FINAL REPORT

SARA GROUP

Sudbury Area Risk Assessment
Volume II

Appendix Q:

IEUBK Lead Modelling Overview and Results

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SUDBURY AREA RISK ASSESSMENT
VOLUME II

APPENDIX Q: IEUBK LEAD MODELLING OVERVIEW AND RESULTS

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APPENDIX Q: IEUBK MODELLING OVERVIEW AND RESULTS

Q-1.0 INTRODUCTION

The following appendix provides an overview and results of computer simulation modelling conducted using the U.S. EPA Integrated Exposure Uptake Biokinetic (IEUBK) model for lead. This modelling was conducted as one element of the weight-of-evidence approach used to evaluate the potential health risks to Sudbury children arising from exposures of lead. More detailed information on the IEUBK model, its development, and the software itself, can be obtained for the U.S. EPA's *Addressing Lead at Superfund Sites* webpage, located at http://www.epa.gov/superfund/lead/index.htm.

The Integrated Exposure Uptake Biokinetic (IEUBK) computer model is a simulation model developed by the U.S. EPA to predict childhood lead exposure and retention. It has the ability to quantify the relationship between environmental lead concentrations in different media (*e.g.,* soil, water, air and food), and blood lead (PbB) levels in children of different ages (0 to 84 months) (U.S. EPA, 1994a). Estimates of a likely distribution of PbB concentrations are centered on the geometric mean concentration and can be used to calculate the probability that concentrations in children will exceed an acceptable level. This acceptable level is typically at or below 10 µg/dL, the concentration at which health effects of concern have been identified to occur (U.S. EPA, 1994a, 2002).

Q-2.0 DESCRIPTION OF THE IEUBK MODEL FOR LEAD EXPOSURE IN CHILDREN

The IEUBK model has become a standard tool for performing lead risk assessments. Variants of the IEUBK model have been developed that address uncertainty associated with model variables (*e.g.,* Lee *et al.,* 1995). However, the IEUBK model provides the most scientific, generally-available method for both estimating the risk of exceeding benchmark PbB levels, and estimating environmental concentrations of lead that may result in elevated PbB levels. By comparing the model's results with empirical PbB data, a number of studies (*e.g.,* Hogan *et al.*, 1998, Zaragoza and Hogan, 1998) have confirmed that, assuming appropriate inputs, the IEUBK model can reliable estimate criteria.

Advantages of use of the IEUBK model over other methods of lead risk assessment include:

- The model is highly defensible due to a high degree of documentation and rigorous peer review;
- The model addresses a wide range of exposure pathways;
- Bioavailability of lead from different media is specifically addressed;
- The model incorporates a "biokinetic" component that addresses lead's complex toxicokinetics (as opposed to using a target risk-based exposure limit); and,
- Use of the model is straightforward, due to its availability on the Internet and a user-friendly interface.

The only disadvantage of note is that use of the model is more complex than use of a single risk-based criterion.

The IEUBK model was developed to account for the unique aspects of lead exposure, bioavailability, and toxicokinetics. The model is comprised of four main components which work together to predict PbB levels from environmental media concentrations:

- Exposure;
- Uptake;
- Biokinetics; and,
- Variability.

These components are described in detail below.

Q-2.1 Exposure Component

Children may come into contact with lead in their environment in a variety of ways, depending on their daily activities and the ways in which they utilize local resources (*e.g.,* yards, playgrounds, water bodies). The path a chemical travels to reach an environmental medium (*e.g.,* air, soil, water, food, *etc*.) that a person may come into contact with is referred to as an exposure pathway. The means by which a chemical moves from the environmental medium into the body is called an exposure route. There are three major exposure routes through which chemicals can enter the body: inhalation, ingestion and dermal absorption (*i.e.,* through the skin). The IEUBK model addresses inhalation and ingestion. The likelihood of appreciable dermal absorption of inorganic lead compounds is low, and is therefore not explicitly addressed.

The exposure component of the IEUBK model uses both receptor- and media-specific (*i.e.,* soil, dust, air, water, food) intake rates in combination with environmental media concentrations to estimate total daily intake rates of children on a µg lead/day basis. Both media concentrations and receptor intake rates are controlled by the user, therefore, "default" values and/or relationships provided by the U.S. EPA can be supplemented with site-specific data when available. The model's default, receptor-specific media intake rates were based on a variety of studies that examined typical and/or national average intake rates for specific age in the United States. In the absence of site-specific lead concentrations such as indoor dust and indoor air data, the model has the ability to project indoor concentrations based on measured outdoor soil and air data. The medium of greatest concern at sites with lead-impacted soil is generally the soil itself. Children can be exposed to soil through incidental ingestion as a result of play, hand-to-mouth behaviour, or any other activity that involves oral contact with unclean objects. Furthermore, small children tend to have greater physical proximity to soil and dust.

The resulting estimated daily exposures in children are used as input data for the uptake component of the model.

Q-2.2 Uptake Component

The uptake component of the IEUBK model determines what proportion of a child's total daily lead intake will be transferred to the child's blood plasma (where it can be delivered to critical organ systems) and what proportion will be eliminated from the body. Lead uptake can be defined as the amount of lead absorbed per unit time from both the gut and the lung into the systemic blood flow (U.S. EPA, 1994a).

Only a fraction of a child's total daily intake that actually enters the systemic blood flow; is referred to as the absorption fraction.

Absorption data taken from studies in humans, primates and rats suggest a non-linear relationship between lead intake and lead absorption (U.S. EPA, 1994a). Sherlock and Quinn (1986) conducted a number of diet studies of bottle-fed infants exposed to lead both in water and in formula mixed with lead-impacted water. Sherlock and Quinn were able to quantify a relationship between lead intake and lead absorption. The dose dependency of lead absorption was described by a "curvilinear" relationship (U.S. EPA, 1994b). In other words, as the lead intake rate increased, the rate at which lead was absorbed into the systemic blood system decreased. This type of non-linear absorption kinetics is addressed by the IEUBK lead model. At higher intake rates (*i.e.,* greater than 200 µg lead/day), the relationship between lead absorption and lead intake appears to be non-linear, while at doses less than 100 to 200 µg/day, the relationship appears to be linear in nature (U.S. EPA, 1994a). It should be noted that other factors, such as the specific lead compound and particle size, could affect the rate of absorption at lower doses. For example, studies conducted by Barltrop and Meek (1975) illustrated that lead in a sulfide, chromate, naphthenate or octoate form was 40 to 67% less bioavailable relative to lead in the more soluble carbonate form. Table Q.1 illustrates the default bioavailability than the IEUBK model for each medium of concern.

Table Q.1 Default Bioavailability Values used within the IEUBK Model

Medium of Concern	Absorption Fraction *via* Gut	Absorption Fraction *via* Lungs
Soil and Dust	30%	NA
Diet	50%	NA
Water	50%	NA
Air	NA	35% bioaccessible[1] 100% bioavailable

[1] Bioaccessible refers to the amount that is available for absorption via the lung.

There are two mechanisms by which lead absorption is characterized: saturable (active) and non-saturable (passive) absorption. "Saturation" occurs when further absorption is limited by existing body burden. Uptake rates in the IEUBK model are both media- and age-dependent. When saturation effects are not occurring, the IEUBK model will estimate total absorbed lead intake by adding all medium specific absorption values, where absorption from each media is equal to the age-dependent intake rate, multiplied by the media-specific absorption fraction (U.S. EPA, 1994a). However, to more accurately reflect absorption at higher doses, the saturable mechanism of absorption is also included. Thus, the total lead absorption is given by the sum of both the active and passive mechanisms of uptake.

Q-2.3 Biokinetic Component

The biokinetic component of the IEUBK model calculates the mass of lead in each body compartment over time, as a result of physiologic and biochemical processes. This involves a network of differential equations used by the biokinetic model to estimate the mass of lead as a function of time within each body compartment. The differential equations used within the biokinetic model form the basis of the mass balance approach.

