Community Lead Exposure of Children in Developing and Emerging Economies: Problems, Policies, and Solutions Based on Case Studies in Eastern Europe, Caucasus, and Central Asia

Guidance Document
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Guidance Document

Developed by the
AIHA Construction Committee and the AIHA International Affairs Committee

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Introduction

The purpose of this reference document is to provide recommendations on lead poisoning prevention in developing and emerging economies, drawing on the examples of conditions in the countries of Eastern Europe, Caucasus, and Central Asia (the former Soviet Union states). In some of these areas, the mean blood-lead levels (BLL) for children are extremely high. This document describes methods to promote safe and healthy community environments and to improve understanding among international experts in environmental and public health problems involving lead (Pb), with a review of policies, standards, and proposed solutions. It describes up-to-date scientific approaches to lead poisoning prevention with regard to unique conditions in Eastern Europe, Caucasus, and Central Asia as a starting point, and goes on to provide a wider perspective by citing examples in other countries, such as Nepal. The data and conclusions in the paper are based on the extensive experience of the group of authors in dealing with lead poisoning issues in Kazakhstan, Russia, and other developing countries. This publication significantly highlights a problem that seriously influences the health of millions of children.

The intent of the American Industrial Hygiene Association (AIHA) in producing this reference document is to benefit local public health officials and environmental protection professionals, working in developing countries, and AIHA members in building collaborations to resolve lead poisoning problems throughout the world.

The document covers the environmental behavior of lead, lead toxicology and bioavailability, lead contamination and poisoning in each region, possible solutions and barriers to overcome, program approaches, suggested environmental and biological criteria, medical intervention, economic damage evaluation, and success stories. The problem of community lead exposure is viewed from the standpoint of the definition of industrial hygiene as a science of anticipation, recognition, evaluation, and control, as well as the Centers for Disease Control and Prevention (CDC) National Institute for Occupational Safety and Health (NIOSH) definition of the hierarchy of controls. AIHA hopes to promote better understanding among governments, environmental and public health professionals, physicians, and advocates in the countries of Eastern Europe, Caucasus, and Central Asia as well as in other regions of the world, concerning the importance of intervention to protect children from lead poisoning.
Chapter 1: Childhood Lead Poisoning: What Do We Know?

Lead in the Environment: Sources, Uses, Fate, and Environmental Levels

Elemental or metallic lead (Pb) has been used for more than 6,000 years. The metal was employed in numerous practical applications and goods because of its softness and malleability. While documented lead poisoning dates back to nearly 2,500 years, its use and production remain widespread, sometimes with tragic results. For example, at least 400 children recently died from paraoccupational lead poisoning in Nigeria. Furthermore, in the World Health Organization's most recent ranking of environmental health threats, lead exposure is in the top five that together account for nearly 10% of deaths and disease burden globally and around one-fourth of deaths and disease burden in children. WHO has highlighted the importance of responding to hot spots of lead exposures, such as mines and smelters. Childhood lead poisoning from paint was first brought to the world's attention in Australia in the early 1900s, eventually resulting in a lead paint prevention act in Australia in 1920 and an international ban of the use of lead in residential paint by the International Labor Organization. The United States chose not to comply with the ILO ban and had no restrictions during this time and childhood lead poisoning became epidemic, despite the fact that the problem was well understood.

The 1976 European Union (EU) directive 76/769/EEC banned the use of lead carbonate and lead sulfate in paint except for historic buildings or art restoration. The use of all lead-based paint in residential applications was officially banned by the 1989 EU directive 89/677/ECC. Some industrial applications of lead-based paint are still allowed in the United States and EU (e.g., for road paint and marine applications).

A detailed review of lead environmental sources, fate, and levels in various media can be found in the Agency for Toxic Substances and Disease Registry (ATSDR) toxicology profile for lead. The toxicity of lead has been most recently updated by the National Toxicology Program and in Jacobs (2012). Lead is a multimedia pollutant that sometimes makes lead exposures difficult to control.

Lead content in the earth’s crust is around 0.0013%. Lead in its elemental or metallic form is a bluish-white metal of bright luster, very soft, highly malleable and ductile. Elemental or metallic lead is found in nature (“native lead”), but its occurrence in nature is rare. Lead is chiefly found in nature as PbS (lead sulfide, as the mineral galena) and less frequently as PbSO₄ (lead sulfate, as the mineral anglesite), and PbCO₃ (lead carbonate, as the mineral cerrusite). Metallic lead is typically obtained by roasting PbS-containing ores or by recycling lead batteries. Lead is used commercially in a variety of forms and compounds.

- The grid plates of storage batteries are composed of metallic lead but also typically contain antimony, some tin, and small amounts of arsenic and copper.
- Lead pigments were used in paint to speed drying, increase durability, and resist moisture. The most common lead pigments are basic lead carbonate [white lead, 2PbCO₃·Pb(OH)₂], lead carbonate, and lead sulfate, which are all used in white paint, although lead is found not only in white paint. For example, lead chromate (PbCrO₄) is a yellow pigment. Basic lead chromate (2PbO·CrO₃) and red lead (Pb₃O₄) are red pigments. The manufacture of paint containing high concentrations of lead (greater than 600 mg/kg) for interior and exterior residential surfaces, toys, and furniture was banned in the United States in 1977, but many reports have shown that new lead-based paint is being manufactured in many countries. The Consumer Product Safety Improvement Act of 2008 lowered the 600 mg/kg level to 90 mg/kg. The 1976 EU directive 76/769/EEC banned uses...
of lead carbonate and lead sulfate in paint except for historic building or art restoration. The use of all lead-based paint in residential applications was officially banned by the 1989 EU directive 89/677/ECC. Some industrial applications of lead-based paint are still allowed in the United States and EU (e.g., for road paint, marine applications). However, in several developing countries, lead in architectural paint exceeds 600 ppm by a large margin. For example, a recent study of lead content in residential paint in Asian, African, and South American countries shows as high as 96% of the samples exhibiting paint levels above 600 ppm.23 This finding of manufacture of new lead paint has been confirmed in other recent studies.24,25

- Litharge, a yellow lead monoxide [PbO], was used as a paint pigment in the manufacture of glass, fluxing of earthenware, as filler in rubber, and in plumber’s cement.26 It is still used in plumber’s paste, glass, and other applications.27

- Tetraethyl lead [Pb(C2H5)4] is a liquid used as an additive in gasoline to increase both the octane number and resistance to engine knock.28 Leaded gasoline was used in the United States from approximately 1923 until 1991.29 As a result of the Clean Air Act of 1970, leaded gasoline phaseout began in 1976 in the United States. As of Jan. 1, 1996, leaded gasoline was banned from use in all road vehicles in the United States. In the EU, leaded gasoline was banned as of Jan. 1, 2000. The production of leaded gasoline in Russia was banned as of July 1, 2003.30

- Lead arsenate (PbHAsO4) was used as an insecticide.31 Its use declined in the late 1940s and early 1950s when DDT became available.32 Lead arsenate use was banned in 1988 in the United States.33

- Plumber’s solder is a metal alloy used to join copper pipes typically used for residential water distribution. Various compositions exist, but the most common solder is composed of equal parts of lead and tin (50/50 solder) with some trace metals.34 The 50/50 solder was used in plumbing applications until the 1980s, when it was replaced by silver, antimony, and copper alloys, typically with tin. Note that 60/40 and 63/37 (percentage lead and tin) solders are currently used in electrical and electronic applications.35

- Metallic lead is used for pipes, radiation shields, weights (such as on fishing lines and for balancing tires), bullets and lead shot, and other products.36

- Lead may also be found in common household items such as lead-glazed ceramic pottery and cooking utensils, tin cans (with soldered joints), jewelry and toys (in paints and enamels), imported medicines and home remedies, cosmetics, and some candies and food coloring.37,38

Elevated concentrations of lead can be found in environmental media such as soils, water, and air and are typically the result of industrial activities (pollution).

- Some lead naturally exists in soils, typically referred to as background concentrations. The arithmetic mean concentration of lead in soils in the United States is 19 mg/kg39 and typically ranges from less than 10 to 30 mg/kg.40 The levels of lead (dissolved) in surface water and groundwater in the United States typically range between 5 and 30 µg/L.41

Emissions from primary lead and other metal smelters (processing of primary ore minerals such as galena) or secondary lead smelters (recycling of batteries) can result in elevated concentrations of lead in the air and soil around the smelters.42 Such primary and secondary smelters are common around the world. During the smelting process, the lead is in a molten state and results in the release of lead in vapor and particulate forms. If the lead in the gaseous emissions is not controlled (e.g., by
the use of filters), the lead is dispersed in the air and deposited on the ground. The lead is usually in the form of small amorphous (noncrystalline) lead oxide particles, which are relatively soluble and react with water and soil to form other compounds such as lead sulfates, carbonates, and phosphates, depending on the soil composition. In high organic-content soils, lead associated with the organic matter has also been observed as a result of the dissolution of soluble lead oxides and subsequent incorporation into the organic matrix. Concentrations of lead in soil greater than 60,000 mg/kg (6%) have been measured near smelters.43

- Waste products from the smelters typically result from the production of elemental lead. The largest waste stream is the molten slag that is cooled in air or with a water stream, resulting in a glassy solid product. Small inclusions of lead exist in the glass matrix (usually present as lead oxides). Concentrations of lead in slag and lake sediments contaminated with slag from a smelter in Trail, British Columbia (Canada), have been measured up to 920 mg/kg.44 Maximum concentrations of lead in slag measured at the Midvale Tailings Superfund site in Utah (United States) ranged from 11,800 to 24,800 mg/kg depending on the type of slag (e.g., water-cooled and air-cooled).45

- Wastes from mining of high-grade ore result in waste rock or low-grade ore being disposed at the mining sites. Waste from the milling and mineral processing facilities (processes to concentrate the lead minerals) is typically disposed of near the facilities. This may be in the form of fine-grained tailings and small particles of lead sulfide or lead sulfate (lead sulfide oxidized in the environment and may be as weathering rims on the lead sulfide), which are susceptible to wind transport. Lead concentrations in tailings typically range from several thousand mg/kg to percentage levels. Lead concentrations in the tailings at the Sharon Steel Superfund site in Utah (USA) averaged 5,500 mg/kg.46

- Deposition of lead from car exhaust occurs when cars burn gasoline containing tetraethyl lead, which can result in air and soil contamination near major highways and in the neighborhoods. The lead typically reacts with water and soil to form lead oxides, sulfates, carbonates, and phosphates. The U.S. Geological Survey (USGS) measured lead in soil samples near seven highways in Massachusetts where the concentrations ranged from 10 to 770 mg/kg.47 In one of its studies, the Washington State Department of Transportation measured lead concentrations in soil samples ranging from 176 to 4,460 mg/kg, which were collected approximately 80 feet from the road pavement.48

Lead from waste battery storage, recycling, and cracking facilities may be deposited in the soil. During the process of cracking open the plastic casing on waste batteries to recover the lead, sulfuric acid solutions containing dissolved lead in the batteries may be spilled or discharged where it reacts with the surrounding soil. The soil typically neutralizes the acid resulting in lead sulfate and carbonate. Metallic pieces of the lead plates that may also be present in the soil typically weather to lead carbonate or lead oxides, or even lead chloride (depending upon the environment). These secondary forms usually exist only as rims around the primary lead metal particles, because lead is not very mobile in soil. Concentrations of lead in soils at a battery recycling facility in Puerto Rico have been observed up to 29,000 mg/kg.49

- Concentrations in drinking water can be elevated where lead service lines are used, or where water chemistry and sources are not properly considered. Concentrations of lead in industrial wastewater discharges (before treatment) have been reported as high as 900 mg/L (paint formulation), 880 mg/L (porcelain enameling), and 560 mg/L (ore mining and processing).50 The 1991 U.S. Environmental Protection Agency (U.S. EPA) action level for lead
in drinking water is 0.015 mg/L.\textsuperscript{51} The EU standard of lead in drinking water is 0.010 µg/L (effective Dec. 25, 2013).\textsuperscript{52} Lead in water can result from discharges of industrial wastewater; dissolution of lead solder used in water pipes; use of lead drinking water service lines and fixtures; the discharge of acid mine drainage from abandoned mines; reactions of rain with waste tailings or waste rock at mining facilities; the dissolution of lead from batteries as a result of contact with sulfuric acid; and so on. Lead can exist in the dissolved aqueous state in water typically as the lead cation (Pb\textsuperscript{2+}), or it can be complexed (e.g., Pb-chloride complexes).

