Environmental Lead Contamination in the Rudnaya Pristan – Dalnegorsk Mining and Smelter District, Russian Far East

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Abstract

The results of 30 years of studies by a Russian scientific team and a preliminary survey of soil metals concentrations conducted by a joint US-Russian research team in a remote mining and smelting region of the Russian Far East (RFE) indicate significant soil lead contamination and a high probability of childhood lead poisoning. Lead concentrations in residential gardens and yards (500 – 4600 mg/kg) and in roadside soils (500 – 23000 mg/kg) exceeded USEPA guidance for remediation. Preliminary biokinetic estimates of mean blood levels suggest children are at significant risk of lead poisoning from soil/dust ingestion. Samples of other potentially important pathways, such as air, surface and ground water, paint, interior dust and garden produce, as well as pediatric and occupational blood lead levels, are needed. An assessment of the industry's ability to reduce exposure levels through modernization and more effective control of emissions and materials handling should also be accomplished. Lessons from around the world in remediating severe contamination preventing childhood lead poisoning must be applied in innovative ways to meet the logistical, social, and economic challenges in the RFE.

Key words: lead poisoning, contamination, mining, Russia, heavy metals

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Introduction

Lead exposure has been extensively assessed throughout much of the world – in gasoline, paint, air, water, interior dust, soil and food. In mining and industrial districts, ingestion of soil and dust contaminated with heavy metals is commonly the primary exposure route of lead to children. In Russia, studies of such regions lack comprehensive environmental and health characterization.

In a preliminary survey of potential environmental pathways in the Rudnaya Pristan - Dalnegorsk mining region of the Russian Far East (RFE), US and Russian collaborators collected samples of soil, sediment, and mine and smelter wastes in the summer of 1997. The investigation was limited to non-invasive residential and public sector sampling to determine if environmental contamination exists near Rudnaya Pristan's primary lead smelter and around Dalnegorsk's mining and milling activities. Soil, sediment and industrial waste samples were collected in the RFE mining region and analyzed in the US for lead and other metals. This paper presents these data and estimates lead intake by area residents. In addition, unpublished environmental and health data, previously collected at the site by the Russian collaborators, are presented. Results indicate significant environmental contamination and a high probability of childhood lead poisoning.

Site Background

The eastern slope of the Sikhote-Alin mountain range, about 300 miles north of Vladivostok, has been home to a large mining district for about 100 years (Figure 1). The Dalpolimetall Production Association specializes in extraction of lead/zinc ore and smelting of lead, bismuth and silver, providing employment for about 5000 people. The mining district is located in the steep mountain valley of the Rudnaya ("rich ore") River, which flows 40 km from its headwaters near Dalnegorsk (pop. 40,000) to the mouth of the Sea of Japan in Rudnaya Pristan (pop. 4,000). Dalnegorsk is a heavily industrialized city containing lead/zinc mining and concentrating facilities and one of the world's largest boron mining and refining plants.

The major lead/zinc mines are located in the adjacent mountains and produce galena ores. Early concentrating methods were gravitational techniques producing waste tailings averaging several percent lead being discharged to the river. Flotation milling techniques were introduced in the early 1930's with discharges to the river continuing until the 1960's when tailing impoundments were introduced.

Ore concentrates are transported 30 km in open rail cars from Dalnegorsk to Rudnaya Pristan, where the Rudnaya River discharges into the Sea of Japan. At the mouth of the river, approximately 1.5 km from the bay, is the Rudnaya Pristan lead smelter (Figures 2 and 3), established in 1930 by actor Yul Brynner's family and the only facility smelting raw concentrates in Russia. It is likely one of the last remaining open-hearth furnaces in the world. The Soviets nationalized the plant in 1932 and few technological improvements have been made since. One of the few updated technologies was installation of a mechanized forklift in 1970, to replace hand labor to feed and stir concentrates in the furnace. The plant is in abject disrepair operating with 1930's technology and few health and safety precautions. About 200 workers work 6-hour shifts with no annual shutdowns for maintenance. Interior ventilation fans are frequently turned off to conserve electricity, making working conditions particularly difficult. The plant produces 25,000 tonnes per year of antimonial lead and occupies 2.5 hectares. The smelter is adjacent to the village of Rudnaya Pristan and is less than half a mile from public schools. The concentrator is in the center of Dalnegorsk and is surrounded by high-rise apartments.

