILDREN: UPDATE TO THE DEFAULT VALUES FOR THE INTEGRATED EXPOSURE UPTAKE BIOKINETIC MODEL FOR LEAD IN U.S. CHILDREN

OVERVIEW

Since 1994, the Office of Land and Emergency Management (OLEM), formerly known as the Office of Solid Waste and Emergency Response (OSWER), has recommended the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK model) as a risk assessment tool to support environmental cleanup decisions at current and future anticipated residential sites (U.S. EPA, 1994a,b). The IEUBK model predicts blood lead levels (PbB) in young children (birth to 7 years of age[1]) exposed to lead from several sources of exposure and routes. The IEUBK model uses more than 100 input parameters that are initially set to default values. Of these, there are 46 parameters that may be input, or modified, by the user; the remainder are internal variables that are unavailable for modification (U.S. EPA, 1994a).

The IEUBK model uses empirical data from numerous scientific studies of lead uptake and biokinetics, contact and intake rates of children with contaminated media, and data on the presence and behavior of environmental lead to predict a plausible distribution centered on the geometric mean (GM) of PbB for a hypothetical child or population of children (EPA, 2020).[2] The relative variability of PbB concentrations around the GM is defined as the geometric standard deviation (GSD). The GSD encompasses biological and behavioral differences, measurement variability from repeat sampling, variability as a result of sample locations, and analytical variability.[3] From this distribution, the IEUBK model estimates the risk (*i.e.,* probability) that a child's or a population of children's PbB concentration will not exceed a certain PbB level (U.S. EPA, 1998, 1994a; White et al., 1998).

The default values for the *Inhalation Rate* parameter in the IEUBK model (v. 1.1, build 11) represent age-specific central tendency estimates for the inhalation rates for children (birth to 7 years of age) in the U.S. These values were designed to represent a combination of physiological considerations including age, body size, lung capacity, and activity of the child, paired with a time- and activity-based regression analysis (U.S. EPA, 1994a, 1989; Phalen et al., 1985; Nutrition Foundation (NF), 1982; International Commission on Radiological Protection (ICRP), 1975; Altman and Dittmer 1972, 1971). Briefly, Phalen et al. (1985) paired male and female body mass data from Altman and Dittmer (1972, 1971) with inhalation rates associated with three levels of physical exertion (*i.e.,* low, light and heavy) to determine time-weighted inhalation

[1] To better align the CDC recommendation and the risk predictions for lead exposure at Superfund sites, the TRW Lead Committee recommends that the default age range in IEUBK model be modified to match the 1-5 year age range (12-72 months).

[2] The GM represents the central tendency estimate (*e.g.,* mean, 50th percentile) of PbB concentration of children from a hypothetical population (Hogan et al., 1998). If an arithmetic mean (or average) is used, the model provides a central point estimate for risk of an elevated PbB level. By definition a central tendency estimate is equally likely to over- or under-estimate the lead-intake at a contaminated site. Upper confidence limits (UCLs) can be used in the IEUBK model; however, the IEUBK model results could be interpreted as a more conservative estimate of the risk of an elevated PbB level. See U.S. EPA (1994a) for further information.

[3] The IEUBK model uses a log-normal probability distribution to characterize this variability (U.S. EPA, 1994a). The biokinetic component of the IEUBK model output provides a central estimate of PbB concentration, which is used to provide the geometric standard deviation (GSD). In the IEUBK model, the GSD is not intended to reflect variability in PbB concentrations where different individuals are exposed to different media concentrations of lead. The recommended default value for GSD (1.6) was derived from empirical studies with young children where both blood and environmental lead concentrations were measured (White et al., 1998).

rates.[4] U.S. EPA (1989) later combined the results from Phalen et al. (1985) with data from the NF (1982) and the ICRP (1975) to construct age-specific daily inhalation rates. U.S. EPA (1994a) matched these inhalation rates into the age categories in the IEUBK model.

The purpose of this document is to provide a summary of the published literature and the technical basis for an analysis of the currently available data on inhalation rates to support and update the *Inhalation Rate* parameters in the IEUBK model (Table 1). The age-specific variables recommended herein were derived by using more representative inhalation rate data for children, and a more representative methodology for estimating childhood inhalation rates in the U.S. The proposed estimates for the *Inhalation Rate* parameter in the IEUBK model are based on energy expenditure data available from the Institute of Medicine's (IOM) doubly-labeled water (DLW) dataset (IOM, 2005) and the linear equations developed by Brochu et al. (2006) and Layton (1993) to convert metabolic energy to inhalation rates (Table 1).