- Older homes are likely to have lead paint on the interior and exterior surfaces, which may be peeling or otherwise deteriorated, or which may have been scraped to create a smooth surface for new paint. More than 24 million homes in the United States have lead-based paint hazards in the form of deteriorated lead-based paint, contaminated house dust and contaminated bare soil, and about one-fourth of the U.S. housing stock has lead-based paint (38 million housing units).\textsuperscript{53,54} The paint chips from weathered exterior surfaces accumulate in the soil around the house foundation. Lead in paint is typically in the form of lead carbonate, but it may also be present as lead oxide, lead chromate, and other lead salts. Paint from houses in London (UK) constructed before 1910 had average lead concentrations ranging from 78,400 to 141,200 mg/kg.\textsuperscript{55} The single highest value was 430,000 mg/kg (43%).\textsuperscript{56} Paint from houses constructed from the 1910s to the 1990s had lead concentrations ranging from 10 to 177,000 mg/kg.\textsuperscript{57} Interior paint samples from “high-risk” houses in California ranged from 20 to 309,713 mg/kg.\textsuperscript{58} Lead concentrations in new paints for residential use in the United States currently are limited to a maximum of 90 mg/kg.\textsuperscript{59}

Lead Toxicology

The toxicology of lead is a discipline with a long history that has continued to develop actively during recent decades.

Bioavailability and Toxicokinetics

The deposition of airborne lead in the respiratory tract of adults varies from 30 to 85%, and in children it is even higher.\textsuperscript{63}

Children absorb as much as 50% of ingested lead with about 32% retention,\textsuperscript{64,65} in comparison with adults who absorb 5 to 15% of total ingested lead and usually retain less than 5% of what is absorbed, although there is wide variability.

Because of lead’s long half-life in bone, and its deleterious effect on the central nervous system and other organs, lead exposure prevention is critical; lead exposure should be controlled for all ages. Lead has a potential half-life in bone of 27 years, so exposure at any age can result in residual exposures as bone stores are mobilized. During pregnancy, mobilization results in fetal exposure (Reiss and Halm, 2007; Gulson et al, 1997).\textsuperscript{66,67} Children with poorer nutrition (e.g. iron deficiency) may absorb more lead and are at greater risk from exposures (Cunningham, 2012).\textsuperscript{68} Inadequate nutrition (e.g. calcium deficiency) can also exacerbate the release of lead to the
fetus during pregnancy (Gulson et al., 2004). The Centers for Disease Control and Prevention (CDC) has released guidelines for management of lead exposure in pregnancy and lactation.

Lead compounds vary in their ability to produce toxic effects, although all have been shown to have toxic effects. The amount of lead that actually enters the body as a result of lead solubilization in the gastrointestinal fluid from an ingested medium and from inhalation depends to some extent on the physical-chemical properties of the lead and of the media. The physical-chemical properties are affected by the form, compound, or chemical species of the lead; the size distribution of the lead-containing particles; and the matrix associated with the lead particles (although those characteristics are not usually considered in regulations anywhere in the world because total lead is more relevant).

The bioavailability of different toxic compounds has been defined differently in various sources. Some of the recent publications use the term “bioaccessibility” as an experimentally determined estimate of what is potentially bioavailable. In other words, the bioaccessibility is the percentage of lead compound that is rendered soluble in the stomach acidic aqueous media. Bioavailability, then, is the overall percentage of ingested lead, in the case of the oral pathway, for example, that enters the bloodstream. For purposes of this document, the bioavailability of ingested lead compounds is defined as the product of the experimentally measured bioaccessibility multiplied by the fraction of bioaccessible lead taken up by the organism. A similar concept can be applied to the inhalation route of exposure. Our definition of bioavailability is consistent with the U.S. EPA concept and is used in BLL modeling.

A summary of the overall bioaccessibility of the various forms of lead follows:

- Low bioaccessibility (1 to 20%): PbS, lead in slag, Pb metal, Pb-FeOOH
- Medium bioaccessibility (20 to 60%): PbSO₄, Pb₃[PO₄]₂, Pb-MnOOH
- High bioaccessibility (60 to 100%): PbCO₃, PbO, PbCl₂ Despite these differences, all forms of lead are toxic.

The low bioaccessibility of lead in slags is the result of the lead being enclosed in a silicate (glass) matrix, and therefore lead is not available for complete dissolution in the gastrointestinal fluid. Lead carbonate in paints and amorphous lead oxides from smelter emissions are very soluble in the acidic gastrointestinal fluids and therefore have a high bioaccessibility. Lead dissolved in the aqueous phase is typically 100% bioaccessible. Importantly, it is not necessary to determine bioaccessibility before taking action to control exposures, because no form of lead has been found to be safe. However, differences in the bioaccessibility of lead are an important characteristic for modeling of toxicity and may be useful in establishing lead remediation criteria, although total lead can and has also been used.

The amount of dissolution of lead in the gastrointestinal fluids and uptake in the human gut also depends on the size of the lead-containing particles. The smaller particles are more easily and rapidly dissolved. The ease and rate of dissolution also depends on the matrix of the lead-containing particle. As discussed above, the lead in slag is less bioavailable, although exposures should still be controlled.

Standard in vitro tests (laboratory tests) for assessing bioaccessibility in soils simulate dissolution in the human gut and have an excellent correlation with in vivo swine studies ($r^2 = 0.83$, $p = 0.0001$).

To describe the behavior of lead in different compartments of the body, the Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children, developed by U.S. EPA, can be used. This model (and the corresponding software) can be used to predict the risk (e.g., probability) that a typical child, exposed to
specified media concentrations of lead, will have a BLL greater or equal to the level associated with adverse health effects. Other models are also available. It should be repeated that prevention of exposure to all forms of lead is the best response to preventing lead poisoning.

Mechanisms of Toxicity

The major mechanisms of lead toxicity are adverse effects on the peripheral and central nervous system, enzyme inhibition, protein binding, mimicry (when lead substitutes iron and calcium in cellular transportation and reactions), production of reactive oxygen species, and aberrant DNA manifestation.

Multiple biochemical effects of lead are reported. Lead binds to proteins, modifies their tertiary structure, and inactivates their enzymatic properties. Mitochondria are particularly sensitive to lead. Despite the presence of a normal or increased intracellular content of iron, the lead-affected mitochondria are starved for iron. Lead interferes at several points in the heme synthetic pathway in all cells, and that interference of lead ultimately can be responsible for the general toxic effects of lead, possibly even in the nervous system. It should be emphasized that heme is of vital importance for hemoglobin and myoglobin (responsible for oxygen transport); various cytochromes involved in electron transport; energy generation and chemical metabolism; peroxidase and catalase for H2O2 activation; and for many other enzyme systems.

In the toxicity of lead, molecular and ionic mimicry plays an important role. One example is the substitution of lead for iron (Fe) in the synthesis of essential proteins. Iron-containing proteins (brain components) can be nonfunctional when lead substitutes for iron. Obviously, this is especially important when the essential nutrient iron is in low concentrations and lead is in high concentrations.

Health Effects of Lead

Lead can cause various toxicological effects on the human body, including neurological, neurobehavioral, developmental, hematologic, renal, cardiovascular, immunological, and skeletal. In addition, lead compounds have been classified as carcinogenic.

The neurological system is especially susceptible to lead toxicity. Lead can affect the brain and peripheral nervous system in multiple ways. In particular, lead may act as a surrogate for calcium and/or disrupt calcium homeostasis. Lead affects virtually every neurotransmitter system in the brain, including glutamatergic, dopaminergic, and cholinergic systems. All these systems are critically important for synaptic plasticity and cellular mechanisms for cognitive function, learning, and memory. High exposure to lead (probably at BLL greater than 80 μg/dL) may cause clinically overt lead encephalopathy. Various studies report a 1- to 4-point IQ deficit for each μg/dL increase in BLL within the range of 5 to 35 μg/dL, and the data show that the rate of IQ deficit is higher at the lower blood-lead levels, showing that even so-called low-level exposure must be controlled.

Hematological effects of lead range from increased urinary porphyrins, coproporphyrins, δ-aminolevulinic acid (ALA), and zinc-protoporphyrin to anemia. The most sensitive effects of lead are the inhibition of δ-aminolevulinic acid dehydratase (ALAD) and ferrochelatase. A progressive, exponential increase in erythrocyte protoporphyrin concentration is observed at blood-lead levels of 5 to 90 μg/dL. The World Health Organization (WHO) indicated that anemia is the classic clinical manifestation of hematological lead toxicity. The severity and prevalence of lead-induced anemia correlate directly with the blood-lead concentration. Younger and iron-deficient children are at higher risk of lead-induced clinical anemia.
Reproductive effects of lead toxicity are widely known as well. Effects reported in men include reduced libido, spermatogenesis reduction, chromosomal damage, infertility, abnormal prostatic function, and changes in serum testosterone. In women, effects include infertility, miscarriage, premature membrane rupture, pre-eclampsia, pregnancy hypertension, and premature delivery. Lead can pass through the placenta, exposing the fetus to maternal blood lead from both the mother’s current as well as her past exposures. Lead can be stored in the mother’s bones and can then be mobilized as her need for calcium increases to meet fetal bone development. Likewise, mother’s milk that is rich in calcium can be adversely impacted by the lead stored in bone from previous exposures.

The major renal effect of acute lead poisoning is disruption of the proximal tubular architecture, with laboratory evidence of disturbances in proximal tubular function. Chronic lead nephrotoxicity consists of interstitial fibrosis and progressive nephron loss, azotaemia and renal failure. Lead nephropathy is the main manifestation of renal lead toxicity.