Until 1961 when tailings impoundment ponds were installed, untreated wastes from milling operations were discharged directly to the river. River sediments, having lead levels 50 to 700 times background, have historically been used as a soil amendment in gardens and are a potential addition to the dietary lead burden. The river is also heavily used for recreation and irrigation. It is common in the RFE for home gardens to supply as much as 70% of the residents' food. In this region, the soil is contaminated not only from the smelter under both routine and upset conditions, but also from open transport of ores in rail cars, and possibly, by lead paint and other sources.

Data collected by Russian Collaborators prior to 1997 Study

Scientists from Far East State University and the Pacific Geographical Institute, housed at a research station near the smelter, have monitored environmental indicators since 1972. Numerous investigations from areas beyond the smelter's impact have been published (Arzhanova et al. 1995; Elpatyevskaya, V.P. 1995, 1996; Gusarova and Ivanova 1996; Khristoforova, N.K. 1989a, 1989b; Kukharenko, L.A. 1996; Tkalin et al. 1995; Tyurin et al. 1995; Yelpatyevsky et al. 1995; Yelpatyevsky, P.V. 1995, 1996). However, studies within the smelter's impact zone were classified as State secrets during the Soviet era. Kachur (1996) summarized the available environmental and health data collected from 1990-1996 from the most contaminated areas. Selections from his report have recently been translated and are summarized in this section, unless otherwise noted.

Neither the analytical techniques nor the laboratory quality assurance and quality control used in the studies summarized by Kachur are known beyond what is described herein. It is plausible that reported concentrations are lower than what would be measured using state-of-the-art techniques. Orlova et al. (1995) have shown that Russian data on lead in soils may be significantly lower than split samples analyzed in the US. (Russian samples were typically analyzed by spectral analysis, without prior sample digestion, whereas US analyses used nitric acid digestion followed by atomic absorption spectroscopy.)

Air and Precipitation Analyses

Before 1964, there was no air pollution control equipment in place at the smelter, although a baghouse was utilized to recycle captured particulates. In 1964, mechanical processes, such as cyclones, were installed to control dust emissions. An estimated 250,000 m^3 of gases are discharged annually through three stacks. The main stack is 42 meters high. The annual discharge includes 85 tons of dust, comprised of 50 tons of Pb, 5 tons of Zn, 6 tons of Sb, 1 ton of Bi and 0.5 ton As. Smelter gases are estimated to carry 4,800 tons of SO_2 and over 200,000 tons of CO and CO_2 annually. In the summer, the predominant winds are to the northwest, up the Rudnaya River or towards the north, up the Koreiskiy stream. In the winter, the wind is predominantly towards Rudnaya Bay. When the main stack is used, maximum pollutant concentrations are found 0.4 – 1.8 km from the smelter, at a 2-3 m/sec wind speed. When the lower stacks are used, maximum concentrations are found 0.3 – 1.0 km from the smelter. Table 1 summarizes ambient air data; sampling and analytical methods are not specified.

The particulate matter data are high, compared to US national ambient air quality standards. In the mid-1970's the US standard was 0.075 ug/m^3 Total Suspended Particulate (TSP) annual average with a 0.2 ug/m^3 daily maximum. Precipitation studies from the site have included snow and rain. Near the smelter, snow samples were reported to contain large amounts of dust, with 3-5% Pb, 3-5% Zn, 2% Cu, 2% As, 0.5% Bi and 0.5% Sb. Combining these concentrations with TSP values from Table 1 suggest Pb in air ranging from 7.5 ug/m^3 to 16 ug/m^3. The US NAAQS for lead is 1.5 ug/m^3. The Russia standard is 0.3 ug/m^3.

Metal concentrations in precipitation are reported in Table 2. An estimated 40 tonnes (40,000 kg) of dust is deposited annually in the 5 km^2 area around the smelter (Zone 1). If the dust is 3-5% Pb this equates to 1200-2000 kg Pb/year. In Zone 2, a 20 km^2 area around the smelter, excluding Zone 1, an estimated 20 tonnes (20,000 kg) is deposited or about 600-1000 kg Pb/year. Samples were decomposed by hydrofluoric acid and $HClO_4$, digested with 5% HCl, and analyzed by atomic absorption (AA) (Hitachi 180-70).

Vegetation Analyses

An approximate 3 km strip around the smelter is denuded and heavily eroded. Surrounding shrubs and trees are stressed, lack normal lichen cover and exhibit poor, abnormal growth due to sulfur dioxide emissions. After an extensive dry weather period, oak leaves were collected and 0.5 g of dust per 1 kg leaves was measured. This dust loading did not include metals concentration data or specify the collection method.