The biokinetic model begins by calculating the volumes and weights of each compartment within a child's body, as a function of age. The transfer rates between these compartments and elimination mechanisms are then estimated, and an initial PbB concentration is calculated for a newborn child (including maternal contribution). Lead masses in each body compartment, and hence PbB levels, are calculated for each iteration or interval of time from birth to 84 months of age (U.S. EPA, 1994a). Lead masses are estimated for several different compartments within a child's body including:

- Plasma-extracellular fluid (ECF);
- Red blood cells;
- Liver;
- Kidney;
- Trabecular bone;
- Cortical bone; and,
- Other soft tissue.

These particular body compartments were selected for a variety of reasons. The liver and kidney were selected as they are considered potential target sites of toxicity, while bone has a potential to be a major area of lead accumulation (U.S. EPA, 1994a). The whole blood consists of two compartments, red blood cells and the extracellular fluid (ECF). It is assumed that the nervous system would be well perfused by blood.

The IEUBK model operates under the assumption that lead is transferred between the ECF compartment and most other compartments *via* first-order kinetics, and at a rate of transport that is independent of compartment lead concentrations. The only transfer mechanism that is dependent on concentration is the transfer rate between plasma and red blood cells. The IEUBK model assumes that a lead saturation level does exist for red blood cells, and therefore, this transfer coefficient helps to govern the age-dependent accumulation of lead in various compartments (U.S. EPA, 1994a).

As previously mentioned, the lead mass for each body compartment of a newborn child is the starting point for the biokinetic algorithm. The masses of each compartment are calculated for each time step from birth to 84 months of age, the child's PbB concentration is then calculated as the average monthly value over the number of time intervals in one month (U.S. EPA, 1994a).

Q-2.4 Variability Component

Variability in PbB levels will exist in any given population of children, even if all individuals within that population are exposed to similar levels of lead. There are many reasons why different PbB levels may exist among a group of similarly exposed children. These include biological and behavioral variability, differences in food consumption rates, as well as variability, reproducibility and analytical errors within environmental lead measurements. The probability distribution component of the IEUBK model addresses variability of PbB levels associated with a typical child or a population of children. It should be emphasized that the IEUBK model does not address variability in PbB levels as a result of substantially different intake rates among children; rather, it addresses the variability observed within a group of similarly exposed individuals.

This component of the IEUBK model uses the predicted population geometric mean PbB level, as estimated by the previous components of the model, to calculate a lognormal probability distribution of PbB levels centered on this the geometric mean. The probability distribution is created by the application of a geometric standard deviation (GSD) that is based on empirical studies of lead-exposed children. By generating a probability distribution of PbB levels, the model is able to calculate the probability that a population of exposed children's PbB concentrations will exceed a selected level of concern (*e.g.,* 5% probability of exceeding 10 µg/dL). The GSD recommended for use with the IEUBK model is 1.6. This value is based on a series of empirical studies of several specific sites throughout North America. Several statistical methods were used to derive and verify this GSD, and U.S. EPA recommends that the default value of 1.6 be employed unless there are site-specific empirical studies available.

The predicted distribution of PbB levels can also be used to “back-calculate” a soil lead level that contributes to a benchmark “exceedance” of a particular PbB level (given other sources of exposure).

Q-3.0 IEUBK MODEL APPLICATION AND RESULTS FOR THE HHRA

To validate the risk characterization derived using the SARA exposure model, blood lead concentrations in receptors up to the age of seven years were also predicted using the U.S. EPA's Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children (Windows 32 Bit Version Build 264). The peer-reviewed exposure parameters and risk characterization assumptions set as default values within the IEUBK model were maintained unless scientifically defensible site-specific values were available. This allowed for the prediction of blood lead concentrations that were reflective of the unique characteristics of the distribution of lead throughout the Sudbury environment and among the potential sources of contamination, while still relying on the widely accepted approaches used within the IEUBK model.

Q-3.1 Site-Specific Parameters Used within the IEUBK Model

Blood lead concentrations for child receptors in each of the five COI were assessed using the Sudbury-specific exposure point concentrations (EPCs) for outdoor soil, indoor dust, drinking water, outdoor air, and dietary items. EPCs were defined as the upper 95% confidence limit on the arithmetic sample mean of a given environmental medium and region. Parameters associated with each exposure scenario are described in detail below; and, along with a comparison to parameters used within the model developed by the SARA Group, are summarized in Table Q.2.

As previously discussed in Section 6.6, the IEUBK model is a simulation model used to specifically predict childhood lead exposure and retention. It has the ability to quantify the relationship between environmental lead concentrations in different media (*e.g.,* soil, water, air and food) to blood lead (PbB) levels in children of different ages (0 to 84 months) (U.S. EPA, 1994a). Some of the IEUBK model default input parameters differ slightly from those used in the SARA model (due to the use of site-specific data and assumptions). As stated previously, the peer-reviewed exposure parameters and risk characterization assumptions set as default values within the IEUBK model were maintained unless scientifically defensible site-specific values were available. Values in **bold** within Table Q.2 were used in the IEUBK model to predict blood lead concentrations for the current assessment.

Table Q.2 Comparison of Exposure Parameters Used in the SARA Exposure Model to IEUBK Default Values

Exposure Parameter	Receptor Age Categories (years)[a]						
	0-1[b]	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**
Inhalation Pathway							
Ventilation Rate (m^3/day)							
SARA Model	6.9	10.8	10.8	10.8	18.8	18.8	18.8
IEUBK Model	**2**	**3**	**5**	**5**	**5**	**7**	**7**
Time Spent Outdoors (hrs/ day)							
SARA Model	3	3	3	3	3	3	3
IEUBK Model	**1**	**2**	**3**	**4**	**4**	**4**	**4**
Bioavailability (%)[c]							
SARA Model	100						
IEUBK Model	**32**						
Percentage of Lead from Outdoor Air in Indoor Air (%)							
SARA Model	100						
IEUBK Model	**30**						
Body Weights (kg) (average of males and females)							
SARA Model	12.4	16.5	16.5	16.5	32.2	32.2	32.2
IEUBK Model	**7.4**	**11.4**	**13.4**	**15.7**	**18.2**	**20.4**	**22.3**
Drinking Water Pathway							
Consumption Rate (L/day)							
SARA Model	0.82	1.1	1.1	1.1	1.3	1.3	1.3
IEUBK Model	**0.2**	**0.5**	**0.52**	**0.53**	**0.55**	**0.58**	**0.59**
Bioavailability (%)[c]							
SARA Model	100						
IEUBK Model	**50**						
Soil/ Dust Ingestion Pathway							
Soil + Dust Ingestion Rate (g/day)							
SARA Model	0.08	0.08	0.08	0.08	0.08	0.08	0.08
IEUBK Model	**0.085**	**0.135**	**0.135**	**0.135**	**0.100**	**0.090**	**0.085**
Bioavailability in Soil (%)							
SARA Model	**33[c]**						
IEUBK Model	30						
Bioavailability in Dust (%)							
SARA Model	**40[c]**						
IEUBK Model	30						
Soil/Dust Weighting Factor (% Soil)							
SARA Model	45						
IEUBK Model	**45**						
Food Consumption Pathway							
Total Dietary Lead Intake (µg Pb/day)							
SARA Model[d]	**6.02**	**13.74**	**16.15**	**18.89**	**15.01**	**16.89**	**18.40**
IEUBK Model	3.16	2.6	2.87	2.74	2.61	2.74	2.99
Bioavailability (%)[e]							
SARA Model	100						
IEUBK Model	**50**						

Table Q.2 Comparison of Exposure Parameters Used in the SARA Exposure Model to IEUBK Default Values

Exposure Parameter	Receptor Age Categories (years)[a]						
	0-1[b]	1-2	2-3	3-4	4-5	5-6	6-7
Dermal Absorption Pathway							
Bioavailability (%)[e]							
SARA Model	0.1						
IEUBK Model	**Not Assessed**						

[a] Parameters used in the SARA model for the infant (0 to <6 months), preschool child (6 months to <5 years) and child (5 to 11 years) were separated into the IEUBK age categories for comparative purposes. Values are the average of parameters for male and female receptors.

