Lead in the Environment: Sources and Human Health Risk Assessment

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LIST OF ACRONYMS AND ABBREVIATIONS

ALM	Adult Lead Model
BLL	blood lead level
cm^2	Square Centimeter(s)
cm^2/event	Square Centimeter(s) Per Event
CEM	Conceptual Evaluation Model
CDC	Centers for Disease Control and Prevention
ft	Feet
GSD	Geometric Standard Deviation
g/day	gram(s) per day
HHRA	Human Health Risk Assessment
IEUBK	Integrated Exposure Uptake Biokinetic Model for Lead in Children
mg/cm^2	Milligram(s) Per Square Centimeters
mg/day	Milligram(s) Per Day
mg/kg	Milligram(s) Per Kilogram
µg/dL	Microgram(s) per Deciliter
µg/L	Microgram(s) per Liter
RAGS	Risk Assessment Guidance for Superfund
USEPA	United States Environmental Protection Agency

1.0 INTRODUCTION AND PURPOSE

Lead is one of the world's oldest contaminants and has been used in many domestic and industrial applications and products. While lead is a desirable element for industrial processes, once it has been used in industry and released into the environment it remains there forever. Past major sources of lead were paint and gasoline. Fortunately, in the United States, lead has been banned in paint since 1978, and was phased out in gasoline beginning in late 1970s through the 1980s.

Although lead is a naturally occurring element that is found throughout the world, it is known to have serious deleterious effects on human health. Extensive research has been conducted on human health regarding the ingestion and inhalation of lead. This research has allowed us to better understand the extent of lead in the environment and the negative impacts on human health. The banning of lead in paint and gasoline has caused lead levels in the environment to decline. While banning lead was a positive step to reduce lead contamination in the environment and the negative impacts on human health, lead still remains a concern. The United States Environmental Protection Agency has created extensive guidelines and use models to evaluate the risk of lead in children and adults.

The objectives of this paper are to (1) provide an overview of the uses, sources, human health risk assessment, and ways to protect humans from the harmful effects of lead and (2) present an overview of the two USEPA models evaluate the risk of lead to human health.

2.0 WHAT IS LEAD AND ITS SOURCES?

Lead is a naturally occurring element found in soil, rocks, and the earth's crust, which is then introduced into the environment naturally through weathering of parent materials and anthropogenically through various industrial processes and applications (Nriagu, 1996). Lead has high electronegativity and can form strong bonds with soil organic matter (Dabkowska-Naskret, 2004; Clark et al., 2006).

Lead is desirable for use in industrial purposes due to the low melting point and a high affinity to bond with other elements (Markowitz, 2000) along with physical properties such as being soft, malleable, waterproof, and corrosion resistant. In addition, lead is easy to extract and smelt, and is found throughout the world (USEPA, 2015a).

Major sources of lead in the environment are:

- Batteries
- Ammunition
- Building & municipal equipment (sheet rock, cables)
- Plumbing materials (pipes, faucets)
- Medical equipment
- Paint (Banned since 1978)
- Gasoline (phased out in 1980s)
- Ceramics
- Scientific equipment
- Toys

Although lead occurs naturally, it does not degrade and cannot be broken down or destroyed. Therefore, once it is in the environment it remains there forever (Peterson, 2007). Anthropogenic products and activities such as lead based paint, lead based petroleum, mining, and smelting has contributed significantly to lead in the environment (Beccaloni et al., 2013). Lead contaminates air, water, and soil when it falls to the ground from vehicle emissions (if lead based gasoline is used) and as a result of weathering and chipping of lead-based paint from buildings, bridges, and other structures (ASTDR, 2007b). In the United States, over 6 million Mg of lead was used in paints between the 1880s and 1970s, with a peak of 1.2 million Mg in the 1920s (McClintock, 2012). A United States Department of Housing and Urban Development study estimates that 25% of all U.S. housing contains significant lead-based paint hazards (Jacobs et al., 2002). Common forms of lead in paint residues are lead carbonates and lead oxides, which have low solubility and mobility (Minca and Basta, 2013). Even though lead in paint is banned, there are still concerns for potential exposure to humans.

Another source of lead contamination is from lead-based ammunition used for recreation in shooting ranges and hunting. Metallic lead from ammunition is deposited on soil in shooting ranges, which can then leach into the environment. Lead weathering can occur when lead ammunition comes in contact with soil and is exposed to environmental conditions. This lead will ultimately be transformed into particulate and ionic lead species and will be dispersed into the environment. Lead concentration in two shooting ranges in Florida showed that surface soils had 10-10,000 times higher lead than the average background soils (Cao et al., 2003).