Plant extracts have also been reported as 0.3 mg/l arsenic, 9 mg/l Zn, 20 mg/l Pb and 0.5 mg/l Cu. The exact method of extraction was not specified. Dry combustion (450 ^{o}C) with ash decomposition by 5% HCl was used for metals analyses. Measurements were made by AA (Hitachi 180-70) using Russian soil sample standards.

Leachate and Water Analyses

Area mine dumps have pH levels of 2.5 - 3.9, high concentrations of lead, zinc and cadmium, and produce substantial leachate (Elpatyevskaya V.P. 1995, 1996; Yelpatyevsky et al. 1995; Yelpatyevsky P.V. 1995, 1996). A small (<0.5 hectare) sedimentation pond along the Koreiskiy stream, receives 2,900 m^3/day wastewater from the smelter, estimated to carry 100 kg Pb, 50 kg Zn, 50 kg Cu and 20 kg As annually. Concentrations of arsenic up to 3 mg/l have been measured. The wastewater pH is reported at 8.5. Metals concentrations leaving the pond and entering Koreiskiy stream, which flows into the Rudnaya Bay, are not known. Water samples were filtered through 0.45 micrometer nylon filters, decomposed by HF and HClO4, digested by 5% HCl and analyzed by AA.

Biological Samples

A survey in 1986, reported hair lead levels in kindergarten children (average 9.6 ug/g) and in smelter workers (average 286.6 ug/g) (Table 3). Hair lead concentrations as a function of work duration at the Rudnaya Pristan smelter are also presented. These values were significantly higher than background samples, taken in Tierney, an unindustrialized town about 150 km north of Rudnaya Pristan. Sampling and analytical techniques are not available. Kachur also reports the need for population monitoring, based on unpublished reports of abnormal levels of basophilic stippling among school-aged children in the lower Rudnaya Valley. No blood lead measurements have ever been taken among either the occupational or community populations.

Joint US/Russia Soil Survey Materials and Methods

US/Russian collaborators sampled soil, sediment, mine and smelter wastes in Rudnaya Pristan and Dalnegorsk during July 11 - 19, 1997. The soil sampling procedures and analytical protocols used were based on USEPA procedures (USEPA 1984, 1986, 1987). Sample locations focused on areas where exposure to soil and sediment was observed or possible. Sample areas include roadside, gardens, yards, riverbanks, railroad, beach, and playgrounds.

Two types of soil samples were collected: grab and composites consisting of 3-5 sub-samples. Soil surface composites were collected from the 0-1 inch layer. Any debris or surface vegetation, such as grass or leaves, was cleared from the ground surface prior to sample collection. A clean stainless steel trowel was used for the collection of every sub-sample. Each sub-sample was equally spaced and equally portioned. The 3-5 sub-samples were then placed in a Ziploc© bag and homogenized. Tailings, riverbank and railroad tie samples were collected as composites, similar to the soil samples. Grab samples were collected of paint chips from the outside of one house and of dust from old submarine battery casings commonly used for water storage.

Generally, a team of four people collected the samples. Two people (one US scientist and one Russian translator) explained the study and obtained the property owners' permission for sampling. A third person performed the actual sample collection, while the fourth assisted the sampler, recorded notes in the field logbook, labeled the sample bag and attached the completed sample tag. Standard decontamination and sample banking procedures were used. Sample equipment and supplies had been shipped from the US to the RFE in a stable container. Samples and equipment were carried back to the US in backpacks by the team. A USDA permit accompanied the samples for clearance through US customs. Samples were sieved to -80 mesh and analyzed by USEPA Method 3051 and 7420 for lead by Anatek Laboratories in Moscow, Idaho. Fifty-two of the original 62 soil samples collected were reanalyzed in the fall of 1999 for the metals, copper, zinc, arsenic, cadmium, and iron, as well as lead. These samples were not sieved and were analyzed by x-ray fluorescence (XRF) by Dr. John Drexler of the University of Colorado at Boulder, Colorado.

Results

Soil samples were collected from gardens, yards, play areas, the railroad right of way and the Rudnaya Bay beach; dusts taken along roadsides; mine tailings from the flotation ponds near Dalnegorsk; and river bank samples along the Rudnaya River. Four "other" samples were collected as described below. Table 4 summarizes metals tested in 1999 in the two towns, and includes preliminary remediation goals (PRGs) for comparison (USEPA 1999). Arsenic averages exceeded the residential soil PRG. Averages for the other metals were below the PRGs, but some maximum concentrations exceeded them. The remaining focus of this paper is lead, unless otherwise mentioned. A paired T-test was performed on the lead samples analyzed in 1999 and those analyzed in 1997, and revealed no significant difference ($p=0.17$). Therefore, the data discussed herein are the 1997 lead results because of the larger number of observations ($n=61$). Table 5 summarizes the 1997 lead results discussed in this section.