[b] Ventilation, drinking water consumption, soil + dust ingestion, and dietary intake rates for the 0 to 1 age category is the average of the infant rates (representing age 0 to 6 months) and the preschool child rates (representing age 6 months to 1 year).

[c] Bioavailability values used within the SARA model (*i.e*., 66% for soil and 81% for dust) represent the relative bioavailability. These values were adjusted to represent an absolute bioavailability (*i.e*., 33% for soil and 40% for dust) for use in the IEUBK model.

[d] Total dietary lead intake values represent an average of those predicted for each age group in each of the 5 COI.

[e] Bioavailability values presented for the SARA Model represent relative accessibility factors (RAFs).

The bioavailability values for lead in soil and dust used within the IEUBK model were derived from the results of the site-specific *in vitro* determined bioaccessibility (IVBA). The IVBA of 78% for soil and 95% for dust were converted to an absolute bioavailability (ABA) following the protocol recommended by the U.S. EPA (2007) which first involved the conversion of the IVBA to the relative bioavailability (RBA) using the following formula:

$$RBA = 0.878 \times (IVBA - 0.028)$$

The resulting RBA values of 66% for soil and 81% for dust were used to predict exposure from soil and dust pathways within the SARA model. Since the IEUBK model requires the use of an ABA for lead in soil and dust, an additional step was taken to convert the RBA values to ABA values. This was accomplished by multiplying the RBA by the ABA for soluble lead (50%) to determine the ABA of lead in soil and dust (*i.e*., 33% and 40%, respectively).

In addition to those values presented in Table Q.2, the use of the IEUBK model to predict blood lead concentrations in children from each of the 5 COI included site-specific levels of lead in outdoor soil, indoor dust, outdoor air, and drinking water (Table Q.3). Using the IEUBK default value representing the percentage of lead from outdoor air in indoor air, the predicted indoor air concentrations for each COI were predicted based on the measured outdoor air concentrations.

Table Q.3 Environmental Media Concentrations Used Within the IEUBK Model to Predict Blood Lead Concentrations

Environmental Medium	Hanmer	Sudbury Centre	Falconbridge	Copper Cliff	Coniston
Outdoor Soil (µg/g)	19.2	35.9	82.3	97.9	52.0
Indoor Dust (µg/g)	98.4	116	144	150	127
Outdoor Air (µg/m^3)	0.010	0.031	0.015	0.022	0.008
Indoor Air (µg/m^3)	0.003	0.0093	0.0045	0.0066	0.0024
Drinking Water (µg/L)	0.488	0.313	3.67	1.39	0.313

Inhalation Exposure Pathway

Measured EPCs of lead in outdoor air for each of the five COI were entered into the IEUBK model to predict blood lead concentrations. Since indoor air concentrations were not measured as part of the Sudbury Soils Study, the IEUBK default assumption was adopted in which concentrations of lead in indoor air are assumed to be 30% of those measured in outdoor air, rather than the assumption of 100% used in the HHRA itself. All other parameters associated with the inhalation pathway, including ventilation rates, fraction absorbed by the lungs, and time spent outdoors, were set to the IEUBK default values.

Drinking Water Exposure Pathway

Measured EPCs of lead in drinking water for each region were used to predict blood lead concentrations. IEUBK default values were used to represent the daily consumption rates and the bioavailability of lead in drinking water.

Soil/ Dust Ingestion Exposure Pathway

Concentrations of outdoor soil and indoor dust were measured as part of the Sudbury Soils Study. The EPCs for these media were used within the IEUBK model. Soil- and dust-specific ABAs were also derived as part of the HHRA and were incorporated into the IEUBK model (as described above). The soil/ dust ingestion rates and weighting factors used were the IEUBK model default values.

Food Consumption Exposure Pathway

As a component of the Sudbury Soils Study, concentrations of COC were measured in Sudbury-specific food items. This included fruits and vegetables derived from local agriculture and home gardens, wild blueberries, wild game, and local fish. As part of the HHRA, background COC intake rates resulting from the consumption of the Canadian market food basket were estimated based on Canadian food intake rates and typical metal concentrations observed in supermarket foods (see Appendix D of this volume). These values were used within the SARA model to predict daily intake rates for each receptor from each COI. The total daily dietary lead intake rates (µg/kg/day) predicted by the SARA model were adjusted by the IEUBK receptor-specific body weights to derive a dietary lead intake (µg/day) to be entered into the IEUBK model as described below.

Receptor body weights used within the IEUBK model were calculated using the following equation:

$$BW(t) = \left[\frac{8.375}{1 + \exp\left\{ \frac{-(t - 3.80)}{3.60} \right\}} \right] + \left[\frac{17.261}{1 + \left\{ \frac{-(t - 48.76)}{20.63} \right\}} \right]$$

where:

BW	=	body weight (kg); and,
t	=	receptor age (months)

For the current assessment, receptor body weights were calculated for months 0 to 84 and grouped within the IEUBK age categories (Table Q.4). The weights among the 12 monthly values within each age category were averaged to represent a single body weight for each category.

The daily lead intake (µg/kg/day) resulting from the consumption of all dietary items predicted using the SARA model were averaged for male and female infants (0 to <6 months), preschool children (6 months to <5 years) and children (5 to 11 years) from each COI. Since the IEUBK age categories are broken down into smaller age groups than those used within the SARA model, the intake rates for the preschool child and child receptors were applied to multiple IEUBK age categories. Since the first IEUBK age group spans 0 to 12 months of age, the dietary lead intake was assumed to be equal to that predicted for the infant for the first six months, and that predicted for the preschool child for the remaining six months. Table Q.4 illustrates the results of this approach for receptors living in the Town of Falconbridge.

Table Q.4 Scaling Dietary Lead Intake Rates for IEUBK Age Categories and Body Weights for Falconbridge Receptors

IEUBK Age Categories (Years)		Average Body Weight (kg)	Total Daily Dietary Lead Intake Predicted by SARA Model (µg/kg/day)	Body Weight Adjusted Daily Dietary Lead Intake (µg/day)	
0 to 1	0 to 0.5	5.75	0.19 (as per Infant)	1.09 x 0.5	5.92
	0.5 to 1	9.10	1.18 (as per Preschool Child)	10.7 x 0.5	
1 to 2		11.4	1.18 (as per Preschool Child)	13.5	
2 to 3		13.4	1.18 (as per Preschool Child)	15.8	
3 to 4		15.7	1.18 (as per Preschool Child)	18.5	
4 to 5		18.2	0.8 (as per Child)	14.5	
5 to 6		20.4	0.8 (as per Child)	16.3	
6 to 7		22.3	0.8 (as per Child)	17.8	

The IEUBK default daily dietary lead intake rates (µg/day) were significantly lower than those predicted by the SARA model for all age groups (Table Q.5). In addition, as a result of factors such as reduced environmental deposition of lead and the reduction/elimination of lead solder in the canning process, concentrations of lead in supermarket food items have declined significantly over the past several years. To address this reduction in potential lead exposure, the U.S. EPA has provided an input file that can be loaded into the most recent version of the IEUBK model that contains predicted daily lead exposures for children based on the consumption of dietary items. These updated dietary lead intake values are significantly lower than the previous IEUBK default values which are based on FDA food monitoring data collected in the late 1980s.