Fortunately, in the United States, lead has been banned in paints since 1978 and phased out in gasoline since the mid-1980s (EPA, 2015a). Grams of lead per gallon of lead gasoline spiked in the late 1960s. However lead in gasoline has been drastically reduced due to its phase out (Figure 1). Many other countries are beginning to ban lead based products as well, but lead still remains in the environment in potentially dangerous levels.

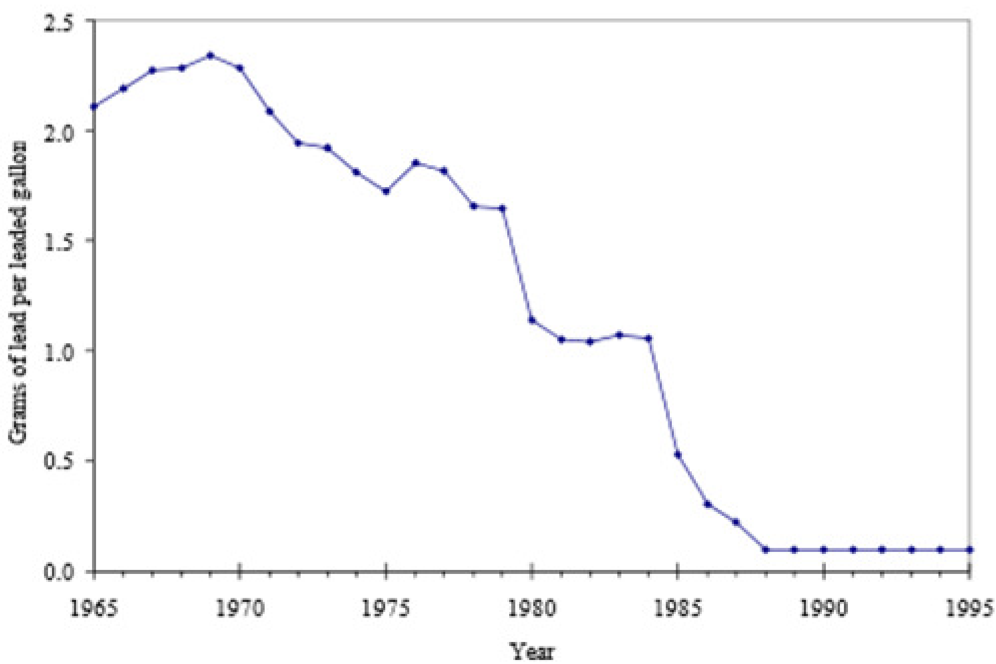

Figure 1: Lead Content in Gasoline from 1965 to 1995 (Newell and Rogers, 2003)

Historically, lead emissions have been from fuels in on-road motor vehicles. This use has deposited lead in the environment causing risk to human health. As a result of EPA's regulatory efforts to remove lead from on-road motor vehicle gasoline, emissions of lead from vehicle emissions have declined by 95 percent between 1980 and 1999, and levels of lead in the air decreased by 94 percent between 1980 and 1999 (USEPA, 2015a).

3.0 HOW ARE HUMANS EXPOSED TO LEAD?

Humans can be exposed to lead via ingestion and inhalation resulting in lead poisoning (Figure 2). However, ingestion is the main source of exposure (Islam et al., 2007). Higher lead soil concentrations are generally found in larger, urban areas with large populations of people (Datko-Williams et al., 2014)