Soil

Fifteen (15) garden samples in Rudnaya Pristan and Dalnegorsk averaged 2095 and 741 mg/kg, respectively. Two (2) gardens sampled at houses in the valley between the smelter and mill towns had considerably lower lead levels. Residential yards in Rudnyaya Pristan averaged

2241 mg/kg lead. Schoolyards and play areas in Rudnaya Pristan averaged 553 mg/kg; in Dalnegorsk those areas, which were across the street from the concentrator, averaged 2589 mg/kg. The most contaminated areas were the railroad right-of-ways, ranging from 24,400 to 95,000 mg/kg. These samples likely contained concentrates spilled along the track. Two samples along the beach of Rudnaya Bay, both a recreational and industrial area, measured 610 and 6200 mg/kg.

Dust

Roadside dust samples in Rudnaya Pristan ranged from 2020 to 22,900 mg/kg, averaging 6119 mg/kg. One of these samples, taken from the porch of a house on Gregory Street, across the street from the smelter, measured 4610 mg/kg. In Dalnegorsk, 2 roadside samples measured 510 and 1250 mg/kg.

Mine Tailings

Two (2) samples from the flotation tailings pond near Dalnegorsk were collected, measuring 672 and 1180 mg/kg.

River Bank

Nine (9) samples were collected along the banks of the Rudnaya River at approximately 4 mile intervals. Families were picnicking and children were swimming at nearly every sample point during collection. The highest sample measured 1950 mg/kg lead.

Other Samples

An exterior paint chip, collected from a house with badly deteriorating paint, measured 7470 mg/kg. At one house within one km of the smelter, large fiberglass boxes were being used to collect rainwater from the rooftop. These boxes were cases from spent submarine batteries, which had been reprocessed at the smelter. The boxes were found discarded and scattered throughout Rudnaya Pristan. The rusty residue inside one of the cases measured 293,000 mg/kg lead. In the summer of 1997, some of the railroad ties in Rudnaya Pristan were being replaced along the line used to transport concentrates from Dalnegorsk to the Rudnaya Pristan smelter. The old ties were encrusted with spilled concentrates that measured 135,000 mg/kg lead. These ties were left discarded, and were probably used as firewood or erosion control. A dust/soil sample taken at the scale house at the port on Rudnaya Bay measured 65,900 mg/kg. This area was easily accessible by the public and adjacent to the beach used for recreation.

Blood Lead Estimates

The Integrated Exposure Uptake Biokinetic Model (IEUBK) (v. 99d) and the Adult Exposures to Lead in Soil (AELS) approach recommended by the USEPA were applied to the soil data collected July 1997. The IEUBK is used to model exposure and sources of lead and toxicokinetics in children ages 0.5 – 7 years old and to predict childhood blood lead concentrations (USEPA 1994a, 1994b). The AELS estimates adult blood lead concentrations through algorithms developed to represent industrial or recreational exposure to lead in soil (USEPA 1996).

The IEUBK model is an integrated exposure model reflecting lead intake from air, diet, drinking water, soil, dust and other sources. However, for these analyses only soil and dust parameters were entered to reflect blood lead levels. All other intake and absorption parameters were US default values. Comprehensive scenarios were not developed because ingestion, intake and absorption parameters for dietary, paint and airborne sources in Far East Russia are unknown. The three IEUBK scenarios modeled were:

1. the overall town geometric mean soil lead concentration (2775 mg/kg) for Rudnaya Pristan using the Multiple Source Analysis option (MSA) to estimate dust lead concentrations derived from soil alone (1943 mg/kg).
2. the overall town geometric mean soil lead concentration (2775 mg/kg) for Rudnaya Pristan using the default value (200 mg/kg) for dust lead concentrations.
3. an example home from Rudnaya Pristan (nearest the smelter) using the soil geometric mean (3440 mg/kg) and a dust sample collected from the backdoor of a Gregory Street house (4610 ug/g).

The AELS approach estimates adult blood lead levels due to soil ingestion alone and is not a total exposure model. Contributions to adult blood lead levels from soil exposure were calculated using the product of the soil lead concentration, biokinetic slope factor (BKSF), soil ingestion rate (IR), soil absorption factor (AF), and exposure frequency (EF) divided by the averaging time (AT). The TRWL recommends default values for the following parameters: BKSF = 0.4 ug Pb/dl of blood per ug Pb/day, IR = 50 mg of soil/day, AF = 12% GI absorption, EF = 219 days of exposure/year, and AT = 365 days/year. Four scenarios were modeled using the default values above and varying only soil lead concentrations.