Since the updated values most accurately reflect the current exposure to lead through the consumption of dietary items, and this pathway typically represents a significant source of exposure, the updated values were considered to be the most appropriate for use in the current assessment. However, a significant limitation of using these updated values to predict exposure is that it does not allow for the inclusion of the home garden produce exposure pathway. The input file containing the updated values does not include all of the necessary exposure parameters to allow the IEUBK model to calculate exposure from the consumption of home garden produce and then calculate the remainder of the dietary exposure from the updated market basket values. As a result, if the alternate dietary items option is selected within the model for the purpose of including home garden contributions, the model will predict exposure from home garden produce and then incorrectly use the previous out-dated IEUBK default values to predict the remainder of the dietary exposure. Since these default values are significantly higher than the updated values, the contribution of home garden produce to the total dietary exposure would appear to be incorrectly high when compared to exposures predicted using the updated values without the home garden pathway. The U.S. EPA recognizes this limitation and is in the process of developing a solution to address this issue. Therefore, the IEUBK model was run using the updated default daily dietary intake rates and did not include a home garden or local produce component.

Table Q.5 A Comparison Between SARA and the Default IEUBK Daily Dietary Intake Rates

IEUBK Age Categories (Years)	Body Weight Adjusted Daily Dietary Lead Intake from SARA Model (µg/day)	Default IEUBK Daily Dietary Intake Rates (µg/day)	Updated Default IEUBK Daily Dietary Intake Rates (µg/day)
0 to 1	5.92	5.53	3.16
1 to 2	13.5	5.78	2.6
2 to 3	15.8	6.49	2.87
3 to 4	18.5	6.24	2.74
4 to 5	14.5	6.01	2.61
5 to 6	16.3	6.34	2.74
6 to 7	17.8	7.0	2.99

Q-3.2 Blood Lead Concentrations Predicted by the IEUBK Model

Blood lead concentrations were predicted for receptors in seven age categories for each of the five COI. The predicted blood levels represent the geometric mean for each age category calculated assuming a GSD of 1.6. This value considers biological and behavioural differences in receptors, variability in repeat sampling, variability resulting from sampling locations, and analytical variability (U.S. EPA, 2002).

Predicted blood lead concentrations for all age categories for all five COI as well as the overall geometric mean concentrations were well below 10 µg/dL, the concentration at which health effects of concern have been identified to occur (Table Q.6). The COI of Copper Cliff and Falconbridge had marginally higher concentrations than other areas, but the highest predicted concentration of 3.2 µg/dL for the one to two years of age category was still well below the level of concern. The probabilities of exceeding a BLL of 5 and 10 µg/dL at the EPC for each COI are also presented in Table Q.6.

Table Q.6 Blood Lead Concentrations Predicted by the IEUBK Model (μg/dL)

Age Categories (years)	Hanmer	Sudbury Centre	Falconbridge	Copper Cliff	Coniston
0 to 1	2.0	2.2	2.9	3.0	2.4
1 to 2	1.9	2.2	3.2	3.2	2.5
2 to 3	1.8	2.0	2.9	2.9	2.3
3 to 4	1.7	1.9	2.8	2.7	2.1
4 to 5	1.4	1.6	2.3	2.2	1.7
5 to 6	1.2	1.3	2.0	1.9	1.5
6 to 7	1.1	1.2	1.8	1.7	1.3
Geometric Mean	1.6	1.8	2.6	2.5	2.0
95th Percentile BLL	3.5	3.9	5.6	5.4	4.3
Probability of exceeding a BLL of 5 μg/dL	0.72%	1.5%	7.7%	7.2%	2.5%
Probability of exceeding a BLL of 10 μg/dL	0.004%	0.014%	0.19%	0.17%	0.030%

In Table Q.6, the 95th percentile BLLs were calculated using the following equation as recommended by U.S. EPA (2002):

$$X_{95} = GM \times GSD^{Z_{95}}$$

where:

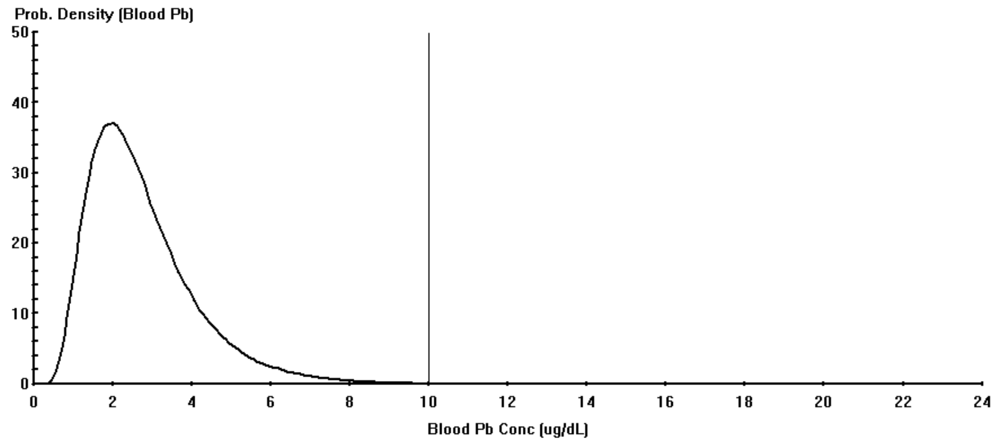
X_{95} = blood lead level at the 95th percentile (μg/dL)

GM = geometric mean blood lead level (μg/dL)

GSD = geometric standard deviation of the distribution

Z_{95} = z-score corresponding to the 95th percentile of the standard normal cumulative distribution (1.645)

Assuming homogeneous concentrations of lead in environmental media and diet, and incorporating the GSD of 1.6 to account for variability, the probability density for Falconbridge receptors shows that less than 0.2% of the population of children up to the age of seven are predicted to have blood lead concentrations greater than the level of concern (10 μg/dL) (Figure Q-1).



Geometric Mean BLL = 2.555 µg/dL
% Above 10 µg/dL= 0.185
% Below 10 µg/dL = 99.815

BLL of concern = 10 µg/dL
GSD = 1.6

Figure Q-1 Probability Density of Blood Lead Concentrations (µg/dL) in Falconbridge Children

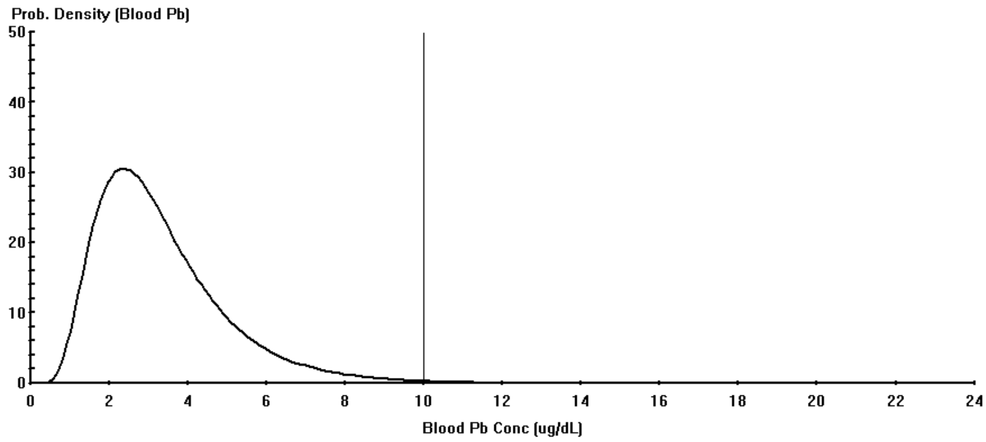
The percent contribution to total blood lead concentration from each of the four exposure pathways was similar for all five COI. The contributions from each media are shown for Falconbridge receptors in Table Q.7.

