Environ Monit Assess (2007) 130:57–72
DOI 10.1007/s10661-006-9450-z

Northern Idaho House Dust and Soil Lead Levels Compared to the Bunker Hill Superfund Site

Susan M. Spalinger · Margrit C. von Braun · Varduhi Petrosyan · Ian H. von Lindern

Accepted: 30 June 2006 / Published online: 14 December 2006

Abstract House dust has been identified as a major exposure medium for lead (Pb) in children. High levels of Pb in soil and house dust have been recorded at the Bunker Hill Superfund Site (BHSS) in northern Idaho, an historic mining and smelting district. Soil and dust remediation at the site was required; however, regional background soil and dust Pb levels had not been well characterized. The objective of this survey was to determine background house dust Pb levels and to compare those levels with concentrations, and dust and Pb loading rates measured at the BHSS. Soil and house dust samples were collected in five towns demographically similar to the BHSS but unaffected by the mining industry. The background concentrations and loading rates were significantly lower than those observed at the site. House age was a significant factor affecting background soil and house dust Pb concentrations and loading rates.

S. M. Spalinger (✉) · I. H. von Lindern
TerraGraphics Environmental Engineering Inc.,
121 S. Jackson St., Moscow, ID 83843, USA
e-mail: spalings@tgenviro.com

M. C. von Braun
Environmental Science and Chemical Engineering,
University of Idaho,
Moscow, ID 83844-3006, USA

V. Petrosyan
College of Health Sciences,
American University of Armenia,
Yerevan 375019, Armenia

Keywords Bunker Hill Superfund Site · House dust · Lead · Loading rate · Northern Idaho · Soil

1 Introduction

The most common cause of excess Pb exposure to children is through everyday hand-to-mouth transfer of Pb contaminated dust (HUD, 1995: Lanphear et al., 1998). House dust is an important exposure medium to many environmental pollutants deposited on indoor surfaces from outdoor and internal sources (Adgate, Weisel, Wang, Rhoads, & Lioy, 1995; Butte & Heinzow, 2002; Colt, Zahm, Camann, & Hartge, 1998; Lanphear et al., 1998; Lewis, Fortune, Willis, Camann, & Antley, 1999; Lioy, Freeman, & Millette, 2002; Sayre & Katzel, 1979; Stern, Fagliano, Savrin, Freeman, & Lioy, 1998). Of special concern are young children who crawl and play on carpeted surfaces, where environmental contaminants are deposited. Children are most susceptible to Pb poisoning due to their developing blood-to-brain barriers, higher absorption rates, and frequent hand-to-mouth activity (ATSDR, 1997; CDC, 1991). According to the CDC (1997), Pb poisoning is the most preventable childhood health problem today in the United States.

Scientists have generally agreed that exterior sources, such as soil and street dust, contribute to Pb in residential dust via transfer of the exterior media into the house (Adgate et al., 1995; Butte & Heinzow, 2002; Lanphear et al., 1998; Lioy et al., 2002; Sayre & Katzel, 1979).