1. The Rudnaya Pristan overall geometric soil mean (2775 mg/kg).
2. The Gregory Street geometric mean (3440 mg/kg).
3. The smelter area geometric mean (3755 mg/kg).
4. The smelter area arithmetic average (17,487 mg/kg).

Results of the three IEUBK scenarios show children (0.5 – 7 years old) are estimated to average 13-27 ug Pb/dl of blood. From the resulting distributions, the percentage of children projected to have blood lead levels greater than or equal to 10 ug/dl ranges from 70 – 97%, while the percentage of children estimated to have blood lead levels greater than or equal to 20 ug /dl ranges from 18 – 70%.

The AELS approach estimates adult blood lead levels to increase by 4 – 25 ug/dl.

Discussion

The results indicate significant soil contamination levels in Dalnegorsk and Rudnaya Pristan confirming earlier Russian studies. Ingestion of contaminated soil and dust is recognized as a primary source of lead poisoning in children. Estimated lead intakes from soil and dust ingestion suggest children in these communities are at significant risk of lead poisoning. This is especially true, as this study did not include evaluation of other potentially significant pathways such as air, surface and ground water, paint, dust and garden produce. Previous Russian investigations indicate significant lead concentrations in air, water and local produce. Reports of elevated hair lead and basophilic stippling levels for both workers and children in the community have been noted. These results indicate a need for further investigation of these environmental exposure pathways as well as of pediatric and occupational blood lead levels. Due to the economic problems in Russia, and the community's dependence on this industry, public health intervention efforts and new industrial control technologies should be introduced simultaneously.

Environmental Samples

Soil samples include residential gardens, yards, schools/playgrounds, railroad rights-of-way and the Rudnaya Bay beach. Residential gardens on average exceed USEPA remedial trigger levels of 400-1200 mg/kg. These values are particularly significant because most of the residents' produce is home grown in kitchen gardens and dachas averaging 2200 mg/kg. Yard soils are routinely tracked into houses, and represent the major contributor to interior dust lead levels. School areas and playgrounds in Rudnaya Pristan average 550 mg/kg, with a maximum of 1350 mg/kg. In Dalnegorsk an apartment building and playgrounds are within hundreds of feet of the concentrator. The 6080 mg/kg value was taken beneath a swing set. The railroad rights-of-way levels represent spilled concentrate along the tracks connecting Dalnegorsk and Rudnaya Pristan. Many residents were observed walking along the tracks through both towns. Children were observed playing in these areas. The spilled concentrate is likely to be redistributed throughout town. The beach along Rudnaya Bay is frequented by area residents for recreation and is adjacent to the shipping port where both concentrates and lead product are exported. The maximum value of 6200 mg/kg represents a significant potential exposure source to those residents. Roadside dusts in both towns indicated high levels, probably due to a combination of airborne deposition and redistribution of spilled concentrates. The contaminated soils and dust are likely contributors to interior dust levels.

The other types of samples suggest additional environmental sources and pathways may also be of concern and need further investigation. The mine tailings samples are generally indicative of good metallurgical practices (TG 1996b), but public access to the ponds is not restricted. The Rudnaya River is heavily used by area residents for swimming, picnicking and fishing. The sediment samples collected along its beaches suggest this is another potential source of lead to the residents. Only one paint chip was collected from an exterior, flaking house wall. In the US, 0.5% is the trigger level for remediation of leaded paint. Our sample measured 0.75%, suggesting that further study is needed to assess the importance of leaded paint in both communities. At one house, fiberglass casings from submarine batteries, reprocessed at the smelter, were being used to collect rainwater. Discarded casings were found scattered throughout town. The dusty residue measured 29% lead. Another example related to poor materials handling was the used railroad ties found discarded. The ties were embedded with concentrates, measuring 14% lead. The scale house along the beach at Rudnaya Bay was easily accessible by the public. Dust samples at the scale house measured nearly 7% lead. These samples indicate that poor materials handling is likely a major source of contamination throughout town.

Blood Lead Estimates

Due to basic assumptions and variables inherent to both the IEUBK and AELS, caution must be exercised when applying the models' results. Default values for such variables as absorption, bioavailability, ingestion, the biokinetic slope factor, amounts of soil found in dust, and exposure frequency rely on American habits and data. Many of these key variables are unknown for the RFE. The common environmental exposure media to lead are soil, dust, water, air and paint. Human factors affecting exposure include age, prior lead exposure, mouthing, pica, nutritional status (especially Fe and Ca deficiencies), individual variation, exposure to other toxicants, physical state (e.g., pregnancy/lactation), concurrent disease, parental occupation and smoking. No data on these factors exist for the Rudnaya Pristan-Dalnegorsk populations. Additional factors such as the availability of running water, food preparation, availability of interior vacuum cleaners, children's play area and indoor/outdoor frequency are also unknown. Due to the lack of site-specific data, the IEUBK and the AELS cannot be comprehensively applied and the blood lead concentration estimates are not representative of total exposure. The models' input parameters and assumptions, and preliminary simulations were instead used as a tool to identify data gaps.