Table Q.7 Percent Contribution of Each Exposure Pathway to Total Blood Lead Concentrations for Falconbridge Receptors

Age Categories (years)	Air	Diet	Water	Soil and Dust
0 to 1	0.06%	27.8%	6.5%	65.6%
1 to 2	0.07%	16.0%	11.3%	72.7%
2 to 3	0.11%	17.3%	11.5%	71.1%
3 to 4	0.13%	16.6%	11.8%	71.5%
4 to 5	0.15%	19.5%	15.0%	65.3%
5 to 6	0.23%	21.4%	16.7%	61.7%
6 to 7	0.23%	23.7%	17.1%	59.0%

Soil and dust contributions were the dominant source of total blood lead levels for receptors of all age categories, followed by diet and drinking water. Contributions from air were insignificant relative to the other exposure sources.

The results of the assessment completed with the SARA model indicated that the concentration of lead in soil for Copper Cliff that was associated with an HQ of 1.0 was approximately 170 µg/g. This soil concentration is associated with an indoor dust concentration of 173 µg/g. Using these values and the drinking water and air concentrations presented in Table 6.5 for Copper Cliff, the predicted geometric mean blood lead concentration was 3.1 µg/dL. The probability density associated with this soil concentration is shown in Figure Q-2.



Geometric Mean BLL = 3.086 µg/dL
% Above 10 µg/dL= 0.619
% Below 10 µg/dL = 99.381

BLL of concern = 10 µg/dL
GSD = 1.6

Figure Q-2 Probability Density of Blood Lead Concentrations (µg/dL) in Copper Cliff Children at the Soil Concentration Associated with an HQ of 1.0

EPCs of lead in soils varied among the COI assessed (19.2 µg/g in Hanmer to 97.9 µg/g in Copper Cliff), and this range in values is reflected in the total blood lead concentrations predicted (Figure Q-3).

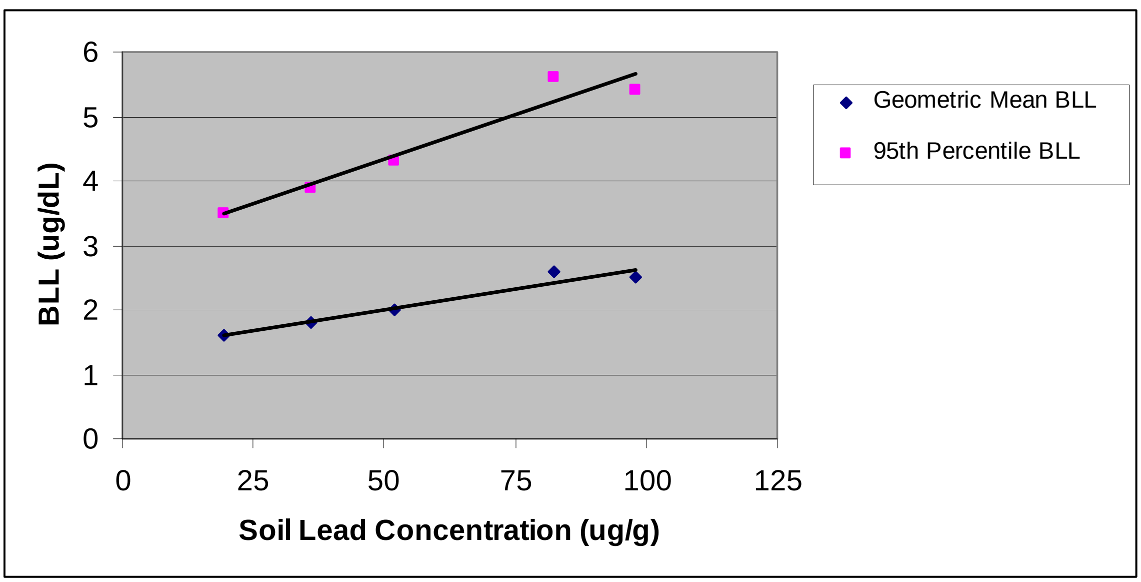


Figure Q-3 Predicted Blood Lead Concentrations Associated with the Range of Soil Concentrations Among the Five COI

This is supported by the U.S. EPA's report that urban background lead concentrations can be estimated to be between 75 and 200 µg/g (U.S. EPA, 1989). As such, the EPCs for the Sudbury area are generally below this range, indicating that exposure to Sudbury soils would not be anticipated to create blood lead levels greater than 10 µg/dL in the vast majority of children in the GSA.

Q-4.0 CONCLUSION

Results of the analyses for lead for the GSA using the SARA model indicate that greater than 95% of all female preschool children (the most exposed receptor) have lead exposures that fall well below those considered to be of concern to human health. Recognizing the limitations associated with using the IEUBK model for a community-based assessment, blood lead levels for each COI were predicted to represent the geometric mean value of a population of children exposed to homogenous lead levels under a similar exposure scenario. Results of this assessment indicate that geometric mean and 95^{th} percentile blood lead levels for each COI at the EPC soil and dust concentrations are well below 10 µg/dL. Based on these results, neither model predicts unacceptable area-wide risks from lead exposure; however, these results do support the need for the development of Soil Risk Management Levels (SRML) for lead to ensure protection of locally impacted zones.

Q-5.0 REFERENCES

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RAW IEUBK MODEL RESULTS

Results for Hanmer

The time step used in this model run: 1 - Every 4 Hours (6 times a day).

****** Air ******

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m^3/day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m^3)
.5-1	1.000	2.000	32.000	0.010
1-2	2.000	3.000	32.000	0.010
2-3	3.000	5.000	32.000	0.010
3-4	4.000	5.000	32.000	0.010
4-5	4.000	5.000	32.000	0.010
5-6	4.000	7.000	32.000	0.010
6-7	4.000	7.000	32.000	0.010

****** Diet ******

Age	Diet Intake(ug/day)
.5-1	3.160
1-2	2.600
2-3	2.870
3-4	2.740
4-5	2.610
5-6	2.740
6-7	2.990

****** Drinking Water ******

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 0.488 ug Pb/L

****** Soil & Dust ******

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	19.240	98.380
1-2	19.240	98.380
2-3	19.240	98.380
3-4	19.240	98.380
4-5	19.240	98.380
5-6	19.240	98.380
6-7	19.240	98.380