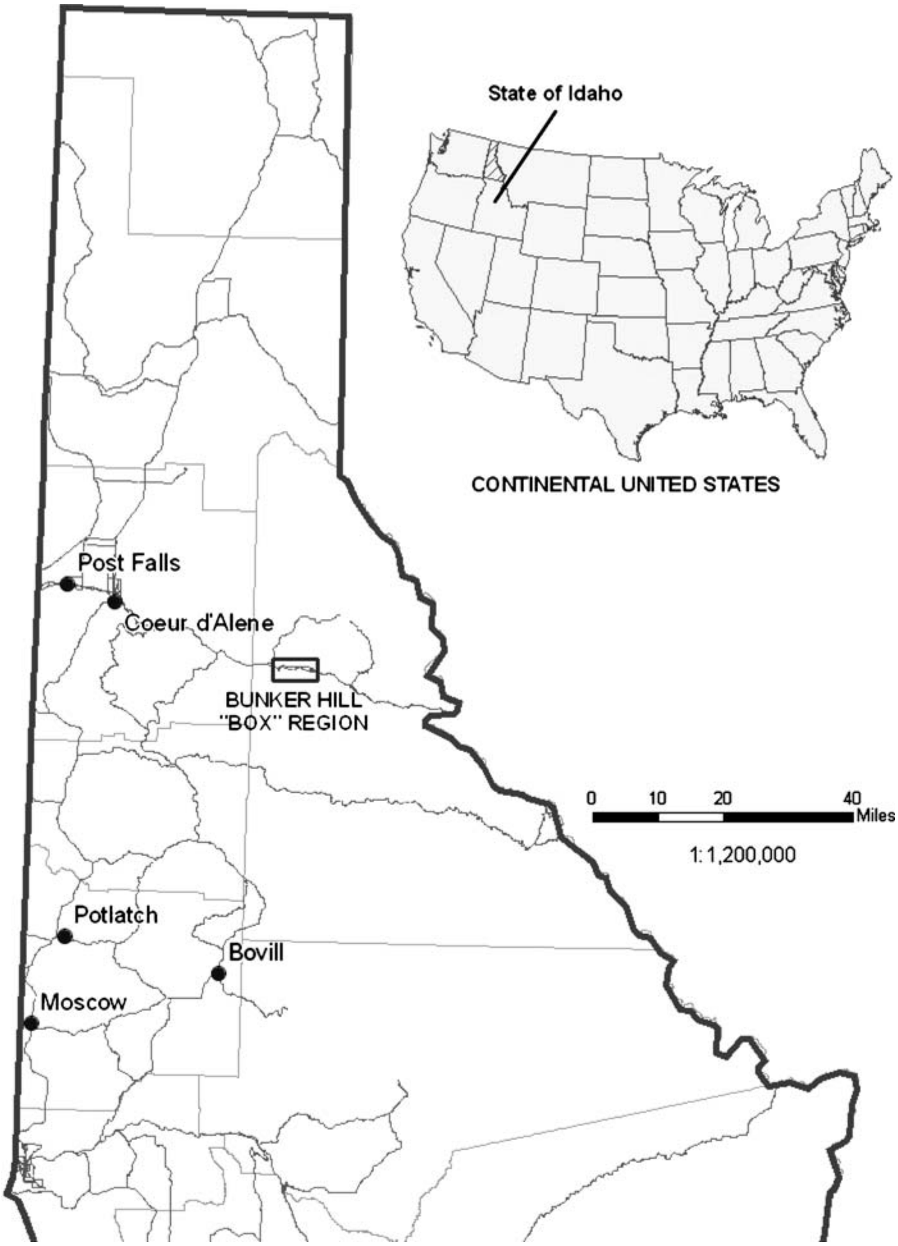


Figure 1 Northern Idaho and the Bunker Hill Superfund Site.

Interior Pb-based paint also contributes to house dust due to chalking and chipping of the paint (HUD, 1995; Marcus & Elias, 1994). Methods used to apportion house dust to exterior or interior Pb-containing sources have recently been applied. Adgate et al. (1998) confirmed findings from other studies that outdoor Pb-containing media (i.e., soils and street dust) are large sources of Pb in house dust. Using a chemical mass balance method, their findings suggest that soil and street dust contribute approximately two-thirds of Pb mass in house dust, while Pb-based paints contribute approximately one-third. Using scanning electron microscopy, results from a study by Hunt, Johnson, Watt, and Thornton (1992), suggested that paint, street dust, and garden soil are the major sources of Pb in house dust. Studies in Christchurch, New Zealand, attributed Pb in house dust to paints (45%), soil (3–5%), street dust (15–20%), and settled aerosols (15–25%) (Fergusson & Schroeder, 1985). The Cincinnati Pb Study showed that 52% of the variation in surface house dust Pb concentrations was due to interior Pb in paint and exterior surface dust Pb (Bornschein et al., 1986). Results from structural equation modeling applied to a ten-year database of the Bunker Hill Superfund Site (BHSS) show that about 20% of the variation in dust Pb concentration is explained by yard soil, city soil, and neighborhood soil (within approximately a 60-m (200 ft) radius of the house) (TerraGraphics, 2000). A linear regression model of the data used in the Coeur d'Alene River Basin risk assessment showed that yard soil, interior paint condition, and community soil concentrations are responsible for nearly 50% of the variation in floor mat dust Pb concentrations (TerraGraphics, 2001).

Many difficulties have arisen while investigating the Pb component in household dust. One reason is that house dust, a heterogeneous mixture of sources, is usually not uniformly dispersed (Hunt et al., 1992). Bero, von Braun, von Lindern, Hammel, and Korus (1997) showed that carpet type and soil particle components affected the Pb distribution and dust removal efficiencies on carpeted surfaces. Exposure to Pb-contaminated house dust is of special concern in areas where mining, smelting, or recycling of Pb has occurred due to excess Pb mass found in these areas (Landrigan & Baker, 1981; Murgueytio, Evans, & Roberts, 1998; Roberts et al., 1974; Yankel, von Lindern, & Walter, 1977).

1.1 Bunker hill mining district

The BHSS encompasses the former Bunker Hill Company Pb/zinc mining and smelting complex and the approximate surrounding 34 square-kilometer (21 square-mile) area. Located in Shoshone County in northern Idaho, the BHSS contains the towns of Kellogg, Smelterville, Pinehurst, Wardner, and Page whose combined populations total over 7,000 (Figure 1). Approximately 4.5 square-kilometers (1,100 acres) of the site lie in the floodplain of the South Fork of the Coeur d'Alene River (TerraGraphics, 1999). The BHSS was placed on the National Priorities List on September 8, 1983.

Over a century of mining wastes and 75 years of smelter emissions left the BHSS contaminated with metals and metalloids. Contaminants of concern include antimony, arsenic, cadmium, copper, Pb, mercury, and zinc. Pb is of primary concern at the site and serves as an indicator of metal exposure (PHD, 1986; TerraGraphics, 2000; von Lindern, Spalinger, Bero, Petrosyan, & von Braun, 2003). During 1973–1974, the smelter operated without proper air pollution control equipment following a fire in the main baghouse. Resulting smelter emissions caused high air Pb levels and deposition of fine Pb particulates into area soils and dusts. Pb poisoning occurred at unprecedented levels in the early 1970s due to air, soil, and dust exposures (TerraGraphics, 1997; Yankel et al., 1977). In those years, the blood Pb levels of children living within approximately a 1.5-km (1 mile) radius of the smelter averaged nearly 70 μg/dl (compared to the CDC action level at that time of 40 μg/dl). Those same children breathed an average air Pb concentration of approximately 17 μg/m^3; played on yard soil with Pb concentrations of 7,400 mg/kg; and lived with house dust Pb concentrations of nearly 12,000 mg/kg (IDHW, 1976; TerraGraphics, 1997).