Lead affects the cardiovascular system, with the pathogenesis including: (1) inactivation of endogenous nitric oxide and cyclic guanosine monophosphate (cGMP), possibly through lead-induced reactive oxygen species; (2) changes in the rennin-angiotensin-aldosterone system, and increases in sympathetic activity; (3) alteration in calcium-activated functions of vascular smooth muscle cells; and (4) a possible rise in endothelin and thromboxane. The primary outcome of lead effects on the cardiovascular system is hypertension, with blood pressure correlating to BLL in observed cohorts and populations.

Lead is also known to cause immunotoxicologic effects, resulting in elevated immunoglobulin E (IgE) levels in children and potentially increased risks of childhood asthma in some groups.

Lead has a long half-life in bone, accounting for over 90% of the body lead in adults. Lead intoxication directly and indirectly alters many aspects of bone-cell function. First, lead may directly alter bone-cell function through changes in the circulating levels of hormones, particularly 1,25-dihydroxyvitamin D3, which modulate bone-cell function. Second, lead may directly alter bone-cell function by perturbing the ability of bone cells to respond to hormonal regulation. Third, lead may impair the ability of cells to synthesize or secrete other components of the bone matrix, such as collagen or bone sialoproteins (osteopontin). Finally, lead may directly affect or substitute for calcium in the active sites of the calcium messenger system, resulting in loss of physiological regulation.

Gastrointestinal disturbances are frequent complaints in persons with increased lead absorption. These disturbances occur in both adults and children. As with symptoms related to the nervous system, the severity of gastrointestinal symptoms also spans a wide range. At elevated blood-lead concentrations in the range of 40 to 60 μg/dL, many of the symptoms are nonspecific and may consist of epigastric discomfort, nausea, anorexia, weight loss, and dyspepsia. At very high blood-lead concentrations, usually exceeding 80 μg/dL in adults but below that level in children, these nonspecific symptoms can become accompanied by severe, intermittent abdominal cramps known as lead colic.

Inorganic lead compounds were reclassified as probably carcinogenic to humans by International Agency for Research on Cancer (IARC). Potential end points are stomach, brain, and breast cancer.

Susceptibility of Children

Children are especially sensitive to lead poisoning because

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a greater proportion of ingested lead is absorbed from the gastrointestinal tract of children than of adults;

- a greater proportion of systemically circulating lead gains access to the brain of children, especially those five years of age or younger, than of adults; and

- the developing nervous system is far more vulnerable to lead’s toxic effects than in mature individuals.

An age threshold has not been determined that would singularly divide the “dangerous childhood” from “safer adult period.” For example, the blood-brain barrier has been reported to be underdeveloped until the age of 6 months in humans. Some publications emphasize the ability of lead to impair blood-brain barrier functions. On the contrary, new evidence shows that many adult mechanisms, including functionally effective tight junctions, are already present in the embryonic brain.

In spite of the controversy in determining the age of maturity, when a body becomes less vulnerable to lead exposure, the overwhelming scientific consensus is that children under 7 years are at much greater risk and require special attention.

No safe blood-lead level for young children has been identified by the CDC. In 2012, the CDC established “reference value” of 5 µg/dL and recommended that related exposures be controlled. Similarly, WHO has concluded, “recent research indicates that lead is associated with neurobehavioral damage at blood levels of 5 µg/dL and even lower.” WHO also emphasized that lead can cross freely from the maternal to the fetal circulation throughout pregnancy, causing serious prenatal brain damage, that requires even stricter regulations and monitoring.

**Safety Criteria for Lead**

There is no unified standard for determining safe levels of lead in environmental media, because no blood-lead level has been established below which adverse health effects are not detected. However, based on international experience, some criteria can be proposed that indicate exposures that must be controlled, according to best practices and regulations.

Levels that should trigger exposure reduction are listed in Table 1 on the next page.

**Prevention and Treatment of Childhood Lead Poisoning**

This section is intended to give guidance to the reader regarding current recommendations for prevention of childhood lead poisoning as well as the treatment of childhood lead poisoning. The content of this section is largely based upon research and public health recommendations developed in the United States and Europe.

However, this document as a whole is intended to address the problem of childhood lead exposure in geographic regions where resources may be limited to implement public health surveillance of lead exposure (i.e., monitoring of BLL in pediatric populations), to perform environmental monitoring for sources of exposure and to provide treatment.

Cessation of exposure is essential to any plan for the treatment of lead poisoning. Removal of the source may range from decontamination of a small area (e.g., building) or remediation of large geographic areas. Cessation of exposure also includes cessation of production of new lead-based paint. Unfortunately, large remediation projects (e.g., decontamination of large land areas such as those surrounding lead smelters) are extremely complex and costly: they are rarely feasible without government funding and resources. However, noting the idea of eliminating exposure, this section will review the most widely promulgated treatment recommendations for lead poisoning in children as well as suggestions for treatment under conditions of limited resources.
A complete review of all the pathophysiological mechanisms of lead poisoning is beyond the scope of this paper. Toxic effects of lead in the human body involve multiple complex mechanisms. Induction of oxidative stress and alteration in gene expression are emerging as important toxic modes of action, especially at lower level exposure. Like many other toxic metals, lead exerts its toxicological effects at the molecular level. It does so by mimicking the divalent cations zinc (Zn++) and calcium (Ca++), interfering with their normal physiological roles (e.g., interruption of neuronal transmission and cellular metabolism), and through lead’s affinity for sulfhydryl groups, especially those of metalloproteases like those found in the heme synthetic pathway. Because of its molecular mechanism of toxicity and the ubiquity of target molecules, lead poisoning manifests in multiple organ systems (e.g., hematopoietic system and central nervous system) and correlates with blood-lead levels and chronicity of exposure. Mild symptoms of

<table>
<thead>
<tr>
<th>Media</th>
<th>Criteria</th>
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<tbody>
<tr>
<td>Lead in blood reference value (children under 7 years)*</td>
<td>≥5 μg/dL</td>
</tr>
<tr>
<td>Lead in residential soil (including schools, playgrounds)**</td>
<td>Short term: ≥200 mg/kg Long term: ≥100 mg/kg</td>
</tr>
<tr>
<td>Lead in ambient air***</td>
<td>≥ 0.15 μg/m³</td>
</tr>
<tr>
<td>Lead in drinking water****</td>
<td>≥ 0.010 ppm</td>
</tr>
<tr>
<td>Lead in residential interior and exterior building paint*****</td>
<td>By XRF method: 1.0 mg/cm² By dry weight: 90 mg/kg</td>
</tr>
<tr>
<td>Lead in settled house dust by HUD wipe sampling method*****</td>
<td>40 μg/ft² (430 μg/m²) floors</td>
</tr>
<tr>
<td>250 μg/ft² (2600 μg/m²) interior window sills</td>
<td></td>
</tr>
<tr>
<td>400 μg/ft² (4300 μg/m²) exterior window troughs</td>
<td></td>
</tr>
<tr>
<td>Lead in toys******</td>
<td>90 ppm (total lead)</td>
</tr>
<tr>
<td>Lead in tableware******</td>
<td>0.5 μg/ml (by leachate method)</td>
</tr>
<tr>
<td>Lead in candies******</td>
<td>0.1 ppm</td>
</tr>
</tbody>
</table>

* The criteria of 5 μg/dL should be established based on the recent scientific developments and recommendations from CDC.

** The level of lead in residential soil corresponding to the proposed acceptable median blood-lead level in children was calculated using the U.S. EPA IEUBK model. With the level of lead in residential soil at 200 mg/kg, in air at 0.15 μg/m³, and in drinking water at 0.015 mg/L, with a conservative assumption of 50% bioavailability of the lead in soil and dust, and with a soil/indoor dust weighting factor of 70%, the model predicts a geometric mean for lead in children’s blood at 4.9 μg/dL, with the fraction of children having lead in blood above 10 μg/dL expected to be 6.8%. With the same assumptions, but with the lead in soil at 100 mg/kg, the geometric mean of lead in children’s blood would be 3.4 μg/dL, with an expectation of 21% of children with lead in blood above 5μg/dL.

*** Corresponds to U.S. EPA National Ambient Air Quality Standard.

**** 0.015 ppm is an U.S. EPA action level; the EU standard for drinking water is 0.010 ppm; the WHO (2008) guideline is 0.010 ppm.122

*****EPA CFR Part 745. It should be noted that use of XRFs in lead-in-paint surveys is currently discouraged by some agencies, for example, by the U.S. Army. The focus, to the contrary, is made on the deteriorated or disturbed paint, and on dust and soil lead hazards. However, XRFs can be useful in screening studies, especially when no good information is available about lead in paint issues in different countries.

****** Corresponds to the levels allowable in the United States.
lead toxicity in children include irritability, hyperactivity, decreased appetite, abdominal pain, and constipation. However, lead toxicity at low dose results in subclinical (i.e., asymptomatic) adverse effects on neurocognitive function and development. This impact is nonetheless of considerable public health concern. As levels increase, clinical manifestations of lead poisoning increase in number and severity and include neurological findings such as peripheral neuropathy, altered mental status, ataxia, seizures, and even cerebral edema, coma, and death. Lead poisoning in childhood can lead to significant and permanent developmental (including cognitive) deficits that may initially be subtle but worsen as lead levels rise and length of exposure increases. Hematologic toxicity includes impaired heme synthesis, hemolysis, and shortened red blood cell life span leading to anemia.

Management priorities should include exposure mitigation, assessment of the severity of poisoning, and determining the need for treatment and/or other interventions. The initial clinical assessment should be directed to the organ systems mentioned above (i.e., neurological and hematological). In children, the neurological assessment should focus particularly on neurocognitive and developmental milestones. Laboratory assessment includes a whole blood-lead level, zinc protoporphyrin level, complete blood count, and evaluation of renal function (e.g., blood urea nitrogen [BUN], creatinine, and urinalysis). Once an exposure and clinical assessment has been accomplished, the question of treatment, and what kind of treatment, needs to be addressed.

Interventions and treatment are largely based on whole blood-lead levels and clinical presentation. No level of lead exposure without deleterious effects has been established. Recent research suggests that BLLs below the previously employed “level of concern” of 10 µg/L are associated with measurable toxicity, especially cognitive impairment in children. Therefore, the CDC now recommends elimination of the use of the term “blood-lead level of concern” and that public health actions be initiated at BLL ≥ 5 µg/dl. However, these new recommendations do not change the current recommendation that chelation therapy be considered when a child is found with a BLL greater than or equal to 45 µg/dl.

Iron and calcium deficiency both increase the absorption of ingested lead. Therefore, dietary supplementation with both of these nutrients is recommended. Because the risk vs. the benefit of dietary iron and calcium supplementation is quite favorable and supplementation can be via diet (i.e., increased inclusion of iron and calcium-rich foods) and/or the use of dietary supplements, routine testing of calcium and iron levels prior to treatment is not recommended. However, because exposure reduction and dietary supplementation may not be sufficient, chelation treatment may be indicated in some children.