****** Alternate Intake ******

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

****** Maternal Contribution: Infant Model ******

Maternal Blood Concentration: 2.500 ug Pb/dL

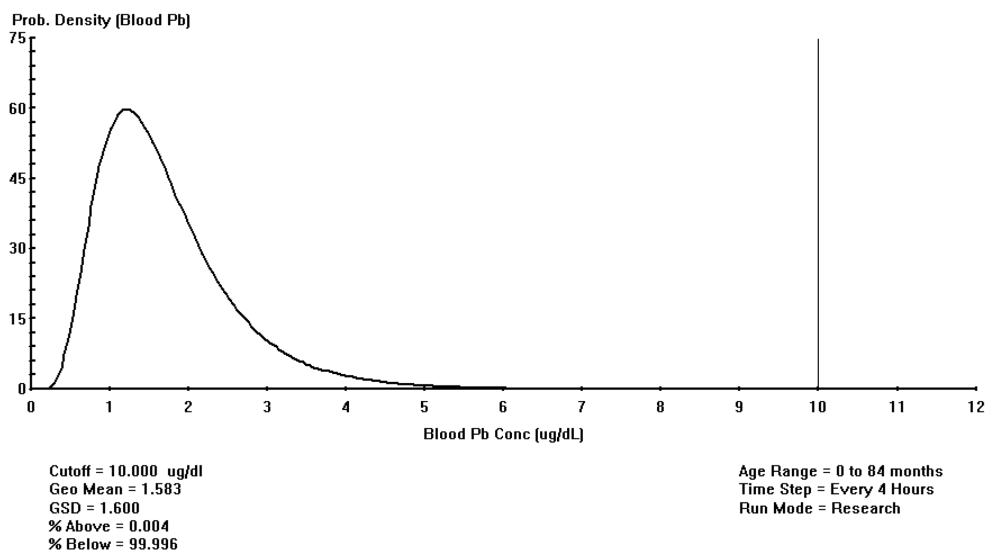
****

CALCULATED BLOOD LEAD AND LEAD UPTAKES:
****

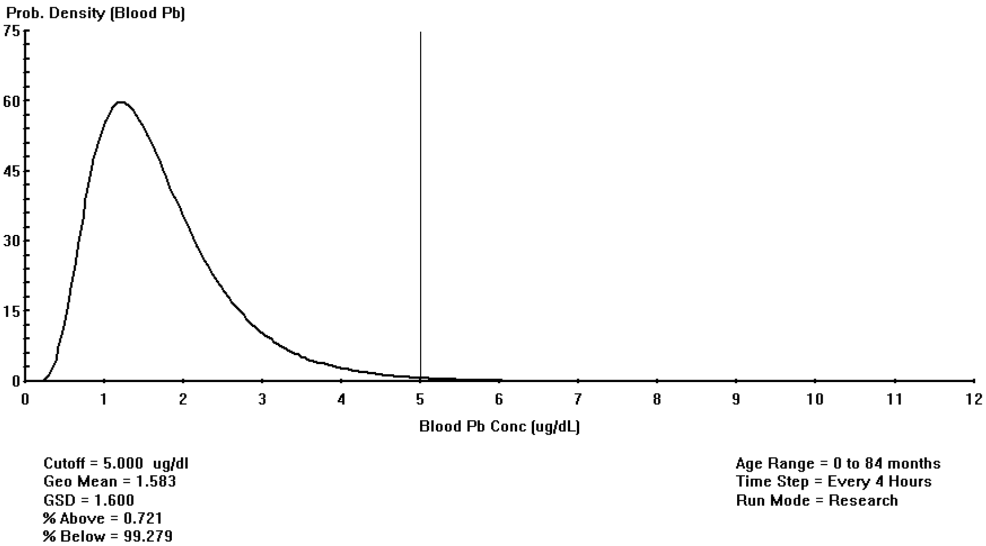
Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.002	1.517	0.000	0.047
1-2	0.003	1.249	0.000	0.117
2-3	0.006	1.386	0.000	0.123
3-4	0.007	1.330	0.000	0.126
4-5	0.007	1.278	0.000	0.131
5-6	0.009	1.346	0.000	0.139
6-7	0.009	1.471	0.000	0.142

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	2.000	3.566	2.0
1-2	3.179	4.549	1.9
2-3	3.194	4.709	1.8
3-4	3.211	4.674	1.7
4-5	2.400	3.816	1.4
5-6	2.167	3.661	1.2
6-7	2.049	3.671	1.1

Hanmer Probability Density Compared to a Blood Lead Level of Concern of 10 µg/dL



Hanmer Probability Density Compared to a Blood Lead Level of Concern of 5 µg/dL



Results for Sudbury Centre

The time step used in this model run: 1 - Every 4 Hours (6 times a day).

****** Air ******

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m^3/day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m^3)
.5-1	1.000	2.000	32.000	0.031
1-2	2.000	3.000	32.000	0.031
2-3	3.000	5.000	32.000	0.031
3-4	4.000	5.000	32.000	0.031
4-5	4.000	5.000	32.000	0.031
5-6	4.000	7.000	32.000	0.031
6-7	4.000	7.000	32.000	0.031

****** Diet ******

Age	Diet Intake(ug/day)
.5-1	3.160
1-2	2.600
2-3	2.870
3-4	2.740
4-5	2.610
5-6	2.740
6-7	2.990

****** Drinking Water ******

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 0.313 ug Pb/L

****** Soil & Dust ******

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	35.900	115.700
1-2	35.900	115.700
2-3	35.900	115.700
3-4	35.900	115.700
4-5	35.900	115.700
5-6	35.900	115.700
6-7	35.900	115.700

****** Alternate Intake ******

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

****** Maternal Contribution: Infant Model ******

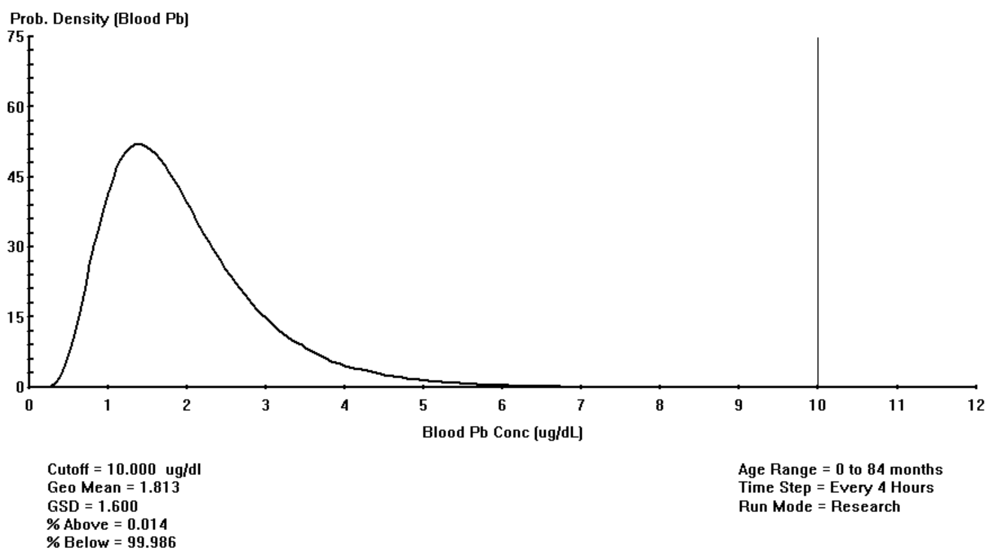
Maternal Blood Concentration: 2.500 ug Pb/dL

****
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
****

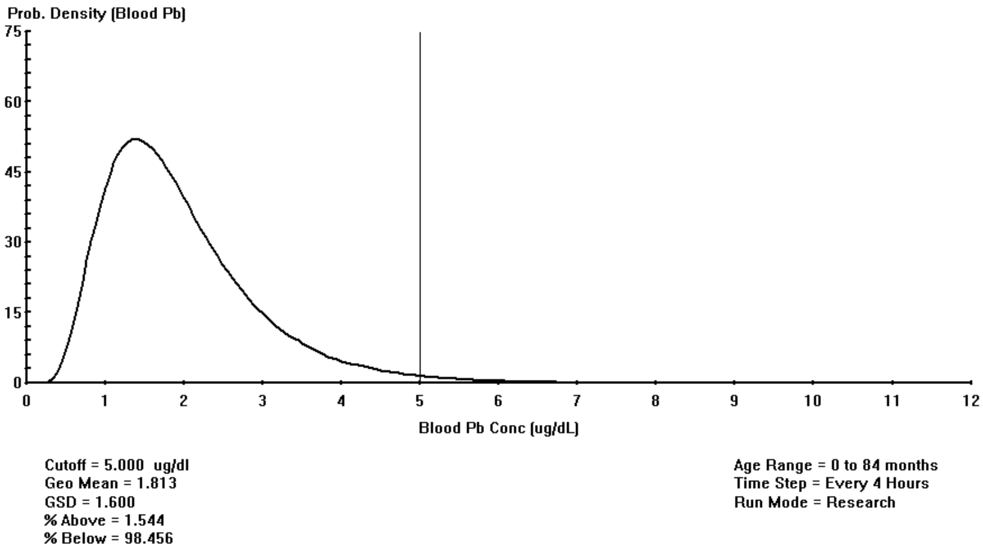
Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.007	1.509	0.000	0.030
1-2	0.011	1.241	0.000	0.075
2-3	0.019	1.378	0.000	0.078
3-4	0.021	1.324	0.000	0.080
4-5	0.021	1.274	0.000	0.084
5-6	0.029	1.343	0.000	0.089
6-7	0.029	1.468	0.000	0.091

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	2.499	4.045	2.2
1-2	3.969	5.295	2.2
2-3	3.992	5.467	2.0
3-4	4.016	5.441	1.9
4-5	3.006	4.385	1.6
5-6	2.716	4.176	1.3
6-7	2.569	4.157	1.2

Sudbury Centre Probability Density Compared to a Blood Lead Level of Concern of 10 µg/dL



Sudbury Centre Probability Density Compared to a Blood Lead Level of Concern of 5 µg/dL



Results for Falconbridge

The time step used in this model run: 1 - Every 4 Hours (6 times a day).