In 1983, when Bunker Hill became a Superfund site, children residing in the BHSS communities had average blood Pb levels of 16 μg/dl. These same children had environmental exposures averaging nearly 2,800 mg/kg Pb in their yard soils and 2,700 mg/kg Pb in their house dust. When the smelter closed in 1981, emissions ceased and BHSS air Pb levels fell below the national ambient air quality standard (NAAQS) of 1.5 μg/m^3. By 1983, air Pb levels averaged 0.18 μg/m^3 (TerraGraphics, 1997, 1999).

The blood Pb action level, set by the Centers for Disease Control (CDC), was decreasing (from 30 μg/dl in 1975, to 25 μg/dl in 1985, and to 10 μg/dl in 1991) as remedial progress at the BHSS was being made (CDC, 1991). Although 10 μg/dl is the current CDC's action level, significant discussion of lowering this level is ongoing as research suggests there is no margin of safety (Lanphear, Dietrich, Auinger, & Cox, 2000). The Remedial Action Objectives (RAO) at the site, with respect to Pb absorption, and soil and dust Pb levels, were based on the Remedial Investigation/Feasibility Study (RI/FS) and established in the Record of Decision (ROD) for the populated areas (USEPA, 1991). The RAOs aimed at reducing Pb poisoning in the community are as follows (USEPA, 1991):

- Less than 5% of children with blood Pb levels of ≥10 μg/dl

- No individual child exceeding 15 μg/dl (nominally less than 1% of the population)

The RAOs for residential soils and dusts in the BHSS are as follows (USEPA, 1991):

- Remediate all residential yards, commercial properties, and rights-of-way (ROWs) that have Pb concentrations >1,000 mg/kg
- Achieve a geometric mean yard soil concentration <350 mg/kg for each community on the BHSS
- Control fugitive dust and stabilize and cover contaminated soils throughout the BHSS
- Achieve mean interior house dust Pb concentrations of 500 mg/kg or less for each community, with no individual house dust Pb level exceeding 1,000 mg/kg

Ultimately, the success of soil remediation will depend on achieving blood Pb RAOs and reducing house dust Pb concentrations to levels below the RAO. Significant decreases in exposure have been observed in yard soils and house dusts at the BHSS due to residential yard and public and commercial soil clean-ups. The site-wide geometric mean blood Pb level of 2.6 μg/dl in 2002, reflects the decreased exposure (TerraGraphics, 2004).

Attempts to remediate the interior of residential houses in the BHSS were deemed unsuccessful in 1990. Six houses were chosen for remediation of carpets, rugs, and upholstered furniture. Carpets contained most of the Pb mass. However, vacuuming and shampooing indicated that substantial removal of Pb from carpets was not achieved (CH2M Hill, 1991).

Soil remediation efforts are near completion in Kellogg, Wardner, Page and Pinehurst. Remediation of all residential yards and commercial/right-of-way properties was completed in Smelterville in 1997. In 1998, Smelterville achieved the soil RAO, averaging 148 mg/kg (geometric mean) with no houses exceeding 1,000 mg/kg. However, dust Pb concentrations averaged 570 mg/kg (geometric mean), with 10% of the houses exceeding 1,000 mg/kg (TerraGraphics, 1999). In 1999, the Smelterville house dust geometric mean was still 595 mg/kg, with 30% of the homes exceeding 1,000 mg/kg (TerraGraphics, 2000).

It was not known if dust Pb concentrations at the BHSS could be reduced to those outlined in the RAOs. In Smelterville, where soil remediation was complete and soil RAOs were met, dust Pb concentrations remained in excess of 500 mg/kg. Lessons learned from Smelterville are important for the other BHSS communities where soil remediation continues. Because regional background dust Pb levels were not well known for northern Idaho, the purpose of this survey was to collect dust samples from houses outside the BHSS, unaffected by the mining industry.

The specific objectives of this survey were:

1. To determine background Pb concentrations in house dust and residential soils for northern Idaho.
2. To evaluate underlying factors contributing to house dust Pb concentrations.
3. To compare the background house dust Pb concentrations to those found at the BHSS.

2 Methods and Materials

2.1 Survey population and survey area

Demographic data from the 1990 U.S. Census were obtained by city and census block groups for northern Idaho towns within and outside the BHSS. Factors compared to the towns in the BHSS included total population, percentage of people having a high school degree, per capita income, percentage of people below poverty level, percentage of houses built from 1980–1990, percentage of houses built from 1960–1979, and percentage of houses built before 1960.