The intended audience is risk assessors familiar with the IEUBK model. For more information on the use of the IEUBK model in Superfund lead risk assessment, refer to U.S. EPA (1994a) or the Technical Review Workgroup for Lead (TRW) website https://www.epa.gov/superfund/lead-superfund-sites-guidance.

Table 1. Comparison of age-specific inhalation rates (m^3/day) for use in the IEUBK model

Source	Age Category (months)							Basis for Age-Specific Value
	0<12	12<24	24<36	36<48	48<60	60<72	72<84	
IEUBK Model Default[a]	2	3	5	5	5	7	7	Methodology U.S. EPA, 1994b, 1989; Phalen et al., 1985 Time- and activity-based estimates Data Source Altman and Dittmer 1971, 1972 ICRP, 1975 Nutrition Foundation, 1982
Updated Inhalation Rates[b]	3.22	4.97	6.09	6.95	7.68	8.32	8.89	Methodology Stifelman, 2007; Brochu et al. 2006; Layton, 1993 Total energy expenditure (DLW method) Data Source IOM, 2005

ICRP: International Commission on Radiological Protection; IOM: Institute of Medicine; DLW: doubly-labeled water

[a]IEUBK model v. 2

[b]Mid-point inhalation rates are provided in the table for comparative purposes only. The proposed update to the IEUBK model will use the estimated regression equation to calculate inhalation rate as a continuous non-linear function of age (see Tables 5 and 6).

[4]Based on data from a series of experiments with tracheobronchial casts, Phalen et al. (1985) formulated regression equations to compute tracheobronchial dimensions as a function of individual body height. Phalen et al. (1985) was then able to predict inhalation rates and particle deposition based on body mass. Values for newborns, infants, children, and adolescents were scaled downward as linear functions of body mass (Phalen et al., 1985).

INTRODUCTION

The IEUBK model predicts PbB in young children (birth to 7 years of age) exposed to lead from several sources and routes. The IEUBK model uses more than 100 input parameters that are initially set to default values. Of those, there are 46 parameters that may be input, or modified, by the user; the remainder are locked (U.S. EPA, 1994a). Default values represent national averages or other central tendency values derived empirical data in the open literature. Default values include: a) lead concentrations in exposure media (*e.g.*, diet representative of national food sources); b) contact and intake rates(*e.g.,* soil/dust ingestion); and c) exposure durations (White et al., 1998). The representativeness of IEUBK model output is wholly dependent on the representativeness of the data (often assessed in terms of: completeness, comparability, precision, and accuracy [U.S. EPA, 1994a]).

Representative site-specific data are essential for developing a risk assessment (as well as cleanup goals) that reflect the current and potential future conditions. The most common type of site-specific data is media-specific lead concentration information (air, water, soil, dust). Until recently, an inexpensive, EPA validated method[5] (U.S. EPA 2017) to estimate bioavailability of lead in soil or dust was not available. Receptor data (*e.g.*, age, body weight, breathing rate, or soil ingestion rate) does not typically vary due to site-specific factors.

To promote defensible and reproducible risk assessments and clean-up plans while maintaining flexibility which is necessary to respond to different site conditions, U.S. EPA recommends the Data Quality Objectives (DQOs) process (U.S. EPA, 2006). DQOs provide a structured approach to collecting environmental data that will be sufficient to support decision-making: http://www.epa.gov/QUALITY/dqos.html.

Inhalation rate is dependent on age, sex, body size, health status, lung capacity, altitude, and activity patterns (U.S. EPA 2008, 1989; Layton, 1993). Infants and children have a higher resting metabolic rate and oxygen consumption rate per unit of body weight than adults due to their rapid growth and lung surface area (U.S. EPA, 2008). The IEUBK model (v. 1.1) inhalation rate default variables were calculated using time- and activity-based methods, which account for some of the inhalation rate dependent factors and may indirectly account for others (U.S. EPA, 1994b, 1989).

In the past 20 years a growing body of evidence supports estimating inhalation rates as a function of individual energy expenditure (EE), or the amount of oxygen required for the metabolic conversion of dietary nutrients (U.S. EPA, 2009b, Layton, 1993). Individual EE data can be used to characterize both short- and long-term inhalation rates using two approaches: 1) average daily intakes of food energy (EFD) from dietary surveys, adjusted for under reporting of foods, and 2) average daily energy expenditure calculated from ratios of total daily energy expenditure (TEE) to basal metabolic rates (BMR). These newer methods allow for direct measurement of energy expenditure to estimate age-specific inhalation rates.