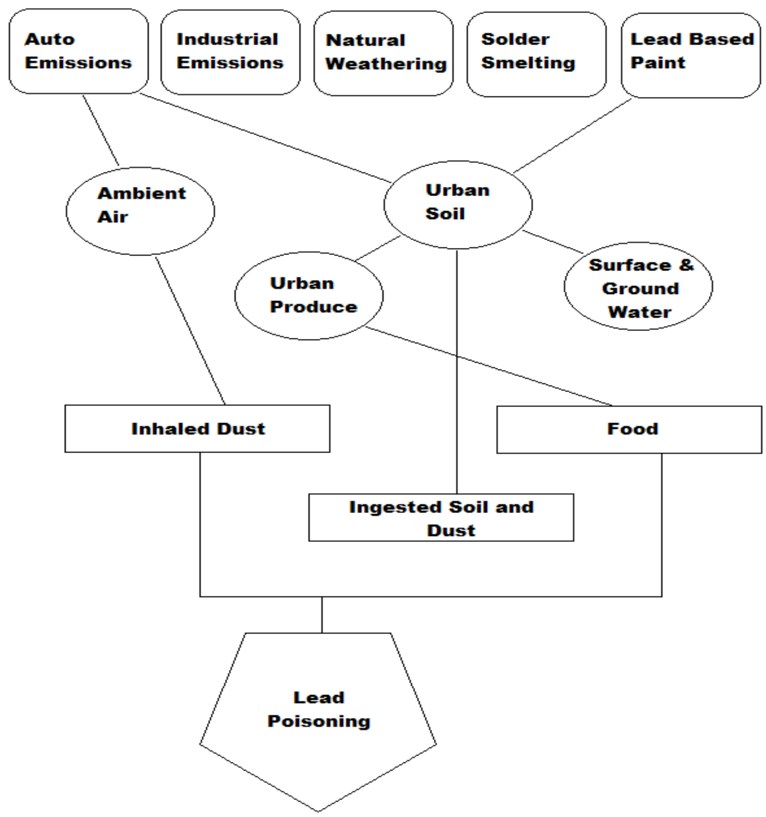

Figure 2 - Lead Sources that Cause Lead Poisoning (adapted from Litt et al, 2002).

3.1 INGESTION OF LEAD

Humans can directly and indirectly ingest lead if it is present in the soils. Lead can also impact drinking water if leached from old pipes. The main sources of lead in soils, especially in populated urban environments, are due to the historic uses of lead in paint and gasoline. Ingestion of soil and dust contaminated with lead is the primary pathway of lead exposure with children being particularly susceptible to lead poisoning (Markowitz, 2000; McClinktock, 2012).

Soils are a sink of lead with the potential for accumulations for hundreds of years without remediation (Datko-Williams et al., 2014). Lead that comes in contact with the organic matter in soil binds to soil particles and becomes immobile (Peralta-Videa et al., 2009). The bioavailability and mobility of lead in the soils is largely controlled by phosphorus, iron, and pH (Clark et al., 2006). The USEPA has set a threshold of 400 mg/kg of lead in residential soils (ASTDR, 2007b). A literature review shows that the median United States soil lead concentration from 1970 to 2012 was 19.75 mg/kg, which is well below the USEPA threshold of 400 mg/kg for residential soils. Even though the average concentration exhibits safe levels, several studies throughout the United States show lead soil concentrations greater than 400 mg/kg. Median soil levels have been reported as 2075 mg/kg in Boston, MA, 880 mg/kg in Oakland, CA, 800 mg/kg in Chicago, IL, and 1051 mg/kg in New Orleans, LA (Weitzman, 1993; Sutton et al., 1995; Finster et al., 2004; Mielke et al., 2006). The properties where these soil samples were taken were chosen because they had a high prevalence of factors that indicate lead could pose a danger to residents. These studies indicate that the combination of older homes, major roadways, and past and present industry contribute to lead soil contamination that is greater than the USEPA threshold. Comparatively, soils in home gardens near a former smelter in France were reported to have mean lead soil concentration of 526 mg/kg (Douay et al., 2013). While this concentration of lead soil is lower than the previously referenced U.S. soil studies, it supports the notion that industrial activities increase lead in soil.

Humans living near industrial areas that use lead can be at risk of lead exposure from soil contamination. For instance, a study conducted in a suburban area of the southeast Huanan province in China analyzed the blood of 64 children living near a typical lead-acid battery plant (Cao et al., 2015). They found the mean blood lead level (BLL) of the participants was 12.45 μg/dl. This was higher than the USEPAs recommended level of 10 μg/dL and may pose a human health risk.

Lead in food items can be a major source of lead exposure and is a concern throughout the world. A study conducted by Pruvot et al. (2006) calculated that the consumption of homegrown lettuce, leeks, and cereals in France was a major contributor of lead exposure. Further, lead found in vegetables in Bangladesh is the main food item that contributes to potential lead exposure (Islam et al., 2014).

Under neutral pH conditions, the bioavailability of lead to plant uptake is expected to be low (Cheng et al., 2011). However under acidic pH conditions, there is the potential for plants to uptake lead. Lead may bioaccumulate in edible vegetables via the root system, foliar uptake, and atmospheric deposition (Finister et al., 2004; Nabulo et al., 2010). Xu et al. (2013) found that even though the total concentration of lead in soil used to grow vegetables was low, some vegetables exceeded food safety limits in China. These results suggest that the lead contamination may be due to the physical contamination on above ground parts, rather than plant tissue.

Even though bioavailability of lead to plant uptake is expected to be low under normal soil conditions, consumers of fruits and vegetables grown in the backyards or in local urban areas can be at risk of ingesting soil laced with lead from past paint or auto emissions. According to the United States Census Bureau (2013), the median year a housing unit in the United States was built is 1975. Survey results show that the median home in the United States was built before lead became a constituent of potential concern. If a resident's house is older than 1978, it is likely that the original lead-based paint is on or around the house, which can contaminate surrounding soil, dust, and air and cause exposure. Dried paint can contain 30-50% lead by weight (Minca and Basta, 2013).