Star plots were used to contrast these variables between towns and census block groups using the Statistical Analysis System (SAS) (version 6.12). The plots illustrate multivariate observations with a star-shaped figure. Each ray of the star represents a different variable, while the ray length is proportional to the size of that variable (Friendly, 1999; Johnson, 1998). The star plots were examined first by town, and then by census block groups. Towns and census block groups similar to the BHSS towns of Smelterville, Kellogg, and Pinehurst were selected as sampling locations. Areas in larger towns, demographically opposite of the BHSS towns, were also chosen to identify underlying factors contributing to house dust Pb levels.

Table I summarizes the socio-economic characteristics used from the 1990 U.S. Census (U.S. Census

Table I 1990 census data for northern Idaho towns chosen as background and BHSS towns (US census bureau CD and maps, 1997)

Area[a]	Total population	Percent having a high school degree	Per-capita income	Percentage below poverty	Percentage of homes built before 1960	Percentage of homes built from 1960–1979	Percentage of homes built from 1980–1990
Background Towns							
Bovill[b]	238	76	9,141	29	75	16	8
Coeur d'Alene[c]	24,566	81	12,107	14	41	42	17
Moscow[c]	18,519	92	10,204	23	41	44	15
Post Falls[c]	7,349	78	10,135	11	15	56	29
Potlatch[b]	831	73	9,724	14	78	15	7
BHSS Towns							
Kellogg	2,591	69	9,407	23	76	22	3
Pinehurst	1,722	70	9,858	15	42	53	6
Smelterville	442	63	8,618	29	78	22	0

[a] Data shown by town and not census blocks.

[b] Town chosen as demographically similar to the BHSS towns.

[c] Town or area of town chosen as demographically opposite to BHSS towns.

Bureau, 1997). In general, characteristics of the BHSS towns (Smelterville, Pinehurst, Kellogg, etc.) are small, rural populations (<3,000 people), with 60% to 70% having at least a high school degree, low per-capita income (<$9,900), higher poverty rates, and older houses, mostly built before the 1980s. Bovill, Coeur d'Alene, Moscow, Post Falls, and Potlatch were the five background towns selected from the star plots (Figure 1). Bovill and Potlatch were selected because characteristics were similar to Smelterville and Pinehurst, respectively. Coeur d'Alene and Moscow were chosen because they contained census blocks with both similarities and differences to the BHSS (separate census block data are not shown in Table I). In order to evaluate underlying characteristics (e.g., house age, paint condition) that may contribute to dust Pb concentrations, Post Falls was selected because of its dissimilarities. Post Falls has a low percentage of the population below poverty and higher per-capita income than the BHSS towns and contains a smaller proportion of houses built before 1960.

Because housing age and type, and other socio-economic characteristics are often similar within a neighborhood, 50 houses were chosen randomly from different neighborhoods throughout each town to avoid data clustering. House locations are not provided to ensure homeowner confidentiality. Participation was entirely voluntary.

2.2 Environmental sampling methods

Three types of environmental samples were collected during the months of March–May, 1999:

- A vacuum cleaner dust sample to quantify Pb concentrations in house dust;
- A floor mat to determine Pb concentration and loading rate into the home during daily activities; and
- A composite yard soil sample to determine possible outdoor sources of Pb.

The sampling methods and procedures followed for this survey are those used at the BHSS in monitoring activities (TerraGraphics, 1999). Once a block or part of town was selected for sampling, door-to-door soliciting began. If the resident/renter refused to participate, solicitation continued at the next house. If a resident/renter agreed to participate, (s)he would sign a consent form. The vacuum bag was collected and the floor mat was placed with directions. The resident/renter completed a questionnaire while yard soil samples were collected. Once sampling was finished, the entire procedure was repeated in a new block of the town. Sampling was not performed if the participant's vacuum cleaner was used anywhere outside of the house (as explained in the vacuum sampling procedure below).

Pb analysis was performed by Maxim Technologies, Inc., Montana, in accordance with USEPA "Contract Laboratory Program Statement of Work for Inorganics Analysis" ILM04.0, method number 200.7 (USEPA, 1995c). All samples were sieved to the minus 80 standard mesh fraction (178 μm) for direct comparison to samples collected at the BHSS (TerraGraphics, 1999). A confidence level of alpha equal to 0.05 was used for all statistical tests. Quality assurance / quality control (QA/QC) samples, such as field duplicates and field splits, were collected, and the laboratory performed QA/QC such as method blanks, matrix spikes/matrix spike duplicates and laboratory control samples.

2.2.1 Vacuum dust samples

House dust collection methods have not been standardized, with the exception of the HUD dustwipe methodology used for dust sampling and post abatement clearance for Pb-based paint (Adgate et al., 1995; USEPA, 1995a, 2001). Vacuum bag samples have been collected from homeowners' personal vacuums at the Bunker Hill site since the early 1970s and represent a substantial portion of the BHSS database. Vacuum bag samples were collected for historical comparisons.

The vacuum dust sample provides a general representation of Pb exposure to individuals inside the house. Therefore, verification that the homeowner's personal vacuum had not been used anywhere outside the house since the vacuum bag was last changed was the first criterion to be met before the vacuum bag was collected. If the criterion was met, the vacuum cleaner was taken outside and either the entire bag was collected or the contents were emptied into a sample container for analysis, regardless of whether the home was carpeted or contained hard floors.