Although it must be emphasized that removal of the source of lead exposure is integral to any lead poisoning treatment plan, additional treatment (i.e., chelation) may also be indicated in certain children. There are several chelating agents available for the treatment of lead poisoning. Dimercaprol (British anti-Lewisite, or BAL) chelates a number of heavy metals, including mercury and arsenic as well as lead, and it has been in use for decades. However, BAL has significant adverse effects that range from rash, nausea, vomiting, and hypertension to hemolysis in patients with glucose-6-phosphate dehydrogenase (G6PD) deficiency. Because BAL is prepared in a peanut oil excipient, it can be administered only intramuscularly and is contraindicated in patients with known peanut allergy.

Calcium disodium ethylenediaminetetraacetic acid (CaNa₂EDTA) is another available parenteral chelating agent. It also forms a stable bond with lead
and is eliminated in the urine. CaNa₂EDTA is administered at a dose of 35 to 50 mg/m² per day, either by continuous intravenous infusion (preferred route) or intramuscular injection 2 to 3 times per day. Continuous intravenous infusion is recommended because intramuscular injection of CaNa₂EDTA is painful and the infusion route helps maintain adequate hydration. Because CaNa₂EDTA can cause zinc deficiency, and to minimize the risk of nephrotoxicity, courses of treatment should be limited to five days. Also, a very similar chelating agent, Na₂EDTA (disodium ethylenediaminetetraacetic acid or edetate disodium) should not be used to chelate children because it can cause fatal hypocalcemia.

One of the most significant challenges in the management of childhood lead poisoning is determining who is in need of chelation. Because of increased susceptibility to the neurological and cognitive toxicity of lead and the potential for permanent impairment, children are more sensitive to the toxic effects of lead compared to adults. Therefore, many of the recommendations for the treatment of lead exposure in adults, including lead exposure in the occupational setting, are not suitable for the management of children. The current CDC recommendations state that chelation therapy can be effective at reducing high BLLs, but it is generally not indicated for individuals with BLLs <45 µg/dl. Chelation has not been clearly demonstrated to reverse the adverse effects of lead toxicity. However, it is still recommended for high BLLs, because reduction of BLL with chelation may prevent further translocation of lead into the brain and prevent or mitigate the progression of lead encephalopathy. Although it was recommended in the past as a tool to determine which patients require chelation treatment, in the average person the lead mobilization test (also known as a chelation challenge test or provoked urine test) is not effective in predicting the body burden of lead. In addition, whereas normal reference intervals for nonchallenge urine metal testing are available, the prognostic or diagnostic significance urine lead excretion post chelation is not well established. Although the blood-lead concentration is a poor indication of body burden, it is the test for which treatment is based. Practitioners should not treat with chelation therapy based on the lead mobilization test, as there are no standards for therapy including when to start, doses to be used, or duration of therapy.¹²⁸

Chelation therapy should never be used to treat elevated BLLs in the setting of ongoing exposure. Patient management should always include environmental intervention (e.g., remediation) to limit or preferably eliminate the exposure.

Ideally, the patient should not be returned to the same environmental exposure without a correction having taken place.

In summary, the preferred treatment of lead poisoning is removal of the exposure and monitoring of BLLs. Chelation therapy is indicated in children with clinically significant neurological toxicity and/or BLLs exceeding 45 µg/dL. Although parenteral chelation agents such as BAL may be used in more severe cases of poisoning, succimer is the preferred oral chelating agent.

However, recommendations for treatment for 5 < BLL < 45 mcg/dl are less clear. As mentioned above, removal from the exposure is a central part of any lead poisoning management plan. Other interventions may be helpful to reduce the impact of lead exposure. Children with elevated blood-lead levels may be at increased risk for learning disabilities and some research has suggested that they even be at increased risk for problems in adulthood (e.g., violence).¹²⁹ Therefore, case management programs for these children should include early identification and intervention strategies (e.g., individual education plans) to help mitigate any cognitive deficits the children may have developed due to their lead exposure.¹³⁰ Although these interventions do not directly
address the problem of the exposure or poisoning, they may minimize the impact lead exposure may have on a child’s education and development, especially in settings where definitive remediation of the exposure is not practical or tenable for any number of reasons (e.g., lack of local government resources). Ongoing monitoring of BLLs is also important to assess whether levels fall in response to environmental interventions or increase, possibly precipitating the need for more aggressive interventions and/or chelation. As mentioned above, nutritional interventions to help mitigate lead’s toxicity (such as a diet with adequate vitamin, calcium, and iron intake) are also reasonable additions to the management of childhood lead poisoning.\textsuperscript{131,132} It is important to note that additional research is needed to develop further approaches to case management as well as educational and developmental support for children affected by lead poisoning in developing countries.
Chapter 2: Lead-Related Problems in the Former U.S.S.R.

Lead in the Former Soviet Countries

Lead contamination of the environment and related childhood lead poisoning is a significant problem for the countries of the former Soviet Union. The Soviet Union exemplified a society where the government was theoretically the owner of all industrial enterprises. No private industry was allowed to exist. The development of industries was conducted based strictly on centralized planning. The huge territories of the country were underdeveloped prior to the 20th century, and an overwhelming industrialization program was introduced and realized in the 1920s and 1930s, with thousands of enterprises built in Russian Siberia, Kazakhstan, Caucasus, and other areas. Mining and metallurgy was a central part of the Soviet industrial revolution.

In Russia, the utilization of lead started in ancient times, as evidenced by old mines and waste dumps found in the Altai, the Urals, and the Far East. The first Russian industrial lead smelter was built in Nerchinsk in the first quarter of the 18th century, and from the middle of that century, the exploitation began of lead deposits of the Altai and the North Caucasus.133

In Central Asia, lead has also been known and used for centuries. In Kazakhstan, in the valley of Achi-say, evidence was discovered of historic mining and smelting of lead ores. In the historic city of Turkestan in Kazakhstan, lead was used to create tiled mosaics in the famed mosque of Azretsultan. There is written evidence of lead smelting in Kazakhstan from the 17th century.134

In the former Soviet Union, the major lead-zinc deposits were in Kazakhstan, Uzbekistan, Tajikistan, and Azerbaijan. The main deposits of lead in Russia are concentrated in Altai, Baikal, Primorye, Yakutia, on the Yenisei River, and the North Caucasus.

Figure 1 is a map showing the main deposits of lead in the countries of the former Soviet Union. The locations of the main smelting facilities are shown in Figure 2.

The main lead-smelting enterprises were located in the North Caucasus (Ordzhonikidze); in the Far East (Dalnegorsk); in East Kazakhstan (lead-zinc plant in Ust-Kamenogorsk, polymetallic plant in Leninogorsk); in South Kazakhstan (Shymkent, based on Karatau lead deposit); in Uzbekistan (Almalyk Mining and Metallurgical Combine); and in Ukraine (Konstantinovka).
Karatau lead deposit); in Uzbekistan (Almalyk Mining and Metallurgical Combine); and in Ukraine (Konstantinovka).

In 1990, the Soviet Union produced 0.45 million tons of refined lead, or 13% of the world’s production.\textsuperscript{135}

As is typical throughout the world, lead was extensively used in the U.S.S.R. In addition to its use in ammunition for firearms, lead was widely utilized in the manufacture of lead acid batteries and for factory equipment that required protection from corrosive gases and liquids. Large amounts of lead were involved in the manufacturing of the shells or covers for electrical cables, to protect them from corrosion and mechanical damage. Lead has been used as a protective shield material against ionizing radiation. Lead oxide (PbO) was introduced into crystal and optical glass production to achieve a high refractive index. Red lead, lead chromate (yellow crowns), and basic lead carbonate (white lead) were used as pigments. Tetraethyl lead has been used as an additive to motor fuel, and in the Soviet Union, a special red pigment was added to leaded gasoline.

In some countries of the former U.S.S.R., the use of leaded gasoline is currently prohibited. For example, in Russia, the Federal Law includes a ban on production and turnover of leaded gasoline in the Russian Federation since July 1, 2003. However, a certain amount of leaded gasoline is probably produced in a so-called noncentralized way. According to the Russian Federation’s Customs Service, imports of tetraethyl lead were about 3,245 tons in 2003 and about 4,735 tons in 2004.\textsuperscript{136} Tetraethyl lead is still used in Russia as a component of jet fuel. Leaded gasoline has been prohibited by law in the territory of the Ukraine since Jan. 1, 2003. In the founding [as opposed to the addition of Armenia] countries of the Eurasian Customs Union (Russia, Belarus, and Kazakhstan), the use of metal additives (iron, manganese, and lead) in motor vehicle fuel is prohibited.\textsuperscript{137}

In the U.S.S.R., paint containing lead was banned for indoor use in 1929\textsuperscript{138}; however, its use continued for bridges, ships, etc. It is difficult to verify that the ban was actually enforced in the country. Vast amounts of official and counterfeit imports of paint from China, after the market reforms in 1991, has reintroduced the lead paint problem into the post-Soviet countries because of the numerous incidents of high lead content in Chinese paints (and paints produced in other countries).\textsuperscript{139}

Other applications of lead in the countries of the former Soviet Union included the widespread use of lead water pipes; lead foil used for many customer products (as for tea packaging); medicinal purposes, such as the “lead water” prescribed for inflammatory diseases of the skin and mucous membranes; and simple or complex lead plasters for chronic inflammatory skin diseases and boils.

Regarding lead in industrial emissions, lead smelting and other metallurgical processes have caused environmental contamination as well. For example, copper smelters, generating significant lead emissions, in the former Soviet Union were situated mostly in Kazakhstan and the Ural region of Russia. Battery plants are another significant source of lead emissions. In Russia, plants of this type are situated in Podolsk, Kursk, Tyumen, and Komsomolsk-on-Amur. In Kazakhstan, a battery plant is located in Taldikorgan.

In spite of the widespread industrial use of lead in the U.S.S.R. and for numerous practical applications, information about lead in the environment in this region is actually very scarce. Although environmental monitoring was not a priority for government officials, the toxic properties of lead were well known to Soviet health experts, and restrictive regulations were issued, especially for occupational purposes. However, the potential lead exposure of children was not recognized as an important problem. For example, in a review of lead toxicity issued by the
Russian Ministry of Health Care issued in 1997, the influence of lead on the health of children is mentioned only briefly. The document, however, quotes some Western authors, referring to the effects of lead on children’s hearing abilities, IQ, the ages when infants start walking and speaking, and stability of posture.

A Russian government report on environmental lead problems (1997) concluded that 10 million urban citizens in Russia are affected by lead contamination of soils. For example, in Moscow, the concentration of lead in soil ranges from 8 to 2,000 mg/kg.

Various effects of lead on public health were described. For example, in Belovo, Kemerovskaya oblast, Russia, where the average BLL was determined to be 9.9 (±0.5)µg/dL, the level of anxiety in children was higher than in other regions, and diseases of the nervous system in infants included encephalopathy and convulsion syndrome. In older children, nervous system diseases included enuresis, epilepsia, and epilepsy. In Krasnouralsk, where the average BLL in children was 13.1 (±0.5) µg/dL, retarded development was observed in 76% of the children. It was suggested that 44% of the children in the urban population of Russia suffer from behavioral and learning issues that could be caused by lead poisoning.