Additionally, lead can be present in tap water from natural sources, or from old lead pipes and other galvanized household plumbing systems (WHO, 2011). The amount and type of lead from pipes and other galvanized household plumbing systems is dependent on the presence of certain minerals, pH, temperature, and other water quality parameters (Schock, 1989; Schock, 1990). Lead can be released from flaking lead carbonate deposits that have been deposited over the time (WHO, 2011).

Results of lead contamination in drinking water from pipes are extremely prevalent. Recent public water supply samples from Flint, Michigan showed a lead level of 25 µg/L (Chow, 2015), which is higher than the USEPA limit of 15 µg/L of lead in drinking water (USEPA, 2014). The lead contaminated water in Flint, Michigan is thought to be from corroded pipes and plumbing materials (Flint Water Info, 2015). In a study of an old water distribution system in Florida, researchers cut 60 year old galvanized steel pipes into sections and exposed the pipes to finishing water from a city treatment plant. Results showed that concentrations of lead in water had a maximum concentration of 172 µg/L, which is significantly higher than the USEPA recommended threshold of 15 µg/L (Clark et al., 2015).

Lastly, populations that consume large game shot by ammunition with lead may also be at danger. For example, Lindboe et al. (2012) found that big game consumers with an elevated intake of moose or other large game meat harvested with lead based ammunition may be exposed to lead that exceeds exposure values of concern.

3.2 INHALATION OF LEAD

Inhalation is another way humans can be exposed to lead. Dusts containing lead may come from vehicular traffic, industrial plants, waste facilities, construction activities, and demolition activities (Wei et al., 2015). The United States was responsible for 80% of all leaded gas sold globally prior to 1970 (Nriagu, 1990). Fortunately, leaded gas has been banned for decades. Even though lead has been banned in gasoline in the United States and many other countries throughout the world, there still remains a threat to human health via inhalation.

Studies show that inadvertent inhalation of lead can be a risk to human health. Concentrations of lead in 56 street dust sampling sites in Beijing, China ranged from 16.7 to 2450 mg/kg which greatly exceeds soil background levels for Beijing (Wei et al., 2015). Another recent study in dust samples in Punjab, Pakistan by Mohmand et al. (2015) found that mean lead concentrations were greater in industrial (189 mg/kg) and urban areas (170.2 mg/kg) as compared to rural areas (61.8 mg/kg). The highest levels of lead in the industrial areas were attributed to leaching of lead batteries, smelters, lead glazes of pottery, insecticide, and flaking from lead buildings.

Occupational risk for lead inhalation is still prevalent. A study conducted in Brazil examined the blood of 20 police officers that are exposed to lead via shooting practice and found that BLL can significantly increase within a few days (Rocha et al., 2014). These results suggest that even acute exposure to lead during shooting events can result in potential human health risks. Although occupational risk from lead exposure is still prevalent, eliminating lead in petroleum products has greatly reduced occupational human health risk from lead. In Sri Lanka, lead has been discontinued in petroleum since 2002, which has greatly reduced BLLs in policemen from a mean of 53.07 μg/dL in 1996 to 4.82 μg/dL in 2015 (Arewgoda and Perera 1996; Sebastiampillai et al., 2015).

Aerosols from shooting events can be a risk to human health as well. A study conducted by Lach et al. (2015) showed that the total aerosol mass concentration of lead in an indoor shooting range was 72 $\mu g\ m^{-3}$ and in an outdoor shooting range was 10 $\mu g\ m^{-3}$. Both of these results were much higher than the background concentration of 0.21 $\mu g\ m^{-3}$. It was estimated that 30-50% of the inhaled particles from the lead aerosols are retained in the respiratory system and then eventually retained in the body.

4.0 HOW CAN LEAD AFFECT HUMAN HEALTH?

Lead affects almost every organ in the body and can cause serious health effects in humans. While people of any age can be affected by lead, children under the age of 6 are the most susceptible to lead exposure. House dust or soil contaminated with lead is particularly a threat to children because of the hand to mouth behavior (Minca and Basta, 2013).