2.2.2 Floor mat dust samples

The floor mat dust collection method was developed for the BHSS and the Coeur d'Alene River Basin Environmental Health Exposure Assessment in 1996 by the U.S. Environmental Protection Agency (USEPA), Panhandle Health District (PHD), the Idaho State Department of Health and Division of Environmental Quality, and the Agency for Toxic Substances and Disease Registry (ATSDR) (TerraGraphics, 1999; TerraGraphics and PHD, 1996). The floor mat dust collection method measures Pb concentration and Pb loading rates (mass/area/time). Dust mats are manufactured by Arko™; the 'Floor Sentry' model is the same model used throughout the BHSS. The mat area is 0.318 square meters (17 by 29 in.). These mats consist of short fiber carpeting with a vinyl backing.

The carpeted floor mat was placed at all participating houses to quantify Pb concentration, Pb loading rate, and dust loading rate. Each mat was placed inside the entry of primary use. Directions on handling the mat (i.e., no vacuuming, sweeping, or moving it around) while placed were provided orally with a written instruction sheet.

The mats were collected from the residence approximately 2 months after placement and handled in a manner so that sample volume was not compromised. All mats were placed into a clean paper envelope and kept flat, fiber side up. They were sealed in boxes at all times prior to sample processing.

The mats were vacuumed for dust collection at a University of Idaho dust-free laboratory. This laboratory was previously used to evaluate vacuuming techniques and carpet types for detecting Pb contamination (Bero, 1994; Bero et al., 1997). Mats were vacuumed by direct contact with the nozzle, from right to left over the entire mat and its vinyl edges, and repeated from top to bottom. Any areas on the mat with remaining visible dust were vacuumed again in the same manner. The mat was then turned over (fiber side down) on the envelope; the back of the mat was struck with a series of blows with a wooden rod (this causes a substantial portion of the remaining soil to fall onto the surface of the envelope). Finally, the surface of the envelope was vacuumed to remove any visible dirt or dust that fell from the mat during the procedure. The recovered dust mass was recorded for each mat vacuumed. The recovered dust mass divided by the area of the mat and the number of days the mat remained at the home provides the dust loading rate, which is then multiplied by lead concentration of the dust to provide the lead loading rate.

2.2.3 Soil samples

Yard soil sample collection consisted of one core subsample for approximately every 150 square meters (500 square feet) of yard. The sample was collected as close to the middle of each approximate measured 150 square meter section as possible. The core samples were obtained from the 0–2.54 cm (or 0–1 in.) layer

Table II Dust and soil lead concentration summary statistics for background towns

	No. of samples	Arith. mean	Std. dev.	Min	Max	Geo mean	Geo std. dev.
Soil (mg/kg)							
Bovill	10	144	139	39	525	112	2.0
Coeur d'Alene	10	59	55	BL[a]	180	38	2.8
Moscow	10	43	42	BL[a]	130	24	3.5
Post Falls	10	70	75	BL[a]	260	45	2.8
Potlatch	10	81	77	20	270	58	2.3
All towns	50	79	88	BL[a]	525	48	2.9
Vacuum dust (mg/kg)							
Bovill	9	145	89	38	337	123	1.9
Coeur d'Alene	10	237	236	58	676	152	2.7
Moscow	10	180	258	BL[a]	830	83	4.0
Post falls	10	172	216	20	748	102	2.8
Potlatch	10	197	125	48	433	156	2.2
All towns	49	187	192	BL[a]	830	120	2.7
Floor mat dust (mg/kg)							
Bovill	8	112	153	22	483	69	2.5
Coeur d'Alene	10	261	379	BL[b]	1,280	130	3.3
Moscow	10	157	280	21	924	68	3.3
Post falls	9	135	88	51	305	112	1.9
Potlatch	10	131	78	32	292	109	2.0
All towns	47	162	229	BL[b]	1,280	95	2.6
Dust loading rate (mg m^{-2} day^{-1})							
Bovill	8	1,373	993	306	3,403	1,076	2.2
Coeur d'Alene	10	704	1,154	12	3,840	265	4.9
Moscow	10	410	361	115	1,315	315	2.1
Post falls	9	403	348	96	1,173	301	2.2
Potlatch	10	1,239	2,470	53	8,001	326	5.1
All towns	47	812	1,347	12	8,001	374	3.5
Lead loading rate (mg m^{-2} day^{-1})							
Bovill	8	0.157	0.257	0.019	0.781	0.074	3.220
Coeur d'Alene	10	0.303	0.583	0.000	1.523	0.058	0.096
Moscow	10	0.141	0.378	0.003	1.215	0.022	5.334
Post falls	9	0.064	0.083	0.010	0.221	0.034	3.076
Potlatch	10	0.125	0.211	0.004	0.651	0.036	5.395
All towns	47	0.160	0.348	0.000	1.523	0.040	4.759

BL=Below Practical Quantitation Limits (PQL) (lead concentrations, if present, were not quantifiable; half the PQL is used for all means and statistics).

[a] PQL is <10 mg/kg.

[b] PQL is <50 mg/kg.

of soil and combined into a single composite sample for the house. Sod and vegetation, if present, were removed from the top centimeter(s) of the sample. Samples taken under or adjacent to trees, shrubs, structures, driveways, and sidewalks were avoided.