CALCULATING ENERGY EXPENDITURE

Inhalation rates were calculated using the TEE approach described by Layton (1993), Brochu et al. (2006), and Stifelman (2007). Information on TEE was extracted from the IOM (2005) DLW database. Data for 957 children (ages 0.22-8 years) were provided in the IOM (2005) dataset.

[5] Method 1340 *In Vitro* Bioaccessibility Assay for Lead in Soils, https://www.epa.gov/hw-sw846

All of the data for children (younger than 8 years of age) were retained for this analysis. Data for males and females were pooled for average body mass index.[6] Inhalation rates were calculated using the following equation (adapted from Layton, 1993):

$$I_R = E \times H \times I_{EQ}$$

Where:

I_R = Inhalation rate (L/minute) (1 L/min = 1.44 m^3/day)
E = Energy expenditure rate (kJ/day)[7] (1 kJ/day = 0.239 kcal/day)
H = Volume of O_2 in liters consumed per energy expended (constant value equal to 0.05 L O2/kJ or 0.21 L O2/kcal)[8]
I_{EQ} = Inhalation equivalent ratio of V_E (time-weighted-average minute volume) to VO_2 (oxygen consumption) (unitless; constant rate equal to 27)[9]

SAS® software (Version 9.3) was used to estimate daily inhalation rates as a function of age using the following non-linear regression equation:

$$I_R = a \times y^b$$

Where:

I_R = Inhalation Rate (m^3/day)
a = Unitless parameter of the nonlinear regression model estimated by nonlinear least squares
y = Total Energy Expenditure (based on Layton's approach)
b = Unitless parameter of the nonlinear regression model estimated by nonlinear least squares

Parameters 'a' and 'b' were determined by nonlinear least squares. Mid-point inhalation rates are provided for comparative purposes only (see Table 4). The proposed update to the *Inhalation Rate* parameter in the IEUBK model will use the estimated regression equation to calculate inhalation rate as a function of age (Tables 5, 6 and Figures 1, 2). The resulting values for inhalation rates are similar to those reported by Kawahara et al. (2011) for 5- to 6-year old Japanese children (8.3 m^3/day vs. 8.1 m^3/day, respectively). For comparative purposes, estimates of other inhalation rate studies that were calculated for this review using linear interpolation are provided in Table 7.

AVERAGE DAILY INTAKES OF FOOD ENERGY (DIETARY SURVEY)

Energy expenditures have historically been estimated using food-energy intake data obtained from nationwide food intake surveys (U.S. EPA, 2011, 2010, 2009a,b, 2008, 1997; Arcus-Arth and Blaisdell, 2007; Layton, 1993). Initially, Layton (1993) utilized food-energy intake data from

[6]Results indicated estimated inhalation rates to be parallel and 7% greater in males than females. However, the TRW Lead Committee does not believe there is sufficient information for all lead exposure and biokinetic variables nor is there necessarily a need to model sex-specific information for typical Superfund site-specific risk assessments.

[7]Layton (1993) noted that inhalation rates for long- and short-term exposures are calculated as a function of energy expenditures that are multiples of the BMR, however, long-term exposures can also be derived from dietary studies that include data on food-energy intakes or the minimal amount of energy required to support basic cellular respiration (as determined by body mass index).

[8]The oxygen uptake factor is the reciprocal of the energy yield of oxygen consumption and equals 0.0476, 0.0508 and 0.0529 L O_2/kJ for carbohydrates, fats, and protein, respectively (Layton, 1993). Layton (1993) estimated the weighted average oxygen uptake (L O_2/kJ) based on data from the 1977-1978 Nationwide Food Consumption Survey (NCFS) (USDA, 1984) and the National Health and Nutrition Examination Survey (NHANES) (U.S. DHHS, 1983).

[9]Individual variability reflects variations in oxygen uptake efficiency, lung physiology, and metabolic efficiency (Layton, 1993).

the U.S. Department of Agriculture's 1977-1978 National Food Consumption Survey (NFCS; USDA, 1984) and the U.S. Department of Health and Human Services 1976-80 National Health and Nutrition Examination Survey (NHANES; US DHHS, 1983) to estimate weighted average oxygen uptakes (liters of oxygen per kilojoule; L O_2/kJ) (Table 2, Table 3 and 4). More recently, U.S. EPA (2011, 2009a) provided recommendations for long-term (>30 days) inhalation rates based partly on the indirect measure of inhalation rates derived from dietary and activity survey responses obtained from the 1994-1996 and 1998 USDA Continuing Survey of Food Intake for Individuals surveys (CFSII).[10]

While dietary data are intended to capture everything that is consumed within a specified timeframe, there are a variety of variables (*e.g.,* age, sex, socioeconomic status, ethnic considerations) or individual behaviors (*i.e.,* not reporting foods that are "perceived to be bad or sinful" including pies, fried foods, sugars) that bias toward under reporting on dietary surveys (IOM, 2005). Layton used a bias correction factor of 1.2 to adjust the total energy intake calculated from dietary surveys (Layton, 1993). Layton's approach is further outlined in U.S. EPA (1997).