A comprehensive study of lead-related problems was performed in several cities in the Russian Ural region. The U.S. EPA IEUBK model was used along with the actual blood-lead measurements, to evaluate the effect of lead exposure in five locations. The results of the study are summarized in tables 2 and 3. The fraction of children with BLL above 10 µg/dL varied from 22 to 62%.

**Table 2. Population Sizes, Lead Emission Sources, and the Number and Ages of Children Tested for Lead in Blood in 1996–2000**

<table>
<thead>
<tr>
<th>City (population)</th>
<th>Industrial sources of lead emission</th>
<th>Number of children in studied samples</th>
<th>Age range (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krasnouralsk (33,600)</td>
<td>A big copper smelter inside the city</td>
<td>357</td>
<td>3–7</td>
</tr>
<tr>
<td>Pervouralsk (164,000)</td>
<td>A big copper smelter located at 9 km windward of the city</td>
<td>339</td>
<td>3–7</td>
</tr>
<tr>
<td>Upper Pyshma (51,000)</td>
<td>A big copper refinery (smelting and electrolysis) inside the city</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Kirovgrad (35,000)</td>
<td>A medium-size copper smelter inside the town</td>
<td>135</td>
<td>4–7</td>
</tr>
<tr>
<td>Kushva (56,800)</td>
<td>The Krasnouralsk and Kirovgrad copper smelters at 50 km in different directions from this city</td>
<td>54</td>
<td>3–7</td>
</tr>
</tbody>
</table>

**Table 3. Blood-Lead Levels in Five Russian Ural Locations**

<table>
<thead>
<tr>
<th>Town</th>
<th>Method, year, (number of children)</th>
<th>% of children with BLL &gt;10 µg/dL</th>
<th>Arithmetic mean BLL ±S.E., µg/dL</th>
<th>Range, µg/dL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krasnouralsk</td>
<td>Modeling</td>
<td>61.1</td>
<td>10.7</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Bio-monitoring, 1996 (107 children)</td>
<td>64.5</td>
<td>11.8 ±0.5</td>
<td>5.0–46.3</td>
</tr>
<tr>
<td></td>
<td>Bio-monitoring, 1997 (250 children)</td>
<td>59.5</td>
<td>11.2 ±0.2</td>
<td>3.2–29.4</td>
</tr>
<tr>
<td>Pervouralsk</td>
<td>Modelling</td>
<td>22.5</td>
<td>7.2</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Bio-monitoring, 1999 (339 children)</td>
<td>25.9</td>
<td>7.4±0.2</td>
<td>2.4–29.04</td>
</tr>
<tr>
<td>Upper Pyshma</td>
<td>Modeling</td>
<td>29.3</td>
<td>8.1</td>
<td>–</td>
</tr>
<tr>
<td>Kirovgrad</td>
<td>Modeling</td>
<td>47.5</td>
<td>10.1</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Bio-monitoring, 2000 (135 children)</td>
<td>60.7</td>
<td>10.8 ±0.4</td>
<td>3.7–28.8</td>
</tr>
<tr>
<td>Kushva</td>
<td>Bio-monitoring, 2000 (54 children)</td>
<td>22.2</td>
<td>7.5±1.08</td>
<td>2.8–22.9</td>
</tr>
</tbody>
</table>
Other examples of lead-related environmental problems in the former Soviet Union include:

- In the city of Dalnegorsk and the town of Rudnaya Pristan in the Russian Far East, where a lead mine and smelter were situated, the average level of lead in soil was found to be 1,000 mg/kg, with a maximum up to 200,000 mg/kg. The average level of lead in the soil of ogorods (gardens where the locals grow vegetables) was 2,000 mg/kg, and at the children’s playgrounds and close to the school, 550 mg/kg. The concentrations of lead in potatoes were 1 to 3 mg/kg. Out of 376 children tested, in 31% the level of BLL was higher than 10 µg/dL and 6% were higher than 20 µg/dL. In Rudnaya Pristan, where the smelter is located, 64% of the children had BLL above 10 µg/dL.

- The annual average of lead in air close to the battery plant in Kursk in the 1990s reached 1.6 µg/m³ and soil concentration was 500 mg/kg.

- In the Ural city of Karabash, where one of the oldest copper smelters in the country is located, the levels of lead, zinc, and arsenic in the soil were found in the ranges of 1,500 to 2,000, 700 to 1,000 and 150 to 300 mg/kg, respectively. The annual average concentration of lead in the air was 24.3 µg/m³.

- In the city of Chapaevsk, where no sources of emissions from lead industries were known, the median level of BLL was 3 µg/dL, and in 3% of children, BLL was higher than 10 µg/dL.

- Concentrations of lead well above background levels were found in soils near Ukrainian airports.

- Producers of military hardware are also sources of substantial releases of lead and its compounds. For example, soldering operations in Russia contribute emissions of lead and its inorganic compounds to the lower layers of atmosphere at the rate of 1 ton per year.

- Painting, impregnation, and enameling works using lead-based compounds are responsible for annual emissions of lead and its inorganic compounds at the level of up to 150 tons per year. Lead releases are also associated with production of lead-containing ammunition, application of lead coatings, and other special works.

The countries of the former Soviet Union have generally inherited the environmental and workplace standards of the former Soviet Union. In Russia, the allowable 24-hour average levels of lead and its inorganic compounds are 0.1 mg/L in water, 5 µg/m³ in working zone air (excursion level 10 µg/m³), and 0.3 µg/m³ in ambient air (excursion level 1 µg/m³).

In Kazakhstan, the allowable level of lead in soil is 32 mg/kg.

**Case Study: Environmental and Public Health Problems of Lead in Kazakhstan**

**Introduction**

The situation with the impact of lead on children in the Republic of Kazakhstan was explored in depth by a group of Kazakhstani and U.S. scientists from 1997 to 2009. The situation in the following cities was assessed:

- **Pavlodar** — a prominent industrial city with emission sources from alumina production, an oil refinery, a chemical plant, and located close to a large regional coal power and ferroalloys facilities

- **Shymkent** — an industrial hub in the south of the country, with the largest lead smelter in the region, which was built in the 1930s and continued to operate until 2012, as well as other industrial pollution sources including an oil refinery, and an asbestos cement plant

- **Tekeli** — a small city with a lead mine, currently discontinued

- **Taldykorgan** — a city with a battery recycling facility
• Ust-Kamenogorsk — a large industrial center with a lead-zinc smelter, a titanium-magnesium facility, beryllium production, and other plants
• Kysylorda — a rural city in a desert region, close to the epicenter of the Aral environmental catastrophe
• Almaty — the former capital of the country, with exceptionally high levels of air pollution from automobiles but without significant industrial emission sources.

Analytical Methods

A wide variety of methods were used to characterize the lead and other heavy metals that were contributing to and impacting the environmental and public health situation.

Lead in blood by anodic stripping voltammetry (ASV) portable device. Blood samples were collected and analyzed on site in selected kindergartens (educational and day-care centers) and other similar facilities using the ESA Lead Care Blood Lead Testing System (model 3010B analyzer). In particular, 50 ul of blood were quantitatively transferred and mixed with a treatment reagent that removes the lead from the red blood cells. The sample was transferred to the ASV instrument, where the lead was detected and results displayed as µg/dL of lead in the blood sample. Analysis took approximately 10 minutes per sample. The instrument calibration was checked using two blood-lead standards (8.2 and 31.6 µg/dL) twice per day.

Zinc protoporphyrin (ZPP) in blood by hematofluorometer portable device. Blood samples were collected and analyzed on site using a Kaulson Laboratories Inc. hematofluorometer model 2001. In the presence of iron deficiency, zinc is incorporated into protoporphyrin 1X in place of iron. ZPP associated with red cells gives rise to red-cell florescence and can be measured by the hematofluorometer. ZPP in blood is an effective indicator of chronic lead intoxication or iron-deficient anemia. The instrument calibration was checked twice per day using three standards (26, 78, and 145 µg/100ml whole blood).

Lead in paint using X-ray fluorescence (XRF). Paint on the walls, floors, toys, eating utensils (plates, bowls, etc), and play equipment at the kindergartens and orphanages was examined using a portable XRF spectrum analyzer (KeyMaster Technologies Inc. model MAP 4). Lead K-shell and L-shell fluorescence was measured and read as mg/cm². The K-line reflects lead concentrations to a depth of several mm, and the L-line is more indicative of lead on the very surface, although K-shell data are more reliable. Calibration was checked before and after each series of analyses.

Metals in soil using X-ray fluorescence (XRF). Direct on-site reading of soil contamination levels was utilized for screening purposes using a portable XRF spectrum analyzer (NITON XL-700 in 2002-2003 and InnovXsystem Alpha-4000 in 2008). Simultaneous K-shell and L-shell analyses were performed by X-ray detection measured in ppm (mg/kg) for the following metals: Pb, As, Mo, Zr, Sr, Rb, Hg, Zn, Cu, Ni, Co, Fe, Mn, and Cr. Co-located composite samples were also collected (usually 4 to 5 composites at each location), dried, and analyzed by a XRF spectrum analyzer. The accuracy of the analyses was checked by reanalyzing selected samples in the United States with a laboratory XRF (Spectrace 7000 according to EPA approved method162). Calibration of the portable XRF instrument was checked before and after each series of analyses. Confirmation of the analytical results was performed using split sample analyses in the U.S.A. and Kazakhstani laboratories (U.S. EPA Method for ICP/MS163).

Bioaccessibility determination. The bioaccessibility of lead in soil and dust was measured for four representative samples from Shymkent, Kazakhstan, using U.S. EPA Method 9200.164,165
Air samples by X-ray fluorescence (XRF). In Shymkent, air samples were collected on filters using personal hygiene sampling pumps. The pumps recorded the volume of air that passed through the filters. The pumps and filters were typically mounted on school rooftops to avoid tampering and theft, except for one pump and filter that was mounted on the property of a fenced-in home, close to the lead smelter, at approximately the height of a person’s breathing zone. The pumps ran continuously and the filters were changed every 24 hours. The air concentration was determined by dividing the mass (determined by the XRF technique), by the total volume of air that passed through the filter during the sampling period. Air sampling and XRF analysis was conducted in general accordance with the NIOSH 7702 method.166

Results

The results of the measurements of lead in blood in different cities in Kazakhstan are summarized in Table 4. The ranges of the content of lead and arsenic in soil are shown in Table 5.

The levels of lead in different types of paint (combined, for all types of measured surfaces) are displayed in Table 6.

In various toys in Kazakhstan, the concentrations of lead determined by a lead leachate method167 were found in the range from 16 to 32,048 ppm, with the maximum acceptable level of 90 ppm.168 In the examples of tableware (cups), the concentrations of lead varied from nondetectable to 0.86 µg/ml (allowable level in the US 0.5 µg/ml).169

Specific results of the measurements performed in different locations (kindergartens and orphanages) in the city of Shymkent are presented in Table 7.

The isoclines of the levels of soil contamination of lead and arsenic in Shymkent are shown in Figure 3.