2.3 Questionnaire

In addition to collecting environmental samples, the head of the household at each participating residence was asked to complete a questionnaire. The same questionnaire was used for the BHSS and the Coeur d'Alene River Basin Environmental Exposure Assessment (TerraGraphics, 2000). The factors used for the background analysis include the number of people residing in the home, age of the house, interior remodeling of the house, and interior and exterior paint conditions. Interior and exterior paint conditions are subjective factors as they were based on the sampler's observations. Three codes were used: 1=good condition, 2=some chipping, and 3= chipping and chalking of the paint.

3 Results

3.1 Dust and soil lead concentrations/loading rates

Vacuum, floor mat, and soil Pb concentrations, and the dust and Pb loading rates for the 50 houses sampled in the five towns are summarized in Table II. Soil data were collected from all 50 houses; vacuum bags were collected at 49 of the 50 houses. At one house, the vacuum sample was not collected because after the resident agreed to participate and soil sampling began, it was discovered that the vacuum cleaner was unavailable. Forty-seven of the 50 (94%) mats placed were collected; three of the participants had discarded the mat. All QA/QC analysis by the laboratory fell within quality control measurements. The overall soil Pb geometric mean concentration was 48 mg/kg; the overall vacuum dust Pb geometric mean concentration was 120 mg/kg; and the overall floor mat Pb geometric mean concentration was 95 mg/kg. The floor mats provide additional information on the rate at which dust and Pb enters the home. Mats collected dust for an average of 61 days, and collected approximately 16 g of dust. The overall geometric mean dust loading rate was 374 mg m^{-2} day^{-1}, while the overall Pb loading rate was 0.040 mg m^{-2} day^{-1} geometric mean.

To explore the relationship between dust and outdoor yard soil Pb concentrations, correlations were performed on the log-transformed variables. Log-transformations were used to correct for non-normal distributions. The correlation between vacuum and soil Pb concentration was 0.42, while the correlation between floor mat and soil Pb was 0.53. Both correlations are significant (all P-values <0.003). Vacuum bag and floor mat Pb concentrations were also significantly correlated (r= 0.63, P<0.0001).

3.2 Factors affecting background house dust

House age categories were used in the analysis and chosen based upon *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* (HUD, 1995). No clear cut-off date exists for Pb in paint. Use of Pb in residential paint was phased out beginning in the 1960s. It was first regulated in 1972 to 0.5% Pb dry weight, and banned in 1978 to 0.06% Pb dry weight or less (HUD, 1995). To preserve quality in the cutoff date for house age, yet maintain sufficient observations between old and new houses, two house age categories were used to analyze the data – houses built prior to 1960 and houses built in 1960 or after.

Variables analyzed were observational in nature; therefore, unbalanced analysis of variance (ANOVA) was performed on the natural log of the five variables (soil, vacuum, and floor mat Pb concentrations, and dust and Pb loading rates). Log-transformations were applied to the data to correct for non-normal residuals and homogeneity of variance. A paired t-test showed a significant difference (P=0.03) in Pb concentrations between the two methods of collecting house dust (vacuum bag versus floor mat). Therefore, the two lead dust concentrations were evaluated separately in the following analyses.

For the background towns, ANOVA was used to determine if Pb concentrations varied demographically and among different house ages. When two factors are analyzed in ANOVA, a significant interaction between the two factors means that the effect of one factor is not independent of the presence of a particular level of the other factor, causing difficulty in isolating the effects of the two factors. Therefore, the significance of the interaction term is provided throughout the results in order to point out which factors are more difficult to interpret. No significant interaction occurred between towns and house age (P=0.4), and no significant differences were observed between towns (P=0.1) except for soil Pb concentrations (P=0.03). A multiple comparison test (using Tukey's method) showed Bovill with significantly higher soil Pb concentrations than Moscow, Post Falls, Coeur d'Alene, and Potlatch. Four of the five variables (floor mat, vacuum, and soil Pb concentrations, and Pb loading rates) showed a significant difference between the two house age categories (all P-values <0.0007). No significant difference existed between house age categories for dust loading rate (P=0.06).

Older houses showed higher Pb concentrations and loading rates, but also contained more variability (Table III). For further statistical analyses, all towns were collapsed into one data set, keeping house age categories separate. In the soil Pb concentration comparison of the background data to the BHSS data,

Table III Summary statistics by house age

	No. of samples	Arith. mean	Std. dev.	Geo. mean	Geo. std. dev.
Soil lead concentration (mg/kg)					
Houses built <1960	29	112.9	101.3	85.1	2.1
Houses built ≥1960	21	33.1	29.7	22.3	2.6
Vacuum lead concentration (mg/kg)					
Houses built <1960	28	263.1	219.1	192.9	2.2
Houses built ≥1960	21	85.4	67.9	63.5	2.4
Floor mat lead concentration (mg/kg)					
Houses built <1960	27	229.8	281.5	143.3	2.6
Houses built ≥1960	20	70.0	56.4	54.6	2.0
Dust loading rate (mg m^{-2} day^{-1})					
Houses built <1960	27	1,151.2	1,665.1	559.1	3.6
Houses built ≥1960	20	353.0	464.4	217.1	2.8
Lead loading rate (mg m^{-2} day^{-1})					
Houses built <1960	27	0.265	0.433	0.080	4.962
Houses built ≥1960	20	0.018	0.014	0.015	2.156

soil data for Bovill were removed based on Bovill's significantly different Pb concentration. Because Bovill was covered in approximately in 1–1.5 m (4–5 ft) of snow when soil sampling occurred, it was difficult to collect samples from the middle of the yard. Therefore, samples were sometimes collected nearer to the sidewalk or house. This may have biased the soil samples collected from Bovill, which is why those data were removed from the soil comparison analysis.