Table 2. Comparisons of estimated basal metabolic rates with average food-energy intakes for individuals sampled in the 1977-1978 National Food Consumption Survey (USDA, 1984)

Cohort/Age (years)	Body Weight (kg)	Basal Metabolic Rate (BMR)		Food Energy Intake (EFD)		Ratio (A)
		MJ/day	kcal/day	MJ/day	kcal/day	EFD/BMR
Under 1	7.6	1.74	416	3.32	793	1.90
1 to 2	13	3.08	734	5.07	1209	1.65
3 to 5	18	3.69	881	6.14	1466	1.66
6 to 8	26	4.41	1053	7.43	1774	1.68

Source: Layton (1993).

Table 3. Daily inhalation rates estimated from the food-energy intakes for cohorts sampled in the 1977-1978 National Food Consumption Survey (USDA, 1984) and estimated inhalation rates for active and inactive respondents[d]

Cohort/Age (years)	L[c]	Daily Inhalation Rate[a] (m^3/day)	Sleep (hours)	Metabolic Equivalent[e]		Inhalation Rates[b] (liters/min)	
				A	F	Inactive	Active
Under 1	1	4.5	11	1.9	2.7	1.6	4.3
1 to 2	2	6.8	11	1.6	2.2	2.9	6.4
3 to 5	3	8.3	10	1.7	2.2	3.5	7.7
6 to 8	3	10	10	1.7	2.2	4.1	9.0

[a]Daily inhalation rate is calculated by multiplying the EFD values in Table 2 by H (volume of oxygen consumed in the production of 1 kJ of energy expended; L/kJ) x inhalation equivalent ratio (I_{EQ}) x (m^3/1000 L) for those under 9 years. I_{EQ} is inhalation equivalent ratio of V_E to VO_2 (unitless)

[b]Inhalation rate for inactive periods is calculated as BMR x H (volume of oxygen consumed in the production of 1 kJ of energy expended; L/kJ) x I_{EQ} x (day / 1440 min) and for active periods it is computed by multiplying the inactive inhalation rate by F. Values of EFD and BMR are from Table 2.

[c]"L" represents the number of years for each cohort. The lifetime averages were computed by multiplying the individual inhalation rates by the respective "L" values, summing the products across cohorts, and dividing the result by 75, the total of the cohort age spans.

[d] The inactive rates are near the 2.5th percentile in Brochu et al. (2006) paper, but the active rates exceed the 99th percentile.

[10]Dietary survey repsonses were based on self-reported dietary data and used to estimate inhalation rates for children from birth to 18 years of age (n=11,147) (as reported by Arcus-Arth and Blaisdell, 2007).

[e] A is EFD/BMR ratio, F is the ratio of rate of energy expenditure during active hours to the estimated BMR. Reproduced from Table 5 of Layton (1993); also cited in U.S. EPA (1997).

TOTAL ENERGY EXPENDITURE (DOUBLY-LABELED WATER (DLW) METHOD)

According to the Institute of Medicine (2005a), total daily energy requirements and expenditures (TEE) are a function of the dietary intake, physical activity, thermoregulation, and the energy required for homeostasis (*e.g.*, depositing new tissues and in producing milk). These values can be accurately measured using the DLW method (Speakman, 1998). The DLW method measures daily metabolic activity based on the administration and rate of disappearance of two stable forms of labeled water: deuterium labeled (^2H_2O) and 18-oxygen labeled ($H_2{}^{18}O$) (Stifelman, 2007; Brochu et. 2006; Layton et al. 1993).[11] These disappearance rates can be used to calculate both water flux and CO_2 respiration rates in the body. In addition to dietary information, the calculated CO_2 rates can be used to calculate TEE.

In 2005, the Institute of Medicine compiled a database of DLW energy expenditure. This database incorporated ethnicity, ages, heights, weights, BMRs, physical activity levels, and TEEs for healthy children in the U.S. (ages 0.22-18 years) and adults (ages 19+ years). The DLW database represents energy expended over a long period of time (*e.g.*, weeks) by people engaged in their usual daily activities, rather than from short-term staged activities, resulting in a more reliable measure of actual activity (Stifelman, 2007).