Lead exposure in children can result in the following (NIH, 2014; Datko-Williams et al, 2014):

- Permanent brain and nervous system damage
- Decreased academic achievement
- Lower than average IQ
- Decrease in cognitive measures
- Behavioral problems
- Delayed growth
- Decreased hearing

Adults are also susceptible to deleterious health effects of lead with pregnant women being extremely vulnerable to the negative effects of lead. Pregnant women can experience miscarriage, premature birth, and reduced growth of the fetus because lead is capable of crossing the placenta (ASTDR, 2007b; NIH, 2014). The placenta is a poor barrier to lead; therefore, pregnant women who are at risk to lead poisoning may put their unborn child at risk. Studies have shown that blood lead levels in the mother and the umbilical cord are linear (Graziano et al., 1990), which means that the mother is able to transfer lead via the umbilical cord to the fetus.

Lead exposure in adults can result in the following (NIH, 2014):

- Increased blood pressure
- Decreased kidney functions
- Decreased fertility
- Increased hypertension
- Cataracts
- Nerve disorders
- Muscle and joint pain and weakness
- Decreased memory and/or concentration problems

In rarer cases, lead poisoning can cause seizures, coma, or death (ASTDR, 2007; NIH, 2014).

It is widely known that lead can have serious effects on human health. At sites where lead is a concern, the USEPA has devised methods to assess how lead affects human health.

5.0 HUMAN HEALTH RISK ASSESSMENT

Human Health Risk Assessments (HHRA) for lead in the United States are completed in accordance with USEPA's *Risk Assessment Guidance for Superfund (RAGS), Volume 1, Part A* (USEPA, 1989), Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) (USEPA, 2010) and the Adult Lead Model (ALM) for adults (USEPA, 2005). Lead HHRA can address potential soil, water, air, biota, and/or sediment exposures for human receptors. Lead HHRA are evaluated for the potential for adverse health effects resulting from current or future human exposures. Lead HHRA are based on data collected from the environmental media of concern. Risk assessment datasets are used to develop the mean concentration. The primary elements of a lead HHRA include (1) Data Collection and Data Evaluation, (2) Exposure Assessment, and (3) Uncertainties Associated with a Lead HHRA.

5.1 DATA COLLECTION AND DATA EVALUATION

Before conducting a lead HHRA, it is important to create a sampling plan. The sampling plan can include sample size, sample depth, sample type (grab vs. composite), sample location, background sampling, geological concerns, hydrogeological concerns, temporal and spatial considerations, and meteorological conditions (USEPA, 1989). There are situations where a HHRA cannot capture site-specific data. Although not preferred, in these instances default parameters can be used and these values will still accurately predict risk (USEPA, 2014).

Blood samples from adults and children can be used in HHRA. However, this is often expensive and undesirable for the human receptors. Therefore, models have been created to simulate blood sampling. These models will be discussed in the Exposure Assessment section.

Once the samples have been collected, the data set must be evaluated. The following steps should be taken to organize the data for the HHRA (USEPA, 1989).

- Gather and sort all data available and evaluate analytical methods
- Compare the data with background levels
- Develop a data set to be used for the risk assessment

Once the sampling plan and data have been evaluated, a mean concentration per media can be established to assess potential risk for the human receptors (USEPA, 2009).

5.2 EXPOSURE ASSESSMENT

The exposure assessment in the risk assessment process includes identification of potentially exposed populations and the development of exposure pathways and the daily exposure intake calculations. USEPA guidelines for lead risk assessment use a mean concentration for the media of concern (USEPA, 2009).

Lead is treated differently than other constituents in the risk assessment process because the degree of uncertainty about health effects of lead is low (USEPA, 2015c). Some health effects of lead such as changes in the levels of certain blood enzymes and aspects of the neurobehavioral development in children could occur at blood levels so low that a threshold could not be developed. Due to these instances, EPA decided to regulate lead by using a blood lead concentration as a biomarker (USEPA, 2015d).

Biokinetic models were developed to assess routes of exposure and determine the distribution of the contaminant among body tissues in humans (USEPA, 2015d). For children, exposure assessments are performed using the IEUBK model (USEPA, 2010). For adults, exposure assessments are performed using the ALM (USEPA, 2005). The IEUBK model is used much more extensively than the ALM because of high susceptibility of children to lead exposure.

5.2.1 IEUBK MODEL

Where children under 7 years of age may be exposed to lead, USEPA recommends the use of the IEUBK Model for Lead in Children (USEPA, 2010). This model can evaluate exposures from lead-contaminated media and predict the likely effects of those exposures on BLLs. The IEUBK model performs a series of computations that quantify exposure, uptake, and a biokinetic component (USEPA, 2010).

The model has four categories that can be used to example conditions at a specific site. The categories are as follows:

- Category A: One location
    - One living environment with one child
    - One living environment with more than one child
    - More than one living environment (apartment/condos) with more than one child with homogenous media concentrations
- Category B: Multiple locations
    - One neighborhood with homogenous media concentrations
- Category C: Multiple locations
    - One neighborhood with heterogeneous media concentrations
- Category D: Multiple locations
    - More than one neighborhood with possible heterogeneous neighborhood ingestion/absorption parameters.