Table 4. Lead in Blood in Kazakhstani Children

<table>
<thead>
<tr>
<th>City</th>
<th>Main source of lead</th>
<th>Number of tests</th>
<th>Mean (µg/dL)</th>
<th>Standard deviation (µg/dL)</th>
<th>Geometric mean (µg/dL)</th>
<th>Geometric standard deviation</th>
<th>Maximum (µg/dL)</th>
<th>&gt;10 µg/dL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almaty</td>
<td>Lead in paint</td>
<td>70</td>
<td>6.1</td>
<td>4.1</td>
<td>5.00</td>
<td>1.9</td>
<td>23.6</td>
<td>16</td>
</tr>
<tr>
<td>Kyzylorda</td>
<td>Lead in paint</td>
<td>303</td>
<td>6.0</td>
<td>3.2</td>
<td>5.42</td>
<td>1.5</td>
<td>25</td>
<td>7</td>
</tr>
<tr>
<td>Pavlodar</td>
<td>Lead in paint, industrial emissions</td>
<td>160</td>
<td>5.4</td>
<td>3.9</td>
<td>4.29</td>
<td>2.0</td>
<td>30.3</td>
<td>9</td>
</tr>
<tr>
<td>Shymkent</td>
<td>Major primary lead smelter emissions</td>
<td>157</td>
<td>20.7</td>
<td>16.0</td>
<td>15.62</td>
<td>2.2</td>
<td>103</td>
<td>66 (95% close to the smelter)</td>
</tr>
<tr>
<td>Taldykorgan</td>
<td>Battery plant emissions</td>
<td>70</td>
<td>8.9</td>
<td>5.9</td>
<td>7.73</td>
<td>1.6</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>Tekeli</td>
<td>Lead mine</td>
<td>75</td>
<td>8.7</td>
<td>6.2</td>
<td>7.49</td>
<td>1.6</td>
<td>38.4</td>
<td>16</td>
</tr>
<tr>
<td>Ust-Kamenogorsk</td>
<td>Lead in paint, industrial emissions</td>
<td>237</td>
<td>6.6</td>
<td>4.2</td>
<td>5.56</td>
<td>1.8</td>
<td>29.4</td>
<td>15</td>
</tr>
</tbody>
</table>
Table 5. Lead and Arsenic Content in the Soil of Kazakhstani Cities

<table>
<thead>
<tr>
<th>City</th>
<th>Pb (mg/kg)</th>
<th>As (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almaty</td>
<td>7–97</td>
<td>ND–22</td>
</tr>
<tr>
<td>Kyzylorda</td>
<td>29–5,628</td>
<td>9–756</td>
</tr>
<tr>
<td>Pavlodar</td>
<td>53–5,568</td>
<td>153–874</td>
</tr>
<tr>
<td>Shymkent</td>
<td>49–24,896</td>
<td>ND–2,539</td>
</tr>
<tr>
<td></td>
<td>(77,000 close to emission source)</td>
<td></td>
</tr>
<tr>
<td>Taldykorgan</td>
<td>33–5,958</td>
<td>ND–160</td>
</tr>
<tr>
<td>Tekeli</td>
<td>43–3,612</td>
<td>9–88</td>
</tr>
<tr>
<td>Ust-Kamenogorsk</td>
<td>53–1,410</td>
<td>1–95</td>
</tr>
</tbody>
</table>

Table 6. Levels of Lead in Painted Surfaces in Kazakhstani Cities (mg/cm²)

<table>
<thead>
<tr>
<th>City</th>
<th>Number of samples</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Geometric mean</th>
<th>Geometric Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>All measurements</td>
<td>1,539</td>
<td>1.11</td>
<td>1.73</td>
<td>0.59</td>
<td>3.0</td>
</tr>
<tr>
<td>Kyzylorda</td>
<td>359</td>
<td>0.86</td>
<td>1.77</td>
<td>0.37</td>
<td>3.6</td>
</tr>
<tr>
<td>Pavlodar</td>
<td>269</td>
<td>1.33</td>
<td>1.55</td>
<td>0.87</td>
<td>2.5</td>
</tr>
<tr>
<td>Shymkent</td>
<td>135</td>
<td>1.64</td>
<td>3.06</td>
<td>0.77</td>
<td>3.4</td>
</tr>
<tr>
<td>Taldykorgan</td>
<td>188</td>
<td>0.99</td>
<td>1.71</td>
<td>0.49</td>
<td>3.2</td>
</tr>
<tr>
<td>Tekeli</td>
<td>48</td>
<td>0.78</td>
<td>0.94</td>
<td>0.49</td>
<td>2.5</td>
</tr>
<tr>
<td>Ust-Kamenogorsk</td>
<td>540</td>
<td>1.11</td>
<td>1.30</td>
<td>0.72</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 7. Results of the Tests for Various Locations in Shymkent

<table>
<thead>
<tr>
<th>Location</th>
<th>Lead in blood: GM, GSD, range (µg/dL)</th>
<th>ZnPP in blood: GM, GSD, range (µg/dL)</th>
<th>Avg. lead concentration in air (µg/m³)</th>
<th>Avg. soil lead concentration (mg/kg)</th>
<th>Average indoor dust lead concentration (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>House of Invalids (close to the lead smelter)</td>
<td>12.8, 1.6, 4.7–22.8</td>
<td>47.4, 1.6, 28–96</td>
<td>7.9</td>
<td>1,313</td>
<td>4,625</td>
</tr>
<tr>
<td>Orphanage 3 (close to the lead smelter)</td>
<td>18.4, 1.4, 9.7–29.9</td>
<td>50.2, 1.5, 23–91</td>
<td>5</td>
<td>794</td>
<td>433</td>
</tr>
<tr>
<td>“Pink Flower” kindergarten (far from the lead smelter)</td>
<td>7.72, 1.6, 3.0–20.5</td>
<td>46.9, 1.4, 13–124</td>
<td>1</td>
<td>104</td>
<td>1,400</td>
</tr>
<tr>
<td>“Sholpan” (kindergarten) (close to the lead smelter)</td>
<td>27.7, 1.8, 2.1–103</td>
<td>57.8, 1.7, 23–325</td>
<td>5</td>
<td>1,530</td>
<td>795</td>
</tr>
</tbody>
</table>

GM – geometric mean
GSD – geometric standard deviation
The situation in Shymkent is the worst in the country and probably one of the worst in the post-Soviet region. It is aggravated by the fact that lead in Shymkent soil is highly bioavailable. Based on the analytical results (XRF and ICP/MS), four representative soil samples ranging from 3,030 to 18,924 mg/kg of lead (<250 µm fraction) were evaluated using the in vitro procedure described above. The bioaccessibility values ranged from 93 to 113%, which means that the lead has the maximum possible availability for a child’s body.

**Economic Evaluation**

The impact of childhood lead poisoning in polluted areas has serious economic consequences. This section demonstrates a way to estimate the effect in U.S. dollars related to the human impact of the Shymkent lead contamination. The consequences of childhood lead poisoning on the economic development and social stability of different regions has been demonstrated in numerous studies. One aspect involves the likelihood of criminal acts. Adjusted total arrest rates were shown to be significantly greater for each 5 µg/dL increase in blood-lead concentration, especially for prenatal and young children’s blood-lead levels.173

We used an estimation of economic benefits of BLL reduction derived from Nevin, 2008 at the level of $8,741 per child per 1 µg/dL BLL in the U.S.A. In proportion to the difference in GDP per capita between the U.S.A. and the Republic of Kazakhstan, this estimation was adjusted to $2,370 per child per 1 µg/dL BLL. For our purposes, no economic impact is assumed below the current target level of 10 µg/dL BLL, which implies a median level of 4.6 µg/dL. Therefore, the economic benefits presented here are likely to be conservative, underestimating the true benefits. The current median BLL in Shymkent’s children was measured to be 20 µg/dL, with a 90% approximate prediction interval of 8 to 50 µg/dL, although the BLL data ranged up to 103 µg/dL. The number of affected children of preschool age in the city was taken as 106,000 per 10 years.

With these assumptions, the Monte Carlo-modeled results of the economic benefits of the proposed lead remediation program in Shymkent are shown in Figure 4.

![Figure 3. Lead and Arsenic in Shymkent Soil (mg/kg) blue isocline, lead; red isocline, arsenic).](image-url)
Thus, the mean estimated economic benefit from lead in blood reduction in Shymkent is roughly 4.6 billion in U.S. dollars over 10 years.

**General Assessment of the Lead Problem in Kazakhstan**

The comparative distributions of lead in blood in all studied cities of Kazakhstan and in Shymkent are demonstrated in Figure 5.

There is an extremely high level of lead impact on children in Shymkent, where annually, based on the estimations above, around 40,000 children of preschool age (0 to 6 years) are suffering from lead poisoning. This is an example of a long-term critical situation that has never been addressed properly. Barriers that prevent situations like this from being resolved will be discussed later.

However, it is clear that Shymkent is not the only city in the territory of Central Asia that has such a high incidence of childhood lead poisoning. For example, recent studies were conducted by the Blacksmith Institution (USA) in Balkhash City, Karaganda region in Kazakhstan, where the largest copper smelter, owned by a British company, operates. The studies demonstrated that the average level of lead in residential areas was 1,626 mg/kg (SD 1,098 mg/kg). This can mean that 87% of the children living in such conditions probably have blood-lead levels higher than 10 µg/dL (according to the U.S. EPA IEUBK model). Lead content in soil strongly correlates with copper concentrations ($r=0.98$, $P<0.05$).

The impact of the new CDC reference blood-lead level of 5 µg/dL compared to 10 µg/dL has a dramatic effect on the interpretation of the Kazakhstani testing results. In Table 8, this effect is assessed.

The case study in Kazakhstan proves that lead should be considered one of the most significant environmental health issues in the countries of the
former Soviet Union. The potential health risks there are very high and require urgent health protection and remediation measures.

For the situation in Shymkent and other locations with intensive industrial lead contamination, remediation of the soil, combined with an effective ongoing community educational program, will dramatically improve the neurobehavioral status of young children. Additional measures should also be implemented, such as environmental and biological monitoring and creation of “clean playgrounds” that could allow children to spend time in safe environmental conditions. Kazakhstan also needs state-of-the-art procedures for the treatment of children diagnosed with lead poisoning.

**Lead Poisoning Prevention: Typical Barriers to Overcome**

To resolve the problem of childhood lead poisoning in the former Soviet Union, many barriers must be overcome. Many of those barriers are rooted in the common history and heritage of the new independent states, in economic realities, in legislative and social environment, in aging industrial facilities, and the unavailability or difficulty in attaining appropriate technology.

Historically, the large-scale industrialization that was performed in this region in a comparatively short period — aggravated by two major wars during the century, general military orientation of the economy, and priorities of space and atomic industries — caused excessive environmental pollution and increased occupational and environmental risks.\footnote{176}
The Soviet government was especially interested in the growth of production, ensuring its ability to supply the population with its minimal needs and to increase the country’s military capabilities. Mining and metallurgy in this context became a sector of special interest. The quick growth of metallurgical production of the Soviet Union was often achieved by ignoring environmental and occupational safety requirements. For this reason, the level of environmental contamination in the former Soviet Union is extremely high and contributes to the low life expectancy in the region.177 In the Russian Federation, the average life expectancy in 2012 was 64.3 years in men, 76.1 years in women.178 Life expectancy in other countries of the region is of the same order.