In 2009, U.S. EPA (2009b) compared the results of dietary survey-derived inhalation rates (Arcus-Arth and Blaisdell, 2007) to results using the DLW method (Butte et al. 2000; Black et al. 1996; Torun et al. 1996). U.S. EPA (2009b) found that the DLW method is the most accurate measurement of the daily TEE, which is necessary for the estimation of daily inhalation rates. DLW energy data are an improvement over inhalation rate estimates based on dietary recall or activity-based survey data (Lamonte and Ainsworth, 2001; Burrows et al., 2010) for the following reasons (Stifelman, 2007):

1) the database is robust;
2) they are direct biological measures (survey bias and recall errors are avoided);
3) subjects are free-living; and
4) the observation period of one to two weeks is significantly longer (reduces effect of transient changes in activity patterns) than what is possible from staged activity measures or survey data.

Table 4. Summary of proposed IEUBK model inhalation rates (I_R)

IEUBK Model Age Group	Age Midpoint (years)	Parameter a	Parameter b	Updated IEUBK Model I_R (m^3/day)
0 < 12	0.5	4.233 (4.084-4.381)[a]	0.396 (0.376-0.417)	3.22 [b]
12 < 24	1.5			4.97
24 < 36	2.5			6.09
36 < 48	3.5			6.95
48 < 60	4.5			7.68
60 < 72	5.5			8.32
72 < 84	6.5			8.89

[11]While the disappearance of ^2H_2O is an index of total water flux in the body (*i.e.*, urine, saliva, or blood samples), the disappearance of $H_2{}^{18}O$ is equivalent to the water flux plus the generation of CO_2 from respiration (Stifelman, 2007; Brochu et al., 2006; IOM, 2005).

I_R: Inhalation rates
[a]Values in parenthesis represent lower and upper confidence levels.
[b]Mid-point inhalation rates are provided in the table for comparative purposes only, the proposed update to the IEUBK model will use the estimated regression equation to calculate inhalation rate as a continuous non-linear function of age.

Table 5. Statistical summary of the non-linear regression model of inhalation rate (m^3/day) on age

Source	DF	Sum of Squares	Mean Square	F Value	Approx. Pr>F
Model	2	50666	25333	13003	<0.0001
Error	955	1861	1.948		
Uncorrected Total	957	52527			

Inhalation rate parameter estimates.

Parameter	Estimate	Approx. Std Error	Approx. 95% Confidence Lower Limits	Approx. 95% Confidence Upper Limits
a	4.233	0.08	4.1	4.4
b	0.396	0.01	0.4	0.4

DF: Degrees of freedom

Table 6. Summary of inhalation rate by age group

Age Range (months)	N	Inhalation rate (m^3/day)						
		Mean	Confidence Limit for Mean Lower 90%	Confidence Limit for Mean Upper 90%	Std Dev	Coeff of Variation	Min	Max
≤ 6	85	2.6	2.5	2.7	0.6	0.24	1.7	4.4
12 < 24	108	4.8	4.7	5.0	1.0	0.20	3.1	8.2
24 < 36	31	5.4	5.1	5.6	0.8	0.15	4.1	6.8
36 < 48	3	8.3	6.6	10.1	1.0	0.13	7.6	9.5
48 < 60	51	7.3	7.0	7.7	1.3	0.18	4.4	10.8
60 < 72	329	8.1	8.0	8.2	1.5	0.18	2.4	15.5
72 < 84	136	8.8	8.5	9.0	1.9	0.21	5.2	19.0
>84	109	9.6	9.3	9.9	1.9	0.20	5.3	17.0

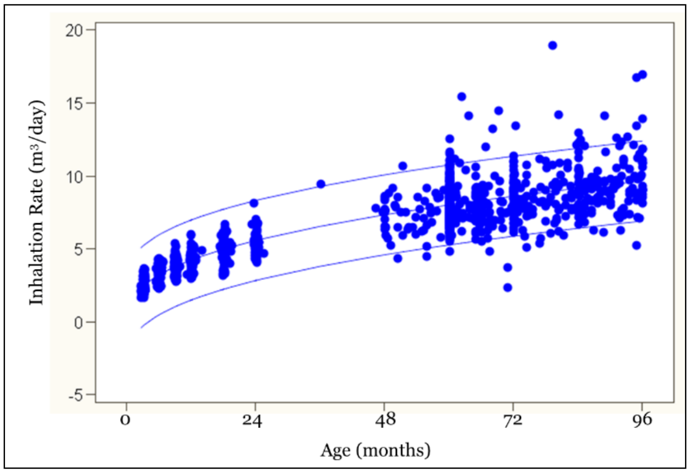

Figure 1. Age-specific inhalation rates (m^3/day) using the TEE approach. The regression line is shown with the approximate 95% confidence intervals.