****** Air ******

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m^3/day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m^3)
.5-1	1.000	2.000	32.000	0.015
1-2	2.000	3.000	32.000	0.015
2-3	3.000	5.000	32.000	0.015
3-4	4.000	5.000	32.000	0.015
4-5	4.000	5.000	32.000	0.015
5-6	4.000	7.000	32.000	0.015
6-7	4.000	7.000	32.000	0.015

****** Diet ******

Age	Diet Intake(ug/day)
.5-1	3.160
1-2	2.600
2-3	2.870
3-4	2.740
4-5	2.610
5-6	2.740
6-7	2.990

****** Drinking Water ******

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 3.670 ug Pb/L

****** Soil & Dust ******

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	82.340	143.570
1-2	82.340	143.570
2-3	82.340	143.570
3-4	82.340	143.570
4-5	82.340	143.570
5-6	82.340	143.570
6-7	82.340	143.570

****** Alternate Intake ******

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

****** Maternal Contribution: Infant Model ******

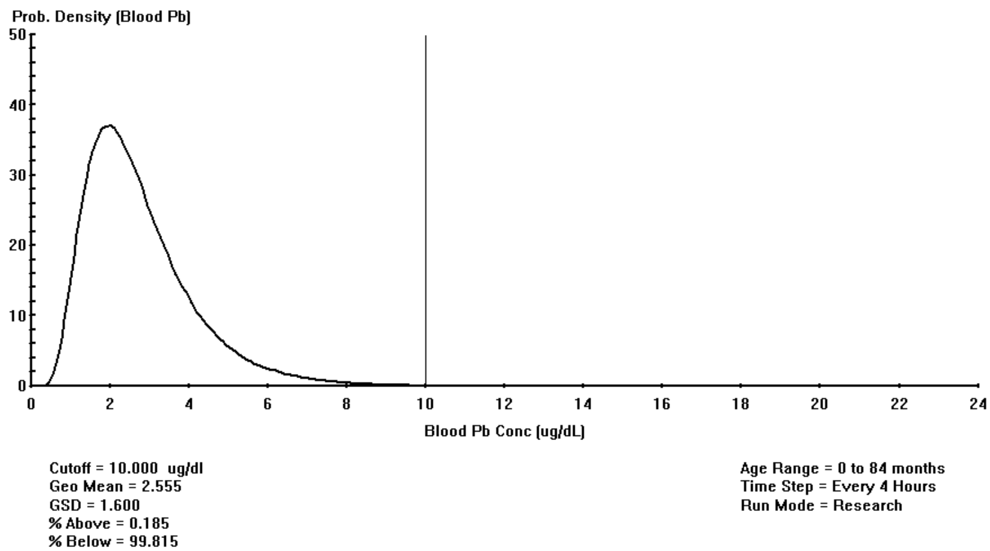
Maternal Blood Concentration: 2.500 ug Pb/dL

****
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
****

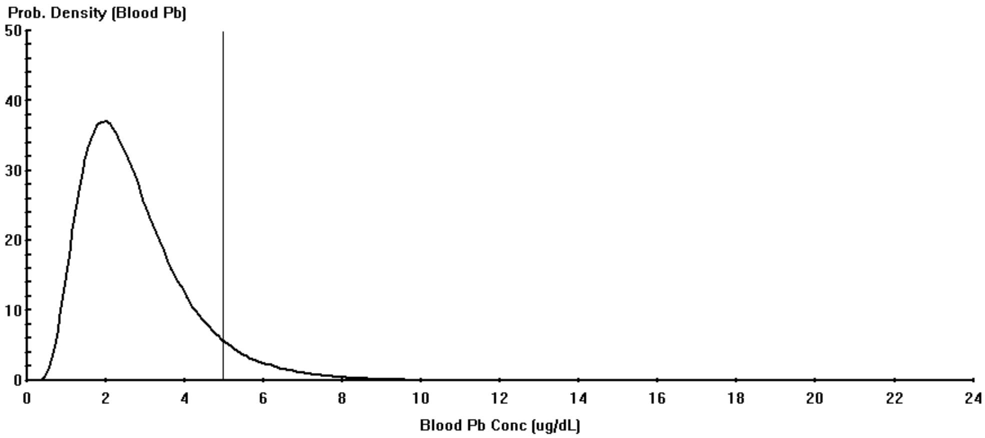
Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.003	1.487	0.000	0.345
1-2	0.005	1.216	0.000	0.858
2-3	0.009	1.354	0.000	0.900
3-4	0.010	1.303	0.000	0.925
4-5	0.010	1.260	0.000	0.974
5-6	0.014	1.330	0.000	1.033
6-7	0.014	1.455	0.000	1.054

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	3.505	5.340	2.9
1-2	5.533	7.612	3.2
2-3	5.580	7.843	2.9
3-4	5.627	7.866	2.8
4-5	4.229	6.473	2.3
5-6	3.827	6.203	2.0
6-7	3.624	6.146	1.8

<u>Falconbridge Probability Density Compared to a Blood Lead Level of Concern of 10 µg/dL</u>



Falconbridge Probability Density Compared to a Blood Lead Level of Concern of 5 µg/dL



Cutoff = 5.000 ug/dl
Geo Mean = 2.555
GSD = 1.600
% Above = 7.660
% Below = 92.340

Age Range = 0 to 84 months
Time Step = Every 4 Hours
Run Mode = Research

Results for Copper Cliff

The time step used in this model run: 1 - Every 4 Hours (6 times a day).

****** Air ******

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m^3/day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m^3)
.5-1	1.000	2.000	32.000	0.022
1-2	2.000	3.000	32.000	0.022
2-3	3.000	5.000	32.000	0.022
3-4	4.000	5.000	32.000	0.022
4-5	4.000	5.000	32.000	0.022
5-6	4.000	7.000	32.000	0.022
6-7	4.000	7.000	32.000	0.022

****** Diet ******

Age	Diet Intake(ug/day)
.5-1	3.160
1-2	2.600
2-3	2.870
3-4	2.740
4-5	2.610
5-6	2.740
6-7	2.990

****** Drinking Water ******

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 1.390 ug Pb/L

****** Soil & Dust ******

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	97.900	150.180
1-2	97.900	150.180
2-3	97.900	150.180
3-4	97.900	150.180
4-5	97.900	150.180
5-6	97.900	150.180
6-7	97.900	150.180