Comparison of Results of this Study to other Russian lead studies

A health committee formed with the Gore-Chernomyrdin Committee (GCC) in 1994 allowed the US Centers for Disease Control (CDC) to expand its focus beyond infectious disease in Russia. CDC's environmental health efforts in Russia focused on pediatric lead exposure, recognizing Russia as one of the world's primary lead consumers. CDC studies of two copper smelter towns in the Urals and a coal mining area in Kemerovo, Siberia, found lead soil levels below 2000 mg/kg (Orlova and Wilson 1998).

A study in Saratov included sampling 60 children and their homes for soil, water, dust and paint (Rubin et al. 1997). Saratov was selected for its mobile-sources (automobiles) and stationary lead sources (including a lead battery factory and a leaded glass factory). This study included the first pediatric blood lead screening among Russian children. The mean blood lead level of 579 samples ranged from 3.0 to 35.7 ug/dl, with a mean of 7.7 ug/dl. Nearly one-fourth of the children had levels above the US level of concern, 10 ug/dl. The environmental samples were nearly all within acceptable US remediation standards. The study indicated that childhood lead poisoning in Russia has been defined by hair analyses. However, the Rubin et al. study showed low correlation between hair lead and blood lead levels. The sensitivity of hair analysis in detecting blood level levels $\geq$ 10 ug/dl was 50%; the specificity was 95%. This technique was not deemed adequate for screening children.

In contrast to the Saratov study, our results in Rudnaya Pristan and Dalnegorsk show that many environmental media exceed US guidance and that it is likely that numerous children exhibit excess blood lead levels. Because the Rubin study showed the insensitivity of hair lead measurements, such as those also reported by Kachur (1996) (Table 3), the need for blood lead samples is further justified.

In a study of sources of lead exposure in industrial and residential areas of Moscow, Orlova et al. (1995) sampled paint, interior dust, drinking water, gasoline, soil and canned food. Some paint and soil samples exceeded US guidance or regulations. Russian canned food ranged from 6 – 1240 mg/kg dry weight, higher than US levels. The study indicated that, although leaded gasoline is banned from sale within Moscow, it is sold elsewhere in Russia. Orlova et al. also showed that sample preparation methods, used in a common Russian geochemical technique to analyze lead in soils, do not use nitric acid digestion and may not be directly comparable to US data. Russian data were up to 2 orders of magnitude lower than US data in split samples. Soil standards in Russia are established at 20 ppm, essentially background levels. However, data appear to be underestimated, by as much as 2 orders of magnitude. Dust levels are not established in Russia. The Russian State Committee on Environmental Protection reported in 1995 that “dust is not considered as a source of lead exposure” due to low levels (Orlova and Wilson 1998).

In this study, many common sources of lead exposure were not sampled and, as Orlova et al. (1995) point out, they may be of special concern in Russia. Leaded gasoline is likely used in the Russian Far East. Supplementing locally grown produce with canned foods may mean both food sources contribute to a resident’s lead burden. Paint and drinking water sources need to be evaluated in the Rudnaya Pristan-Dalnegorsk communities. It is highly likely that dust is a major source of lead exposure at this site.

Comparison to Bunker Hill Superfund Site, Idaho, USA

The US team has had extensive experience at the Bunker Hill Superfund Site (BHSF) in northern Idaho. The Idaho site has interesting parallels with the Rudnaya Valley in the RFE. The mills and smelters were built at approximately the same time and employed similar technologies through much of the century. Both sites are dominated by a major river in complex mountainous terrain. At both sites, residential communities exist in the immediate neighborhood of the industrial facilities.