With the breakup of the Soviet Union, the region entered a transition period, with sharp economic decline and worsening social and environmental conditions, combined with extremely high levels of poverty. It was inevitable that issues concerning environmental protection would come in second behind economic concerns during the transition period.

Industry in the post-Soviet countries, as a rule, went through a privatization process that sometimes did not change its close governmental ties (that in the transition period were the only way of survival for both government and industry). The equipment that industry inherited from the Soviet period was more often than not in a state of disrepair and exhaustion, since due to difficult economic circumstances, there has been little additional investment.

Business owners are often more interested in survival, rather than having much concern for the environment, knowing full well that they will never have to pay significantly for any consequences (except perhaps in the form of health effects). The mode of operation has moved from one of Socialism to simple protectionism. It is this protection of the business through exceptions to rules (and laws) that allows the plant to function under the current economic system. Many groups and individuals have a vision for what is meant by a clean environment, and generally, the concept is not opposed. However, on a practical level, “it is sometimes difficult to achieve in our circumstances today,” is a ready excuse.

Currently, difficulties remain in resolving the problems of environmental contamination left as an “historical heritage” in the new independent states. On a national level, no one takes ownership for the historical pollution, laying the blame on a country (the U.S.S.R.) that no longer exists. The legal framework inherited from the Soviet Union remains complex, with many recent laws simply superimposed on retained older laws and regulations, with resulting inconsistencies, overlaps, and gaps. For example, international experts noticed that one of the countries in the region... developed an extensive corpus of environmental laws and put in place a system of non-compliance response in order to make environmental law work. This system foresees administrative, civil, and criminal liability and provides for administrative and judicial paths of enforcement. It includes a panoply of sanctions (such as corrective orders, fines, permit withdrawal, production closure, imprisonment), comparable in scope with those used in OECD countries. However, pervasive disregard for law — a legacy from the country’s Soviet past — continues to raise concerns... as non-compliance prevents the country from achieving ambitious environmental objectives.179

The present system depends on a rigid analysis of conformity to numerous laws, some of which are inappropriate today for the purpose of protecting the environment. When it comes to enforcement, the system is one of penalties. Rather than considering investment in environmental protection measures, the system sets fines so low that they actually en-
Courage operators to pay them and to consider it a normal business operating cost.\(^{180-182}\)

Sometimes, the recently introduced environmental permit system in the region remains similar to the Soviet central planning system, and also, at times remains highly nontransparent. In international practice, proper environmental impact assessment is a process of systematic analysis and evaluation of environmental impacts of planned activities, consultation with affected parties, and utilization of the results of the analyses and consultations in planning, authorizing, and implementation of the activity. The process is thus based on a number of principles, such as transparency, public involvement, and accountability. In the countries of the former Soviet Union, however, there is a significant lack of quality, scientific validity, and integrity when environmental impact assessment is performed as a part of a permitting procedure. In many situations, if environmental impact assessment were performed for industrial operations in a proper and timely manner, and if environmental monitoring were in place, many of the lead pollution issues in the region could be prevented.

Besides these industries, the population very often is not psychologically prepared to protect its environmental and health interests. The environmental concerns of individuals were historically nonexistent in the region, yielding to much more actual fear of poverty and hunger. A self-perception of people in the region is often one of denial concerning the harmful effect of poisoning.

Another barrier that should be mentioned is the special and artificial requirements for the environmental laboratory tests established by some of the former Soviet republics. In some of those countries, the application of traditional Western (or even internationally accepted ISO standards) laboratory methods and techniques requires local recertification that can sometimes take years. This factor is sometimes cited by the authorities, who are trying to prevent the environmental and health problems of the regions from being known internationally and to keep local control of the situation. Although it is understandable that local health authorities are interested in establishing local procedures, the priority of children’s health should not be questioned. The achievements of Western countries in developing environmental and health laboratory equipment should not be overlooked.

There are other obstacles worth mentioning that are beyond the scope of this document, such as cultural and linguistic differences that frame and shape perceptions of problems, unavailable medical and remediation technologies, and the shifting priorities of international donors. In addition, a local perception, real or imagined, of Western scientist attitudes of superiority can set up roadblocks to progress. Patience is needed to build relationships of trust that address these interconnected barriers that are hindering the prevention of lead poisoning in children.
Chapter 3: Working Together to Protect Children (Recommendations for the International Community)

Why Should International Community Care? (Reasons for International Involvement)

The following are reasons that the international community needs to address the problems of childhood lead poisoning in the countries of the former Soviet Union:

- Lead is a significant environmental factor in many of the post-Soviet countries.
- As our studies show, in many regions, lead issues are not addressed and children are poisoned.
- The international community has the experience to resolve problems of lead contamination that can be effectively applied in the post-Soviet countries.
- Leaving the problems unaddressed can gradually increase the world division into “healthy” and “nonhealthy” territories.
- The results of the studies in developing countries can be beneficial in making further progress in lead toxicology.

What Can Be Done?

In the countries of the former Soviet Union, as well in other countries where the problem of childhood/community lead poisoning is similar, science-based policy should be implemented to prevent the environmental impact of lead. The following steps should be considered:

- Lead poisoning of children should become a priority in public health and environmental protection.
- National screening programs for lead in blood and lead in environmental media should be implemented.
- Criteria and standards for lead should be determined based on the risk assessment approach (as it was recommended in the Chapter 1 of this document).
- Sources of elevated lead exposure should be determined.
- Environmental remediation programs should be introduced.
- Medical intervention policy should be established, with approved methodologies and training for physicians, including chelation treatment methodologies.
- Additional controls are needed to prevent illegal use of tetraethyl lead in motor vehicle fuel.
- Special permitting procedures for lead-emitting industrial sources including life-cycle environmental impact assessment should be beneficial.
- Environmental remediation technologies should be included as a part of international help and technology transfer packages.
- The countries of the region should remove the limitations for applying more modern environmental devices, methods, and standards.

Success Stories

In many countries of the world, the prevention of environmental impacts from lead on the health of children has had positive results, starting with measurement and evaluation of the problems, followed by measures to reduce childhood blood-lead levels.

U.S. Experience

As an example, the trend for lead in blood of children in the United States is summarized in Table 9.183

| Geometric mean of blood-lead level for U.S. children reduced by an order of magnitude in 20 years. |

The observed significant decrease of lead in blood in Western countries is a result of systematic government programs, including:
1. the ban of leaded gasoline;
2. the banning of lead-based paints in households;
3. special measures undertaken to regulate paint renovation in houses where lead-based paint may be present;
4. remediation of industrial sites contaminated by lead; and
5. monitoring of blood-lead levels in preschool children and individual case management for children with elevated lead in blood.

It is obvious, however, that in the United States much more remains to be done, because the latest estimate from CDC is that there are 535,000 children with elevated blood-lead levels.184

**Lead Contamination in the Russian Far East: Case Study**

In the developing world, examples of successful resolutions for the problems with childhood lead poisoning are still very rare. A unique example, however, is a systematic program of lead remediation in the Dalnegorsk and Rudnaya Pristan projects in Russia.185

Rudnaya Pristan is a small industrial town in the Russian Far East, approximately 400 km northeast of Vladivostok. The population averages 5,000 people, including nearby villages. This area is part of the Dalnegorsk District, with the administrative center in the city of Dalnegorsk (population 45,000), about 30 kilometers from Rudnaya Pristan. During the Soviet era, the Dalnegorsk District was developed as an industrial mining area because it has one of the richest mineral deposits in the Far East. The government built numerous mines, plants, and smelters in the area.

Based on the referenced source, the Rudnaya Pristan lead smelter, located at the mouth of the Rudnaya River approximately 1.5 km from the bay, was established in 1930 by actor Yul Brynner’s family. It is the only known remaining open-hearth furnace in Russia utilizing the British “Newman” process. The plant was nationalized by the Soviets in 1932, and few technological improvements have been made since.

Therefore, at present, the main technological processes are much the same as they were in the 1930s. One of the few updates was the installation of a mechanized forklift in 1970, to replace hand labor to stir the ore. The plant appears to be in abject disrepair, operating with technology from the 1930s and with few health or safety precautions. Starting in the 1930s, industrial development of Rudnaya Pristan brought a variety of contaminants into the area. Sources of environmental pollution included construction, operation of the smelter, transportation, and related poor hazardous waste management. Air pollution remains one of the main environmental problems.

Particulates with high lead content come from the smelter stacks and are distributed throughout the site with the wind. From this airborne transport and deposition, lead and other heavy metals accumulated ubiquitously and contaminated soils, houses, and gardens.

An approximate 3 km strip around the smelter is denuded and heavily eroded. The shrubs and trees growing in this area are stressed, lack normal lichen cover, and exhibit poor, abnormal growth due to sulfur dioxide emissions. Plant extracts have been

**Table 9. Blood-Lead Levels of Children (ages 1 to 5) in the United States: National Health and Nutrition Examination Survey for Selected Years**

<table>
<thead>
<tr>
<th>Year</th>
<th>% with BLL ≥ 10 µg/dL</th>
<th>Geometric mean BLL (µg/dL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976–1980</td>
<td>88.2</td>
<td>15.0</td>
</tr>
<tr>
<td>1992–2002</td>
<td>1.6</td>
<td>1.9</td>
</tr>
</tbody>
</table>
Community Lead Exposure of Children in Developing and Emerging Economies: Problems, Policies, and Solutions Based on Case Studies in Eastern Europe, Caucasus, and Central Asia

Guidance Document

reported to have 0.3 mg/L arsenic, 9 mg/L zinc, 20 mg/L lead, and 0.5 mg/L copper.186

According to Sharov, the environment of Rudnaya Pristan has been studied for a number of years and area soils have been found to be highly contaminat-ed with heavy metals, such as lead, cadmium, zinc, and copper.187 A study conducted in 1997 to 1999 revealed dangerous concentrations of lead in soil near the smelter and throughout the town. Sampling efforts focused on roadsides, gardens, yards, river-banks, railroad beds, beaches, and playgrounds. Soil samples taken from residential gardens averaged 2,200 mg/kg lead. School areas and playgrounds averaged 550 mg/kg, with a maximum of 1,350 mg/kg lead in soils. One paint sample was collected and contained 0.75% lead, compared to the U.S. trigger level of 0.5%. The exteriors of houses were commonly painted with lead-based marine paints salvaged from ship maintenance activities in the local port. Soil lead contamination levels up to 95,000 mg/kg were found. The highest levels were from the samples near the railroad where lead concentrate was spilled. Even the lowest concentrations of lead at locations farthest from the smelter still show contamination at 160 to 896 mg/kg, far exceeding the background level.