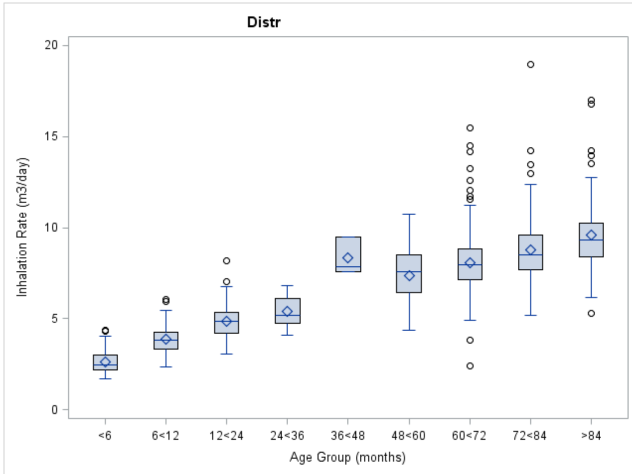

Figure 2. Inhalation rates (m³/day) by age group (months).

Table 7. Comparison of long-term(≥90 days) age-specific inhalation rates

Source	Age Range (months)	Inhalation Rate (m³/d)	Basis for Age-Specific Value	
IEUBK Default [a]	0 < 12 12 < 24 24 < 36 36 < 48 48 < 60 60 < 72 72 < 84	2 3 5 5 5 7 7	U.S. EPA, 1989 Phalen et al., 1985	Methodology Time and activity based estimates Data Source Altman and Dittmer 1971, 1972 ICRP, 1975 Nutrition Foundation, 1982
Updated Inhalation Rates [b]	0 < 12 12 < 24 24 < 36 36 < 48 48 < 60 60 < 72 72 < 84	3.22 4.97 6.09 6.95 7.68 8.32 8.89	Layton, 1993 Brochu et al., 2006 Stifelman, 2007	Methodology Total energy expenditure (DLW) Data Source IOM, 2005
U.S. EPA, 1997 [c]	0 < 12 12 < 24 36 < 60 72 < 96	4.5 6.8 8.3 10	Layton, 1993	Methodology Food-energy intakes Total energy expenditure Data Source USDA/ARS, 1984
U.S. EPA, 2008	0 < 1 1 < 3 3 < 6 6 < 12 12 < 24 24 < 36 36 < 72 72 < 132	3.6 -- 4.1 5.4 8.0 9.5 10.9 12.4	Layton, 1993 Arcus-Arth and Blaisdell, 2007 Brochu et al., 2006 Stifelman, 2007	Methodology Food-energy intakes Total energy expenditure (DLW) Data Source USDA/ARS, 1984, 2000 Black et al. 1996 Torun et al. 1996 Butte et al. 2000 IOM, 2005
U.S. EPA, 2011, 2009a	0 < 1 1 < 3 3 < 6 6 < 12	3.6 3.5 4.1 5.4	Layton, 1993 Arcus-Arth and Blaisdell, 2007	Methodology Food-energy intakes Total energy expenditure (DLW)

	0 < 12 24< 36 36 < 72 72 < 132	8.0 8.9 10.1 12.0	Brochu et al., 2006 Stifelman, 2007	Data Source USDA/ARS, 1984, 2000 Black et al. 1996 Torun et al. 1996 Butte et al. 2000 IOM, 2005
U.S. EPA, 2009b	0 < 12 24 < 36 36 < 72 72 < 132	8.0 8.9 10.1 12.0		
U.S. EPA, 2010	0 < 6 6 < 12 12 < 24 24 < 36 36 < 48 48 < 60 60 < 72 72 < 84	5.4 5.4 8 9.5 10.9 10.9 10.9 12.4	U.S. EPA, 2008 Layton, 1993 Arcus-Arth and Blaisdell, 2007 Brochu et al., 2006 Stifelman, 2007	Methodology Food-energy intakes Total energy expenditure (DLW) Data Source USDA/ARS, 1984, 2000 Black et al. 1996 Torun et al. 1996 Butte et al. 2000 IOM, 2005

[a]IEUBK Model (v.2)
[b]Mid-point inhalation rates are provided in the table for comparative purposes only, the proposed update to the IEUBK model will use the estimated regression equation to calculate inhalation rate as a continuous non-linear function of age (see Tables 5 and 6).
[c] The daily inhalation rate is calculated by multiplying the EFD in Table 2 by $H*I_{EQ}*(m^3/L)$ for those under 9 years of age.