The number of people residing in the home significantly affected Pb loading rate only (P= 0.007). No significant interactions were observed between house age and the number of people residing in the home (all P-values >0.07). When more than four people reside in a house, Pb loading rate increases almost four times over that when less than four live in the house. In houses built prior to 1960, Pb loading rate is 0.2 mg m^{-2} day^{-1} when four or less people reside in the house; it increases to 0.7 mg m^{-2} day^{-1} when more than four people reside in the house.

No significant differences were observed between poor and good inside paint conditions (all P-values >0.1). Poor conditions were condition codes 2 and 3, while good condition was based on code 1. No significant interactions occurred (all P-values >0.1). Differences between house age categories became less distinct in dust and Pb loading rates. However, only one house built in or after 1960 was observed as having poor paint conditions.

No significant differences in dust and Pb loading rates exist between poor and good outside paint conditions (all P-values >0.06). House age differences were not significant (P>0.1) except for Pb loading (P=0.03). However, like inside paint condition, only one observation for a house built in or after 1960 was observed as having poor paint conditions.

Whether or not a house had been remodeled showed a significant difference for dust loading rate only (P=0.01). No significant interactions were observed (P≥0.08). Remodeled houses show lower dust loading rates than houses that have not been remodeled. Although not statistically different (P= 0.06), older houses (built before 1960) exhibited 1.5–2.5 times higher vacuum and floor mat Pb concentrations for remodeled houses than for houses that had not been remodeled. Geometric mean mat and vacuum Pb concentrations for older homes that were not remodeled were 78 and 153 mg/kg, respectively. These concentrations increase to 194 and 224 mg/kg, respectively when older homes have recently been remodeled.

3.3 Bunker hill towns versus background towns

The BHSS data used in the comparison analyses to background data are shown in Table IV. The total number of observations in the 1998 Bunker Hill data decreased because only houses with questionnaire data were used. The geometric mean soil Pb concentration was 245 mg/kg. The geometric mean vacuum dust lead concentration for Kellogg, Pinehurst, and

Table IV Summary statistics of 1998 Bunker hill data used for comparison analysis

	No. of samples	Ave	Std. dev.	Min	Max	Geo mean	Geo std. dev.
Soil (mg/kg)							
Kellogg	158	840	1,389	100	7,910	265	4.2
Pinehurst	22	493	369	37	1,850	383	2.2
Smelterville	40	213	334	100	2,060	140	2.1
All towns	220	691	1,216	37	7,910	245	3.7
Vacuum dust (mg/kg)							
Kellogg	15	786	494	180	2,000	657	1.9
Pinehurst	15	523	504	71	2,000	354	2.6
Smelterville	3	430	269	120	600	345	2.5
All towns	33	634	493	71	2,000	468	2.3
Floor mat dust (mg/kg)							
Kellogg	161	1,846	3,221	130	29,000	1,184	2.2
Pinehurst	28	701	744	160	4,040	529	2.0
Smelterville	41	985	504	224	2,320	923	1.8
All towns	230	1,553	2,751	130	29,000	1,026	2.2
Dust loading rate (mg m^{-2} day^{-1})							
Kellogg	161	440	677	34	4,629	249	2.72
Pinehurst	27	961	1,014	41	4,037	573	3.00
Smelterville	41	562	688	68	3,522	345	2.58
All towns	229	523	742	34	4,629	291	2.82
Lead loading rate (mg m^{-2} day^{-1})							
Kellogg	161	1.260	5.442	0.020	51.250	0.294	3.885
Pinehurst	27	0.707	1.030	0.020	3.590	0.297	3.858
Smelterville	41	0.484	0.524	0.040	2.720	0.317	2.514
All towns	229	1.056	4.589	0.020	51.250	0.298	3.614

Smelterville was 468 mg/kg. The geometric mean floor mat Pb concentration was 1,026 mg/kg. Dust and Pb loading rates at the site averaged 291 and 0.298 mg m^{-2} day^{-1}, respectively.

Unlike the background data, no significant differences exist in the Bunker Hill data between house age categories for any of the five variables (P=0.2). There were also no significant interactions between town and house age (P=0.07). Floor mat and vacuum Pb concentrations and dust loading rate exhibited significant differences between towns (P<0.04). Multiple comparisons showed Pinehurst was significantly different from Kellogg and Smelterville. Soil Pb concentrations and Pb loading rates showed no difference between towns (P>0.05). Smelterville, Kellogg and Pinehurst were each compared to the background survey, although Pb loading rate showed no significant difference between the BHSS towns.