According to Petr Sharov, another important pathway of exposure to lead is the consumption of locally grown fruits and vegetables. It is common in the Russian countryside and is true in Rudnaya Pristan, that people try to grow as much food as possible in their gardens in order to avoid buying food at the market and to ensure a year-round food supply. The primary crop is potatoes, which are grown in larger quantities than any other crop. In Russian cuisine, potatoes are almost always peeled and washed, which excludes the risk of ingestion of contaminated soil with consumption of the potato. On the other hand, lead contained in soils of the area may be accumulated in tubers of the plant and thereby ingested. The next most prevalent garden crops are tomatoes, cucumbers, and a number of berries. Both tomatoes and cucumbers are popular summer foods used primarily for making salads, and marinated or preserved for winter in large quantities. In preparing these vegetables, they are always washed, which reduces risk of ingestion of accumulated lead-containing dust. Like potatoes, these vegetables also may accumulate lead in their tissues from the contaminated soil in which they are grown. Potatoes, tomatoes, and cucumbers are consumed year-round, which may mean year-round exposure to lead for most of the families.

The Blacksmith Institute reported that some vegetables and fruits from the area have been characterized and have yielded average dry weights of 16.5 mg/kg lead, 5.6 mg/kg cadmium, and 32.0 mg/kg zinc in strawberries, with lesser but significant levels indicated in potatoes, cucumbers, and tomatoes.188 Another study conducted in 2003 to 2005 revealed high concentrations of heavy metals in edible parts of potatoes grown in Rudnaya Pristan and neighboring villages. Concentrations of lead ranged from 0.08 to 23.93 mg/kg (2.22 mg/kg average). Concentrations of cadmium ranged from 0.2 to 1.27 mg/kg (0.39 mg/kg average); zinc ranged from 7.39 to 46.14 mg/kg (22.19 mg/kg average); and copper ranged from 0.78 to 7.23 mg/kg (3.10 mg/kg average).

Health studies of the whole Dalnegorsk District conducted during the Soviet era revealed the anomalous structure and extent of local health problems. Respiratory pathologies and infections held first place among the priorities of diseases and health problems. In 1987 to 1989, on average, there were 538 cases of respiratory problems per thousand residents per year, the highest rate among all industrial centers of Primorye. At the same time, there were 1,048 and 1,010 cases of respiratory problems per thousand children in Dalnegorsk and Rudnaya Pristan, respectively. Beginning in 1981, a steady
increase was noted of heart pathologies in children from birth to age 14.

In 2005, in the towns of Dalnegorsk, Serzhantovo, Monomakhovo, and Rudnaya Pristan, BLL testing of children was conducted, which was financed by the Blacksmith Institute and organized by the Far Eastern Health Fund and the Dalnegorsk Division of the Center of State Sanitary and Epidemiologic Supervision for Primorye. In Rudnaya Pristan, 120 children were tested and over 50% of them had blood-lead concentrations above 10 μg/dL. The blood-lead level ranged from 1.6 to 56.7 μg/dL (average 12.4 μg/dL). Spatially, the children at the highest risk of lead poisoning lived closer to the smelter in the central, eastern, and western parts of town. Most of children tested lived in the southern part of Rudnaya Pristan, where the lead health risk is lower. These data generally support the results of the IEUBK analysis, thus indicating that the methods presented for health risk assessment for lead could be successfully used for purposes of developing risk mitigation measures and environmental remediation projects.

As the Blacksmith Institution has reported, an environmental remediation project was implemented in this region. During 2008 to 2009, five playgrounds were cleaned up (by taking the soil out, safely disposing of it, and replacing it with clean soil) at the total area of 6,240 m². Additionally, an educational program was introduced for children and parents. The average blood-lead level for children in Dalnegorsk has been reduced, as shown in Figure 6.

**Lead in Zlatna, Romania**

In Zlatna, a community of approximately 10,000 people in the Transylvanian region of Romania, a comprehensive project was organized by USAID and other supporting organizations, to reduce lead exposure risks for children caused by emissions from a copper smelter. The interventions performed included the following:

1. For the reduction of the exposure of young children to lead:
   - establishment of a multidisciplinary lead working group, which included kindergarten teachers, doctors, and environmental health specialists;
   - procurement of equipment for lead-in-blood tests (atomic absorption spectrophotometer) and enrollment of the local laboratory staff in the International Blood Lead Proficiency Testing Program;
   - training for the local specialists;
   - development of a health education program for kindergartens and for families to reduce lead exposure of children;
   - development of a community awareness program, utilizing newspaper, magazine, radio, and television outlets;
   - institution of a lead awareness counseling program for families; and
   - provision of a summer health education camp for children and parents.

2. For improvement of air-quality monitoring capacity and data management:
   - establishment of an air working group;

**Figure 6. Lead in Blood of the Children of Dalnegorsk (Russia) During Remediation Program Implementation.**
• delivery of a four-day air-quality management and air-monitoring training program;
• procurement, delivery, and installation of two state-of-the-art monitoring stations; and
• operations and maintenance training and follow-up.

3. For improvement of occupational health and safety (OHS) at the smelter:
• establishment of an occupational health and safety working group;
• implementation of a training program on worker’s health and safety;
• equipment procurement and delivery, including respirators and hazardous exposure assessment devices;
• establishment of a medical surveillance program coordinated with worker blood-lead sampling results; and
• provision of a training program for workers and providing workers with the results of workplace air-monitoring and blood-lead testing data.

As an outcome, a 25% reduction of average children’s blood-lead level (age group 1 to 11 years) was reported. The reduction was from 40 µg/dL to 28 µg/dL.189

Example of other heavy metals

Additional cases of potential approaches to the community management of childhood exposures are illustrated for other heavy metal community contaminants. For example, lead and arsenic contamination were addressed during several international environmental health projects. Detailed review of the steps undertaken in Bangladesh, India, and Nepal can be found in selected publications. These approaches to effectively prevent arsenic poisoning in communities involved the active participation of the group of William Carter and Linda Smith, with support from UNICEF, FINNIDA (the Finnish Department for International Development Cooperation), and other NGOs.190–194

The Future of Lead Poisoning Prevention

Childhood lead poisoning is a serious problem that in the last few decades has significantly changed its geographical focus. In developed countries, progress has been made, although far too many children still remain at risk. In the developing world, the situation has worsened, with an increase in the size of contaminated territories and the number of suffering children. Therefore, the future of lead poisoning prevention lies in continuous international collaboration and in a global search for better health and environmental solutions.

Lead is a unique example of a dangerous poison for which public health effects can exist without being identified for decades, gradually degrading the social well-being. Low-level lead poisoning, which does not cause acute symptoms but produces irreversible consequences for the nervous system, does not appear to have been treated as a top priority. However, the impact of lead poisoning is devastating, including a decreased potential of a society to develop, along with an increase in individual aggression and criminalization that negatively affects international stability.

The Western international community is very sensitive to the violation of human rights, especially those of children. However, millions of children worldwide are being involuntarily poisoned by lead, thus violating their human rights. Democracies should acknowledge the problem and take strong diplomatic measures to protect the rights of children to a life unfettered by the bonds of lead. International mechanisms for childhood lead poisoning prevention should be determined and established as soon as possible.

As an example, International Task Force for Children’s Environmental Health (not affiliated with AIHA) pro-
posed a “Zone of Hope” initiative as one part of a solution. “Zone of Hope” is a status that an area can obtain to help alleviate environmental threats to children. The goal of the initiative is to develop international tools to protect children’s rights to a safe environment by enhancing and coordinating information transparency, independent expertise, and business involvement in a manner that is acceptable to local governments and communities.

For inclusion in the “Zone of Hope” status, the criteria for acceptance should be supported by a group of international experts. Data on local conditions and eligibility should be peer reviewed. Incentives will be provided to facilitate industrial and other economic growth as an alternative to processes that harm the environment. The “Zones of Hope” can be announced on the web site of the initiative. Progress will be regularly monitored and reported. International businesses working in the “Zone of Hope” will be invited to assist with local environmental issues in a positive manner and to assist with community education to help minimize negative impacts.

Regions where lead contamination of the environment causes significant health deterioration of children can benefit from inclusion in “Zone of Hope” listings, thus making international involvement necessary and legitimate.

Resolving childhood lead poisoning problems requires significant financial input from local, regional and national governments and the private sector, the last being an area in which the international community should find ways to help. Large foundations and businesses should be made aware of the serious threat of lead poisoning in developing countries, and they should be invited to participate in funding solutions. The status quo of ignoring or postponing prevention of the loss of much of the future generation’s creativity and well-being should be changed.

Conclusions

Lead poisoning of children in developed and developing countries has by no means been eliminated, and mitigating the problem should have a high priority among environmental health issues. Lead is especially dangerous because of its ability to target a vulnerable age group, with its impact starting at low levels of exposure, and its propensity to cause hidden, nonspecific, and irreversible effects. The recent recommendation of the CDC to implement a reference value of 5 µg/dL in blood reflects an opinion within the expert community that significant health and behavioral disruptions from lead in blood may result at even lower levels than previously anticipated.

In the countries of Eastern Europe, Caucasus, and Central Asia (the former Soviet Union states), exposures to lead in the environment during childhood have been seriously underestimated. As a result, hundreds of thousands of children who are residents of numerous communities in those regions continue to be affected every year. Not only the health and well-being of these children is compromised, but also the current and future economic impact from lead pollution on society in the region will total billions of dollars.

The endeavors of local scientists and experts to address lead issues, and government efforts to deal with the problems caused by lead are acknowledged. However, it is clear that the capabilities of these countries will need to be strengthened to resolve the lead problem at a faster pace, more effectively, and in a more comprehensive manner.

Although delays are not acceptable, international organizations and bodies do not seem to be taking action to offer assistance in these situations. Perhaps this is because lead risks have not attracted enough attention and are outside the interests of major donors who may prefer to work with problems that seem more generalized and projects that are
less specific. An apparent lack of funding may also have created limitations in public awareness of the situation in both developed and developing parts of the world. Sometimes, there may be an unwarranted sense of “problem solved,” and the enormity of the remaining problem has not made the news. The consequences of lead exposure of a substantial percentage of children in the post-Soviet region can, however, affect the entire world, given that borders have become more permeable for all aspects of safety, health, environment, and economics.

With this situation in mind, the goal of AIHA with this reference document is to publicize the problem, to help achieve a better understanding of international lead poisoning problems, and to develop shareholders for international collaboration. We encourage cooperation among various groups and countries to finally control and eliminate the problem of lead exposure of children. This document also presents comparisons of lead issues in various regions and provides valuable information for further addressing lead issues in developed countries, where lead remains a significant hazard requiring constant updating of research, knowledge, education, and policy.
Community Lead Exposure of Children in Developing and Emerging Economies: Problems, Policies, and Solutions Based on Case Studies in Eastern Europe, Caucasus, and Central Asia

Guidance Document

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123. This section is written as a starting point for medical professionals to assist in performing further research on what constitutes appropriate treatment for lead-poisoned children. AIHA makes no representation as to the accuracy or applicability of the statements made here and does not necessarily agree with all of the information contained herein. AIHA is not a medical organization and is not in a position to offer medical advice. Only physicians who are caring for specific patients, considering the complete medical condition of each child, are qualified to make specific recommendations and treatments for individual patients.

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Community Lead Exposure of Children in Developing and Emerging Economies: Problems, Policies, and Solutions Based on Case Studies in Eastern Europe, Caucasus, and Central Asia

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