UNCERTAINTY

Limitations in the IOM (2005) database preclude making site-specific statistical inferences about inhalation rates in U.S. children. The data used to estimate the regression model were not obtained from a probability sample (IOM, 2005), and the degree to which they are representative of the U.S. population of children less than 8 years of age is uncertain. However, the data represent a broad range of U.S. children in regard to age, body weight, height and activity level (IOM, 2005). Layton's approach to calculating age-specific inhalation rates is dependent on the inhalation equivalent ratio (I_{EQ}), which relies on an individual's fitness and energy expenditure levels (U.S. EPA, 2009b). The U.S. EPA (2009b) noted that Layton's (1993) I_{EQ} value of 27 may be appropriate for adults, but not necessarily for children.

RECOMMENDATIONS FOR THE IEUBK MODEL

The Exposure Factors Handbook (U.S. EPA, 2011) provides inhalation rate data based on the average of four studies (U.S. EPA, 2009a; Arcus-Arth and Blaisdell, 2007; Stifelman, 2007; Brochu et al., 2006). Brochu et al. (2006) and Stifelman (2007) are based on the same DLW data, but Arcus-Arth and Blaisdell (2007) and U.S. EPA (2009a) are indirect measures of inhalation rates based on dietary recall and activity-based survey responses. These indirect measures are subject to error, and caution should be exercised when interpreting nutrient assessments based on dietary recall data covering only a few days of intake (IOM, 2005).

By contrast, the TEE approach is a direct measure to estimate inhalation rate (Brochu et al., 2006; Stifelman, 2007). Using the DLW methodology in the TEE approach is an improvement over indirect measures of inhalation rate estimates based on dietary recall or activity-based survey data (U.S. EPA 2009b; Stifelman, 2007; Brochu et al. 2006). For this reason, the proposed inhalation rates are preferred for use in the IEUBK model.

The IEUBK model is intended for long-term exposures (≥90 days, U.S. EPA, 1994a) for children (i.e., birth to 7 years of age) who reside (or may potentially reside) at a lead-contaminated site. The TRW Lead Committee recommends estimating long-term average daily TEE using the DLW dataset (IOM,2005) and the linear regression equation described in this document to update the age – specific inhalation rates in the IEUBK model. Based on this analysis, the updated values for the inhalation rates (as shown in Table 7) are recommended for all applications of the IEUBK model where current and future use scenarios are assessed.