****** Alternate Intake ******

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

****** Maternal Contribution: Infant Model ******

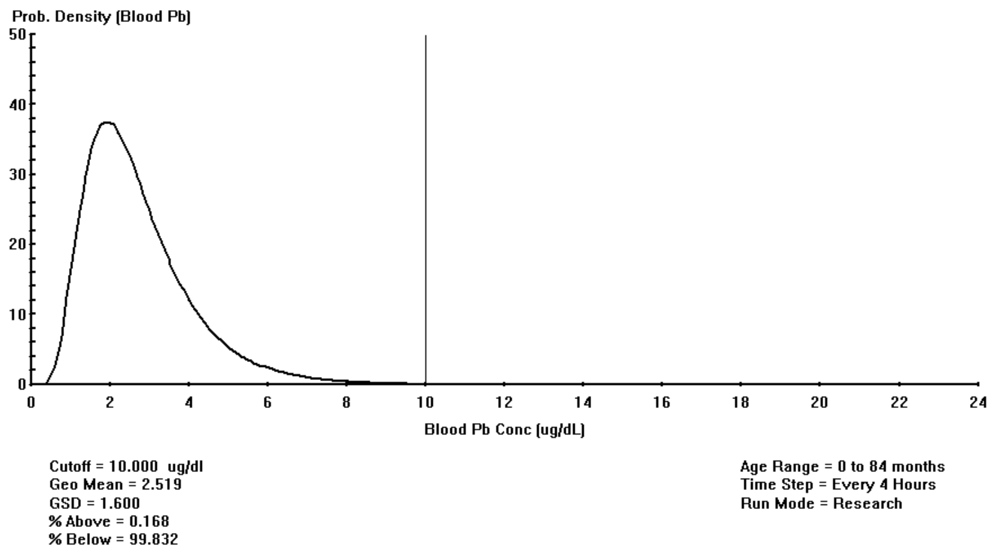
Maternal Blood Concentration: 2.500 ug Pb/dL

****
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
****

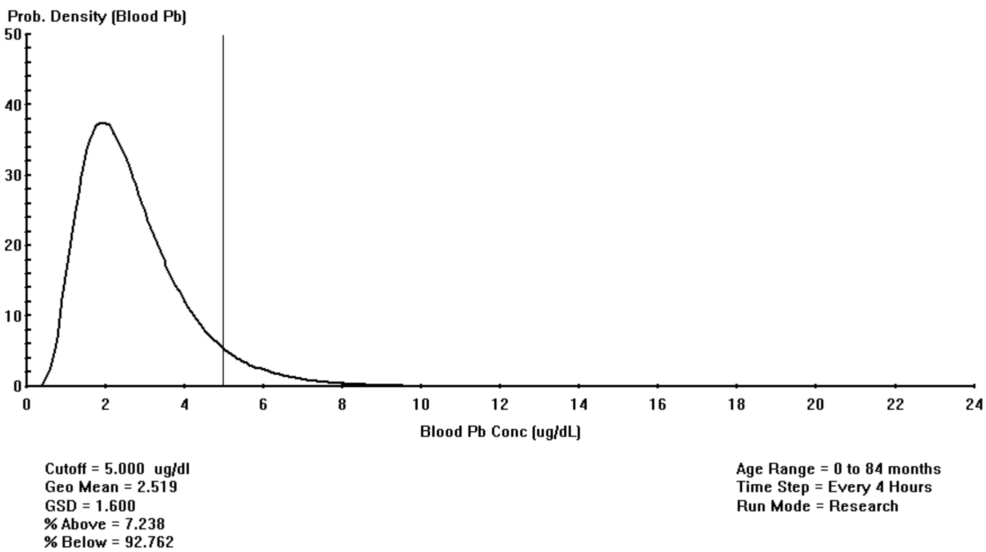
Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.005	1.485	0.000	0.131
1-2	0.008	1.217	0.000	0.325
2-3	0.014	1.354	0.000	0.341
3-4	0.015	1.304	0.000	0.351
4-5	0.015	1.261	0.000	0.369
5-6	0.021	1.332	0.000	0.392
6-7	0.021	1.457	0.000	0.400

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	3.802	5.423	3.0
1-2	6.011	7.561	3.2
2-3	6.063	7.772	2.9
3-4	6.114	7.783	2.7
4-5	4.599	6.244	2.2
5-6	4.162	5.906	1.9
6-7	3.941	5.818	1.7

Copper Cliff Probability Density Compared to a Blood Lead Level of Concern of 10 μg/dL



Copper Cliff Probability Density Compared to a Blood Lead Level of Concern of 5 µg/dL



Results for Coniston

The time step used in this model run: 1 - Every 4 Hours (6 times a day).

****** Air ******

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m^3/day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m^3)
.5-1	1.000	2.000	32.000	0.008
1-2	2.000	3.000	32.000	0.008
2-3	3.000	5.000	32.000	0.008
3-4	4.000	5.000	32.000	0.008
4-5	4.000	5.000	32.000	0.008
5-6	4.000	7.000	32.000	0.008
6-7	4.000	7.000	32.000	0.008

****** Diet ******

Age	Diet Intake(ug/day)
.5-1	3.160
1-2	2.600
2-3	2.870
3-4	2.740
4-5	2.610
5-6	2.740
6-7	2.990

****** Drinking Water ******

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 0.313 ug Pb/L

****** Soil & Dust ******

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	51.980	127.380
1-2	51.980	127.380
2-3	51.980	127.380
3-4	51.980	127.380
4-5	51.980	127.380
5-6	51.980	127.380
6-7	51.980	127.380

****** Alternate Intake ******

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

****** Maternal Contribution: Infant Model ******

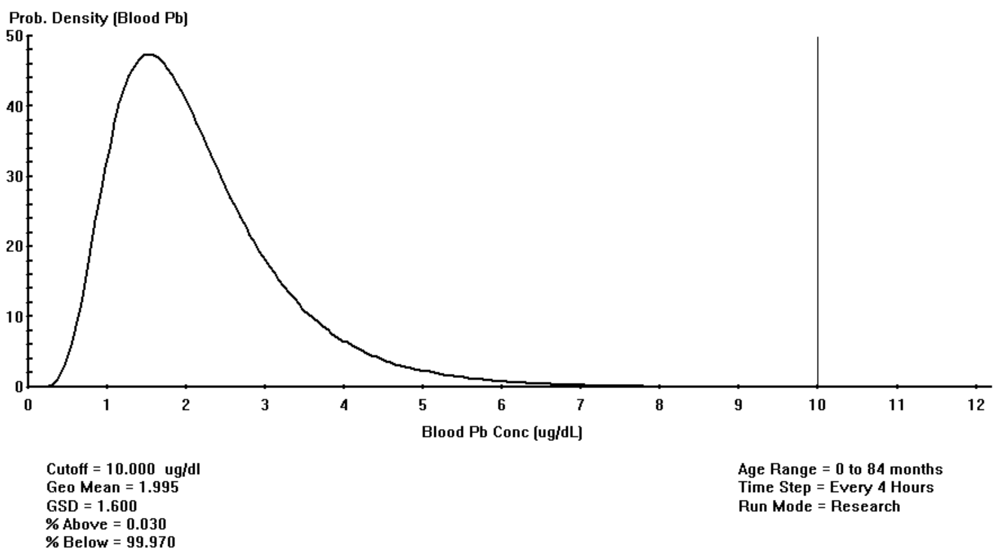
Maternal Blood Concentration: 2.500 ug Pb/dL

****
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
****

Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.002	1.503	0.000	0.030
1-2	0.003	1.235	0.000	0.074
2-3	0.005	1.372	0.000	0.078
3-4	0.005	1.319	0.000	0.080
4-5	0.005	1.271	0.000	0.084
5-6	0.007	1.340	0.000	0.089
6-7	0.007	1.465	0.000	0.090

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	2.889	4.423	2.4
1-2	4.583	5.895	2.5
2-3	4.613	6.068	2.3
3-4	4.644	6.048	2.1
4-5	3.481	4.841	1.7
5-6	3.146	4.583	1.5
6-7	2.978	4.541	1.3

Coniston Probability Density Compared to a Blood Lead Level of Concern of 10 µg/dL



Coniston Probability Density Compared to a Blood Lead Level of Concern of 5 μg/dL