There is variability between different children with different lifestyles, thus, the IUEBK model assumes that the distribution of blood lead values is lognormal and generates the distribution based on a geometric standard deviation (GSD). The GSD can be modified based on site-specific data. It is ideal to collect site-specific values to use in the model. However, this is not always in the scope or budget of a risk assessment. Therefore, EPA has developed default values, as shown in Table 1 (see Appendix A for a full list) for the different media concentration for the different ages of children.

Media	Age-specific Intake Rates							Comments
	0-1 year	1-2 yrs	2-3 yrs	3-4 yrs	4-5 yrs	5-6 yrs	6-7 yrs	
Soil/dust (mg/day)	85	135	135	135	100	90	85	Default values recommended. Intake is apportioned 55% dust & 45% soil
Air (m^3/day)	2	3	5	5	5	7	7	Default values recommended
Drinking Water (L/day)	0.2	0.5	0.52	0.53	0.55	0.58	0.59	Default values recommended
Diet (µg Pb/day)	2.26	1.96	2.13	2.04	1.95	2.05	2.22	Site-specific data may be used to assess exposure to fish, game, or home-grown produce.
Alt. Source	Site-specific data may be used to account for intake of lead in other sources							Refer to the IEUBK User's Guide and 1994 Guidance Manual for more information

TABLE 1 - IEUBK Default Values (Adapted from USEPA, 2015d).

The IEUBK models predict the probability of a child having a BLL above 10 µg/dL and can be computed and compared to USEPA's health-based goal (no more than a 5 percent probability of exceeding 10 µg/dL blood lead (USEPA 2010). Recently, the Centers for Disease Control and Prevention (CDC) has recommended using a new level of 5 µg/dL based on United States children ages 1-5 that are in the top 2.5% when they had their blood test for lead. This reference value of 5 µg/dL is based on the 97.5th percentile of national surveys of blood lead distribution in children in the U.S. This recommended change will likely result in more children being identified as having lead exposure (CDC, 2014a; 2015).

5.2.2 ADULT LEAD MODEL

In adult populations, the female of child-bearing age is the sub-population of main concern, since exposure of the pregnant female to lead can result in exposure to the fetus *in utero*. The ALM is developed to evaluate the potential risks from lead in pregnant females (USEPA, 2003; 2009; 2013). The model uses information on lead exposure from environmental media to predict BLL in an adult female. This information is converted into a lognormal distribution based on a GSD that is assumed to account for variability. The model has default assumptions that can be used if site-specific data are not available (See Appendix B for ALM default values).

5.3 UNCERTAINTIES ASSOCIATED WITH A LEAD HHRA

Uncertainty exists in many areas of the human health assessment. Examples of some uncertainties associated with a lead HHRA:

- Uncertainties Associated with Data Collection and Evaluation
  - Accuracy of sampling methods and analytical procedures
- Uncertainties Associated with Exposure Assessment
  - Concentrations can vary with space and time
  - Assumptions can underestimate or overestimate exposure scenarios
  - If default values are used, it may not accurately portray the site
  - Past levels were 10 μg/dL, EPA is now going to start referencing a levels of 5 μg/dL (CDC, 2014b). However, the model is still using 10 μg/dL.

6.0 WAYS TO PROTECT HUMANS FROM LEAD EXPOSURE

Unfortunately, there is no safe level of lead that humans can be exposed to, but there are several ways that one can protect themselves and their family from lead exposure. The most important thing one can do to protect themselves and their family is to be knowledgeable about the history of the building a family resides in and their work environment. Understanding the age and type of materials used in building structures can help avoid lead exposure.

Children are the most susceptible to lead exposure due to the hand to mouth behavior that children commonly display (Minca and Basta, 2013). Children play outside in a park or their own backyard that may have contaminated soil. Studies have shown that removing the top 6 inches of soil that children are exposed to and filling with clean soil can reduce blood lead levels up to 25% within a few years (Aschengrau, 1994). This is encouraging information if it is known that the soil is contaminated but often times it unknown unless the soil has been sampled. USEPA estimates that a young child may consume up to 10 grams of soil per day; Hence it is important that you take measures to avoid children's contact with soil (USEPA, 2015a) and to use common-sense measures such as washing hands before eating, and washing clothes that may have come in contact with soil.