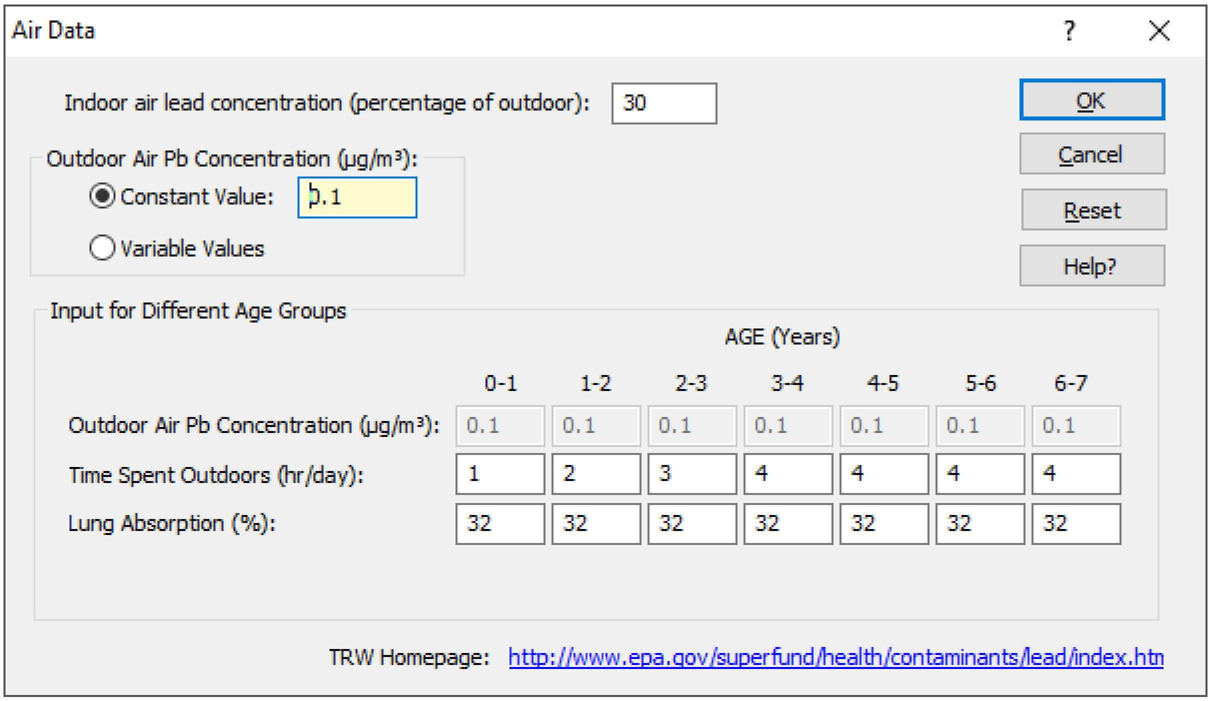

Figure 3. Updated *Inhalation Rates* default values shown in the IEUBK model Air Data Entry Window with age-specific inhalation rates as an internal variable (i.e., not accessible to users).

IMPACT ON IEUBK MODEL PREDICTIONS

When applying the recommended inhalation rates to the IEUBK model (v. 2), along with the other v. 2 default parameters, estimates of daily uptake of airborne lead and total lead uptake both increased for all age ranges (Table 8) although uptake of Pb via the inhalation pathway contributes less than 2% of the total daily lead uptake in the IEUBK model when the v. 2 default airborne lead concentrations is used (*i.e.*, the NAAQS, 0.1 µg/m³, U.S. EPA 2016). For these reasons, the TRW Lead Committee recommends removing the inhalation rate input from the IEUBK model user interface and making it an internal variable of the IEUBK model (See Figure 3). As shown in Table 8, the cumulative effect of the v. 2 model intake values relative to the v1.1, Build11 intake values is a decrease in GM blood lead concentration for each age group that ranges from <0.1 µg/dL in the first year (0 < 12 months) to approximately 0.9 µg/dL for the 26 < 48 month age group. Similarly, the GM blood lead concentration for the 0-84 month age range decreased by 0.4 µg/dL, while the preliminary remediation goals (PRGs) increase.

Table 8. Effects of changes to the IEUBK model variables with a focus on the inhalation rate variable.

Source	Age Range (months)							GM[†] (µg/dL)	P_{10}[†] (%)	PRG[†] for 5% NTE[†] 5 µg/dL (ppm)	PRG[†] for 5% NTE[†] 10 µg/dL (ppm)
	0 < 12	12 < 24	24 < 36	36 < 48	48 < 60	60 < 72	72 < 84				
Existing default IEUBK model value[a]											
Inhalation Rate (m^3/day)	2	3	5	5	5	7	7	2.7	0.3	153	418
Lead Uptake from Air (µg/day)	0.021	0.034	0.062	0.067	0.067	0.093	0.093				
Calculated Total Lead Uptake (µg/day)	5.586	8.368	8.593	8.651	7.045	6.720	6.592				
Calculated Blood Lead Concentration (µg/dL)	3.0	3.5	3.2	3.0	2.5	2.1	1.9				
Proposed default IEUBK model value[b]											
Inhalation Rate (m^3/day)	3.22	4.97	6.09	6.95	7.68	8.32	8.89	2.3	0.09	200	605
Lead Uptake from Air (µg/day)	0.034	0.057	0.075	0.093	0.102	0.111	0.118				
Calculated Total Lead Uptake (µg/day)	5.626	7.172	6.102	6.056	6.424	5.926	6.064				
Calculated Blood Lead Concentration (µg/dL)	3.0	3.0	2.4	2.1	2.1	1.9	1.7				

[†]GM: Geometric mean blood lead concentration (µg/dL) ; P10: Probability of the predicted GM blood lead concentration ≤ 5 or 10 µg/dL; PRG: preliminary remediation goal; NTE: not to exceed. The GM, P10 and PRGs are for the 0-84 month age range. To better align the CDC recommendation and the risk predictions for lead exposure at Superfund sites, the TRW Lead Committee recommends that the default age range in IEUBK model be modified to match the 1-5 year age range (12-72 months).

[a]IEUBK Model (v. 1.1).

[b] IEUBK Model (v. 2). Mid-point (interpolated) inhalation rates are provided in the table for comparative purposes only, the proposed update to the IEUBK model will use the estimated regression equation to calculate inhalation rate as a continuous non-linear function of age (see Table 4).

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