The Bunker Hill Superfund Site is a large complex project with a long history of childhood lead poisoning, health and environmental investigation, public health response, interim remediation and cleanup actions based on site-specific risk-based criteria. A century of mining and smelting activity resulted in ubiquitous heavy metal contamination of soils and dusts. Typical lead concentrations of wastes and soils within the smelter complex ranged to 100,000 mg/kg (10%) or more. Tailings in the flood plain of the South Fork Coeur d'Alene River exceeded 20,000 mg/kg (2%) lead on average. Residential yard soils in the smelter communities averaged 2500 to 5000 mg/kg in the early 1980's. House dust concentrations averaged 2000 – 4000 mg/kg at that time. During 1973-74, following a fire in the main baghouse and smelter operations without full air pollution control facilities, a severe lead poisoning epidemic in area children occurred. Pre-school children living with one-mile of the complex had mean blood lead levels of 69 ug/dl (IDHW 1975). Following smelter closure in 1981, mean blood lead levels among preschool children remained near 20 ug/dl as excess absorption continued due to soil/dust ingestion. Significant co-factors influencing the soils/dust pathway included parental income, socio-economic status, and education level; home hygiene practices; smokers in the home;

child's nutritional status, use of locally grown produce; play area cover (vegetated vs. exposed); number of hours spent outside the home, pica behavior and child's age. An estimated 80% of the typical child's lead intake was from ingestion of soil and dust sources; approximately 40% from indoor dusts, 30% from home yard soils and 30% from community wide sources (TG 1987).

In the past 16 years, over 4000 children living within the site boundaries have been tested for blood lead levels. An integrated risk management and site cleanup strategy has minimized children's exposures as remediation continues (TG 1990, 1993, 1997, 1998, 2000). Remedial Action Objectives (RAOs) to reduce the incidence of lead poisoning in the community are: (1) less than 5% of children with blood lead levels of 10 ug/dl or greater and (2) no individual child exceeding 15 ug/dl (nominally, <1% of the population) (USEPA 1991a, 1991b, 1992).

These objectives are being achieved by a strategy that includes:

1) Implementation of a comprehensive Lead Health Intervention Program including annual door-to-door blood lead surveys with followup efforts and community education components

2) Remediation of all yards, commercial properties and rights-of-way that have lead concentrations greater than 1000 mg/kg

3) Achieving a geometric mean yard soil concentration of less than 250 mg/kg for each community on the site

4) Controlling fugitive dust and stabilizing and covering contaminated soils throughout the site

5) Achieving mean interior house dust lead levels for each community of 500 mg/kg or less, with no individual house dust level exceeding 1000 mg/kg

Using the lessons learned at the BHSF site is especially valuable in the Russian Far East. Long before Superfund remedies were available, the northern Idaho health department employed low-cost health intervention programs to minimize children's exposures to lead in the community through parental and community education. Although never intended as permanent remedies, many of the strategies were successful and could be applied in the Russian Far East. These include counseling regarding the use of locally grown vegetables, education regarding play activities, evaluation of exposures associated with parental occupations, hobbies and other household activities, evaluation of past or planned remodeling activities, and provision of high efficiency vacuums to homeowners without vacuum cleaners.

Special Challenges

In addition to the typical challenges faced in research of this nature, numerous logistical, scientific and financial challenges unique to the Russian Far East must be overcome. For example, street maps are unavailable for these towns, complicating the usually simple task of identifying and recording sampling locations. Analytical techniques and sample locations are not always described in Russian reports. However, the ethical and social challenges are far greater. From an environmental health perspective, smelter closure might seem the obvious solution as upgrading a 1930's vintage smelter may not be feasible. Until soils lead levels can be reduced, it seems that home gardens should not be used. However, these solutions would worsen overall conditions for community residents. The smelter is the primary employer, home gardens are the major source of food and the economic status of the local residents prohibits them from relocating. As a result of previous Soviet economic policies, the social fabric (housing, medical care, retirement) is intricately linked to the employer. It is likely that only the industry, not the Russian government, can provide the resources to make constructive changes. Following a comprehensive environmental and health survey, the challenges of creating a suitable health intervention strategy, occupational exposure reductions and industrial controls will be formidable.

Conclusions/Future Steps

In the United States, ingestion of contaminated soil and dust is the major cause of lead poisoning in young children (ATSDR 1988, CDC 1991, PHD 1986, TG 1996a). Results of the RFE survey indicate high lead concentrations throughout the soils and roadside dusts in the Rudnaya Pristan - Dalnegorsk area. Preliminary biokinetic projections suggest mean blood lead levels significantly greater than 10 ug/dl, the threshold level identified by the CDC in the US (TG 1990). Children and adults exposed to lead contamination found in Rudnaya Pristan and Dalnegorsk are likely at significant risk of lead poisoning.