Vegetables and fruits not washed thoroughly may contain contaminated soil particles (Nabulo et al., 2006; Cheng et al., 2011). Some studies suggest that lead that is transferred to above-ground plant tissues is largely from atmospheric contamination (McBride et al., 2013). Therefore, thoroughly washing vegetables may reduce exposure to lead. Jassir et al. (2005) found that washing vegetables can reduce lead exposure as garden rocket, coriander, watercress, parsley, and lettuce washed had lower lead values (0.078-0.019 mg/kg) as compared to unwashed produce (0.134-0.055 mg/kg). Further, growing produce in raised beds can eliminate exposure to lead. A study conducted in Massachusetts found that lead exposure to children can be reduced 2-3% or 1.8-3.3 µg/day if produce was grown in raised garden beds (Clark et al., 2008).

7.0 CONCLUSIONS

The past and present use of lead in the environment present a potential risk to human health. The use of products containing lead has contaminated the environment and has put populations at risk. Humans are exposed to lead primarily through ingestion and inhalation, which can cause serious health effects in children and adults. Children under the age of 6 are especially vulnerable to lead which can cause nervous system damage, delay development, and have negative neurocognitive outcomes. Adults are also susceptible to deleterious effects of lead. Lead in adults can increase blood pressure, create nerve disorders, decrease kidney functions, and create memory and or/concentration problems. Arguably, pregnant women are at the greatest risk of negative effects of lead because the placenta is a poor barrier to lead. Studies have shown that BLL in the mother and BLL in the umbilical cord are linearly correlated. Fortunately, the effects of lead are being studied to determine what levels in the environment are safe. The USEPA has devised the IEUBK and the ALM models to evaluate the potential for adverse health effects resulting from current or future human exposures. These models have been helpful tools to understand the severity of lead exposure. The diligent research and remediation performed on contaminated sites have allowed understanding of ways populations can protect themselves from lead contamination.

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Appendix A: Default Values for IEUBK Model Parameters

Parameter	Default Value	Units
Indoor air lead concentration (% of outdoor)	30	%
AIR (by year)		
Air concentration		
Age = 0-1 year (0-11 mo)	0.10	µg/m³
1-2 years (12-23 mo)	0.10	µg/m³
2-3 years (24-35 mo)	0.10	µg/m³
3-4 years (36-47 mo)	0.10	µg/m³
4-5 years (48-59 mo)	0.10	µg/m³
5-6 years (60-71 mo)	0.10	µg/m³
6-7 years (72-84 mo)	0.10	µg/m³
Time outdoors		
Age = 0-1 year (0-11 mo)	1	h/day
1-2 years (12-23 mo)	2	h/day
2-3 years (24-35 mo)	3	h/day
3-7 years (36-84 mo)	4	h/day
Ventilation rate		
Age = 0-1 year (0-11 mo)	2	m³/day
1-2 years (12-23 mo)	3	m³/day
2-3 years (24-35 mo)	5	m³/day
3-4 years (36-47 mo)	5	m³/day
4-5 years (48-59 mo)	5	m³/day
5-6 years (60-71 mo)	7	m³/day
6-7 years (72-84 mo)	7	m³/day
Lung absorption	32	%
DATA ENTRY FOR DIET (by year)		
Dietary lead intake		
Age = 0-1 year (0-11 mo)	2.26	µg Pb /day
1-2 years (12-23 mo)	1.96	µg Pb /day
2-3 years (24-35 mo)	2.13	µg Pb /day
3-4 years (36-47 mo)	2.04	µg Pb /day
4-5 years (48-59 mo)	1.95	µg Pb /day
5-6 years (60-71 mo)	2.05	µg Pb /day
6-7 years (72-84 mo)	2.22	µg Pb /day
DATA ENTRY FOR ALTERNATE DIET SOURCES (by food class)		
Concentration:		
home-grown fruits	0	µg Pb/g
home-grown vegetables	0	µg Pb/g
fish from fishing	0	µg Pb/g
game animals from hunting	0	µg Pb/g
Percent of food class:		
home-grown fruits	0	%
home-grown vegetables	0	%
fish from fishing	0	%
game animals from hunting	0	%