This paper was limited primarily to lead in soils. Samples of home garden produce, house dust, paint, water, ambient air and meteorological conditions as well as biological health data (i.e., blood lead concentrations) are needed to indicate where risk management strategies may be applied. An assessment of the industry and the feasibility of modernizing processes and improving emission controls and materials handling is needed. Experiences around the world show that childhood lead poisoning is preventable. Lessons from the Bunker Hill site show that even severe problems can be remedied through a variety of techniques. Applying these findings in the RFE will require strategies that are inexpensive, sustainable and innovative. A better understanding of the environmental and industrial conditions is needed to identify low cost, low maintenance management actions to improve human health in the Rudnaya Valley.

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Table 1. Average annual concentrations (mg/m^3) from Kachur (1996).

Area	**SO_2**	**NO_2**	**CO**	**PM**
Dalnegorsk	0.02	0.04	0.99	0.25
Rudnaya Pristan	0.01	0.03	0.83	0.32

Table 2. Metal concentrations in precipitation near Rudnaya Pristan lead smelter (ug/l) from Kachur (1996)

Zone	Season	Cu	Zn	Cd	Pb	Ag	Sn	Bi	As
1	Summer	29	200	7	4000	3	7	3	12
1	Winter	85	280	6	3000	60	17	50	100
2	Summer	12	70	BDL	850	3	3	BDL	5
2	Winter	20	100	BDL	650	2	8	BDL	12
Background	Summer	1	5	BDL	1	0.1	3	BDL	0.1

zone 1 = within 5 km^2 around smelter

zone 2 = within 20 km^2 around smelter, excluding Zone 1

BDL = below detection level (level not reported)

background = Tierney, un-industrialized town about 150 km north of Rudnaya Pristan

Table 3. Average metals concentrations in hair (ug/g) from Kachur (1996)

Location	**Pb**	**Cd**
Rudnaya Pristan, 1986 Kindergarten Children	9.6	NA
Background Tierney, 1986 Children	0.44	NA
Rudnaya Pristan, 1986 Smelter workers (overall avg.)	286.6	6.7
< 5 yrs. work duration	145.8	NA
5-10 yrs. work duration	127.8	NA
> 10 yrs. work duration	444.4	NA
Background Tierney, 1986 Adults	6.7	0.6

NA = not analyzed

Table 4. Summary of lead and other metals levels (mg/kg) in Rudnaya Pristan and Dalnegorsk

	Lead	Copper	Zinc	Arsenic	Cadmium	Iron (%)
PRG[a]		2900	23,000	0.39	37	2.3
DALNEGORSK						
No. of Samples	12	12	12	12	12	12
Minimum	213	29	593	33	7	0.5
Maximum	5621	805	5438	194	26	3.8
Average	1025	160	1737	101	13	2.6
Standard Deviation	1478	212	1298	40	6	0.8
Geometric Mean	660	103	1442	93	12	2.4
Geometric Std. Deviation	2.3	2.4	1.8	1.5	1.4	1.6
RUDNAYA PRISTAN[b]						
No. of Samples	29	29	29	29	29	29
Minimum	15	20	61	20	5	1.2
Maximum	281926	4256	49392	546	74	4.8
Average	16263	390	5459	113	18	2.5
Standard Deviation	54613	902	11747	122	16	0.9
Geometric Mean	1467	124	1688	78	15	2.4
Geometric Std. Deviation	6.6	3.5	4.4	2.3	1.8	1.4

[a] PRG= preliminary remediation goals (USEPA 1999)

[b] Excludes railroad tie scrapings and battery casing residue

Table 5. Summary of lead levels (mg/kg) in Rudnaya Pristan, Dalnegorsk and Rudnaya Valley

	Lead Concentration (mg/kg)			
	N	**Range**	**x**	**Gx**
Soils				
Residential Gardens				
Rudnaya Pristan	11	476-4310	2095	1626
River Valley	2	128-324	--	--
Dalnegorsk	4	390-1100	741	741
Residential Yards				
Rudnaya Pristan	5	896-4610	2241	1575
Schools/Playground				
Rudnaya Pristan	4	160-1350	553	398
Dalnegorsk	3	772-6080	2589	1626
Railroad				
Rudnaya Pristan	4	24400-95000	59365	49778
Dalnegorsk	1	4390		
Beach				
Rudnaya Pristan	2	610-6200	--	--
Dust				
Roadsides				
Rudnaya Pristan	8	2020-22900	6119	4420
Dalnegorsk	2	510-1250	--	--
Mine Tailings	2	672-1180		
River Bank	9	464-1950	920	824
Other				
Paint Chip	1	7470		
Battery Casing residue	1	293000		
Railroad ties near smelter	1	135000		
Scale house at Rudnaya Pristan port	1	65900		

Arithmetic (x) and geometric (Gx) means are not reported if n<3, indicated by "--"