Parameter	Default Value	Units
DATA ENTRY FOR DRINKING WATER		
Lead concentration in drinking water	4	µg/L
Ingestion rate		
Age = 0-1 year (0-11 mo)	0.20	L/day
1-2 years (12-23 mo)	0.50	L/day
2-3 years (24-35 mo)	0.52	L/day
3-4 years (36-47 mo)	0.53	L/day
4-5 years (48-59 mo)	0.55	L/day
5-6 years (60-71 mo)	0.58	L/day
6-7 years (72-84 mo)	0.59	L/day
DATA ENTRY FOR ALTERNATE DRINKING WATER SOURCES		
Concentration		
first-draw water	4	µg/L
flushed water	1	µg/L
fountain water	10	µg/L
Percentage of total intake		
first-draw water	50	%
flushed water	100 minus first draw and fountain	
fountain water	15	%
DATA ENTRY FOR SOIL/DUST (constant over time)		
Concentration (starting values to be modified using appropriate site data)		
soil	200	µg/g
dust	200	µg/g
Soil/dust ingestion weighting factor (percent soil)	45	%
DATA ENTRY FOR SOIL/DUST INGESTION (by year)		
Soil/Dust ingestion		
Age = 0-1 year (0-11 mo)	0.085	g/day
1-2 years (12-23 mo)	0.135	g/day
2-3 years (24-35 mo)	0.135	g/day
3-4 years (36-47 mo)	0.135	g/day
4-5 years (48-59 mo)	0.100	g/day
5-6 years (60-71 mo)	0.090	g/day
6-7 years (72-84 mo)	0.085	g/day
DATA ENTRY FOR SOIL/DUST MULTIPLE SOURCE ANALYSIS (constant over time)		
Fraction of indoor dust lead attributable to soil (MSD)	0.70	unitless
Ratio of dust lead concentration to outdoor air lead concentration	100	µg Pb/g dust per µg Pb/m^3 air

Parameter	Default Value	Units
DATA ENTRY FOR SOIL/DUST MULTIPLE SOURCE ANALYSIS WITH ALTERNATIVE HOUSEHOLD DUST LEAD SOURCES (constant over time)		
Concentration (starting values to be modified using appropriate site data)		
household dust (calculated value)	150	µg/g
secondary occupational dust	1,200	µg/g
school dust	200	µg/g
daycare center dust	200	µg/g
second home	200	µg/g
interior lead-based paint	1,200	µg/g
Percentage		
household dust (calculated value)	100 minus all other	%
secondary occupational dust	0	%
school dust	0	%
daycare center dust	0	%
second home	0	%
interior lead-based paint	0	%
BIOAVAILABILITY DATA ENTRY FOR ALL GUT ABSORPTION PATHWAYS		
Total lead absorption (at low intake)		
diet	50	%
drinking water	50	%
soil	30	%
dust	30	%
alternate source	0	%
Fraction of total net absorption at low intake rate that is attributable to non saturable (passive) processes.	0.2 u	nitless
DATA ENTRY FOR ALTERNATE SOURCES (by year)		
Total lead intake		
Age = 0-1 year (0-11 mo)	0	µg/day
1-2 years (12-23 mo)	0	µg/day
2-3 years (24-35 mo)	0	µg/day
3-4 years (36-47 mo)	0	µg/day
4-5 years (48-59 mo)	0	µg/day
5-6 years (60-71 mo)	0	µg/day
6-7 years (72-84 mo)	0	µg/day
DATA ENTRY MENU FOR MATERNAL-TO-NEWBORN LEAD EXPOSURE		
Mothers blood lead concentration at childbirth	1.0	µg/dL
DATA ENTRY MENU FOR PLOTTING AND RISK ESTIMATION		
Geometric standard deviation (GSD) for blood lead	1.6	unitless
Blood lead level of concern, or cutoff	10	µg/dL
COMPUTATION OPTIONS		
Iteration time step for numerical integration	4	h

Appendix B: ALM Default Values

Parameter	Unit	Value	Comment
$PbB_{fetal, 0.95, goal}$	µg/dL	10	For estimating RBRGs based on risk to the developing fetus.
$GSD_{i,adult}$	--	1.8 2.1	Value of 1.8 is recommended for a homogeneous population while 2.1 is recommended for a more heterogeneous population.
$R_{fetal/maternal}$	--	0.9	Based on Goyer (1990) and Graziano et al. (1990).
$PbB_{adult,0}$	µg/dL	1.7-2.2	Plausible range based on NHANES III phase 1 for Mexican American and non-Hispanic black, and white women of child bearing age (Brody et al. 1994). Point estimate should be selected based on site-specific demographics.
BKSF	µg/dL per µg/day	0.4	Based on analysis of Pocock et al. (1983) and Sherlock et al. (1984) data.
IR_S	g/day	0.05	Predominantly occupational exposures to indoor soil-derived dust rather than outdoor soil; (0.05 g/day = 50 mg/day).
EF_S	day/yr	219	Based on U.S. EPA (1993) guidance for average time spent at work by both full-time and part-time workers (see Appendix for recommendations on minimum exposure frequency and duration).
AF_S	--	0.12	Based on an absorption factor for soluble lead of 0.20 and a relative bioavailability of 0.6 (soil/soluble).