Dust Pb concentrations in Smelterville were 3–14 times higher than background concentrations (P< 0.02) with both vacuum and floor mat methods (Figure 2a–b). Vacuum Pb concentration (Figure 2a) did not show a significant interaction between town and house age; however, floor mat Pb concentrations did (P=0.04). All subsequent references to significant or non-significant interaction refer to the two factors of house age and town. Figure 2b shows that newer houses in background towns (55 mg/kg) exhibit approximately 30% of concentrations in older houses (143 mg/kg), while Smelterville concentrations in newer houses (755 mg/kg) are about 60% of those in older houses (1,028 mg/kg). Figure 2c shows significantly higher Pb loading rates in Smelterville than in background towns. Pb loading rate also showed a significant interaction (P=0.0002). However, Pb loading rates in Smelterville are significantly higher in newer houses (0.4 mg m^{-2} day^{-1}) as opposed to old homes (0.32 mg m^{-2} day^{-1}); an opposite trend is seen in the background data. Dust loading rates were not significantly different between house age and town, but there was a significant interaction (P=0.002) (Figure 2d). Background towns have higher dust loading rates than Smelterville for older homes, while Smelterville's loading rates increase for newer homes but decrease for the background towns. Soil Pb concentrations also had a significant interaction (P= 0.0001). However, a significant difference between Smelterville's soil concentrations and background towns was observed (P=0.0001). While yard soil concentrations of newer homes in background towns are lower than those of older homes, soil concentrations increase for newer homes in Smelterville (Figure 2e).

Floor mat and vacuum Pb concentrations and Pb loading rates are significantly higher in Kellogg than in background towns (P<0.0001) (Figure 2a–b). However, significant interactions exist (P<0.02). Kellogg dust Pb means are significantly higher than background, with no significant differences between ages of Kellogg homes (Figure 2a–b). Figure 2c shows Kellogg also has significantly higher Pb loading rates than background levels. No significant difference between background and Kellogg levels is observed for dust loading rate (P=0.2). Dust loading rate also shows a significant interaction (P=0.002) because background levels in older houses are higher than in Kellogg and decrease to levels below those in newer houses in Kellogg (Figure 2d). The same trend observed in the vacuum and floor mat data is also noticeable in the soil Pb concentrations. A significant interaction occurred (P=0.005), but yard soil Pb concentrations are significantly higher in Kellogg compared to background towns (P=0.0001) and no difference is observed between house ages in Kellogg data (Figure 2e).

Significant differences were observed between Pinehurst dust Pb concentrations and background concentrations (P<0.0001) (Figure 2a–b). Floor mat Pb was the only variable to have a significant interaction (P=0.03). However, Figure 2b shows that, while background concentrations decrease with house age, Pinehurst concentrations increase slightly with house age. Figure 2c shows significant differences in Pb loading rate between Pinehurst and background towns (P<0.0004). Dust loading rates seen in Figure 2d are not significantly different between Pinehurst and background towns (P>0.12). Figure 2e illustrates the significant differences observed in soil Pb concentrations between the two sites (P=0.0001).

4 Discussion

4.1 Dust and soil lead concentrations/loading rates

The northern Idaho background house dust concentrations are very similar to those reported in a Washington State Department of Health (WSDH) survey that targeted homes built before 1960, households with children less than 3 years old, and households with incomes below the poverty level (WSDH, 1997). The WSOH focused its survey on larger cities throughout Washington and used different sampling methods than those used at Bunker Hill. Although house dust samples were collected by a different method (wipe), the geometric mean Pb concentration in Spokane, Washington was 201 mg/kg.

Outdoor soil is a known source of house dust. The scatter plots and correlations observed between yard soil and house dust Pb concentrations suggest a positive linear trend when log transformed. Soil Pb concentrations had a stronger relationship with floor mat concentrations than with vacuum Pb concentrations. This would be expected because of the nature of the sampling methods. Floor mats measure more of what is entering the home from the main entrance, than do vacuums, which represent a composite, or average, Pb concentration throughout the home. The vacuum method is largely uncontrolled with respect to personal use patterns, but has been used at Bunker Hill since the early 1970s. Therefore, it might be expected that the floor mat Pb concentrations are more highly correlated with outdoor soil concentrations.

Vacuum bag Pb concentrations tend to be higher than floor mat Pb concentrations in the background survey. The opposite trend is seen in Bunker Hill data; floor mat Pb concentrations tend to be higher than vacuum bag Pb concentrations. This result supports the idea that outside sources more significantly affect the floor mat in Bunker Hill than do interior Pb-based paint sources. Higher outdoor Pb concentrations are being brought indoors at Bunker Hill, where more outdoor Pb contamination exists, than interior Pb-based paint sources typical of older housing throughout northern Idaho.

4.2 Factors affecting background house dust

House age was the most significant questionnaire factor analyzed, influencing not only dust Pb concen-

Figure 2 (a) Geometric mean vacuum lead concentrations for background and Bunker Hill towns by house age (95% confidence limits = I). (b) Geometric mean floor mat lead concentrations for background and Bunker Hill towns by house age (95% confidence limits = I). (c) Geometric mean lead loading rates for background and Bunker Hill towns by house age (95% confidence limits = I). (d) Geometric mean dust loading rates for background and Bunker Hill towns by house age (95% confidence limits = I). (e) Geometric mean soil lead concentrations for background and Bunker Hill towns by house age (95% confidence limits = I).

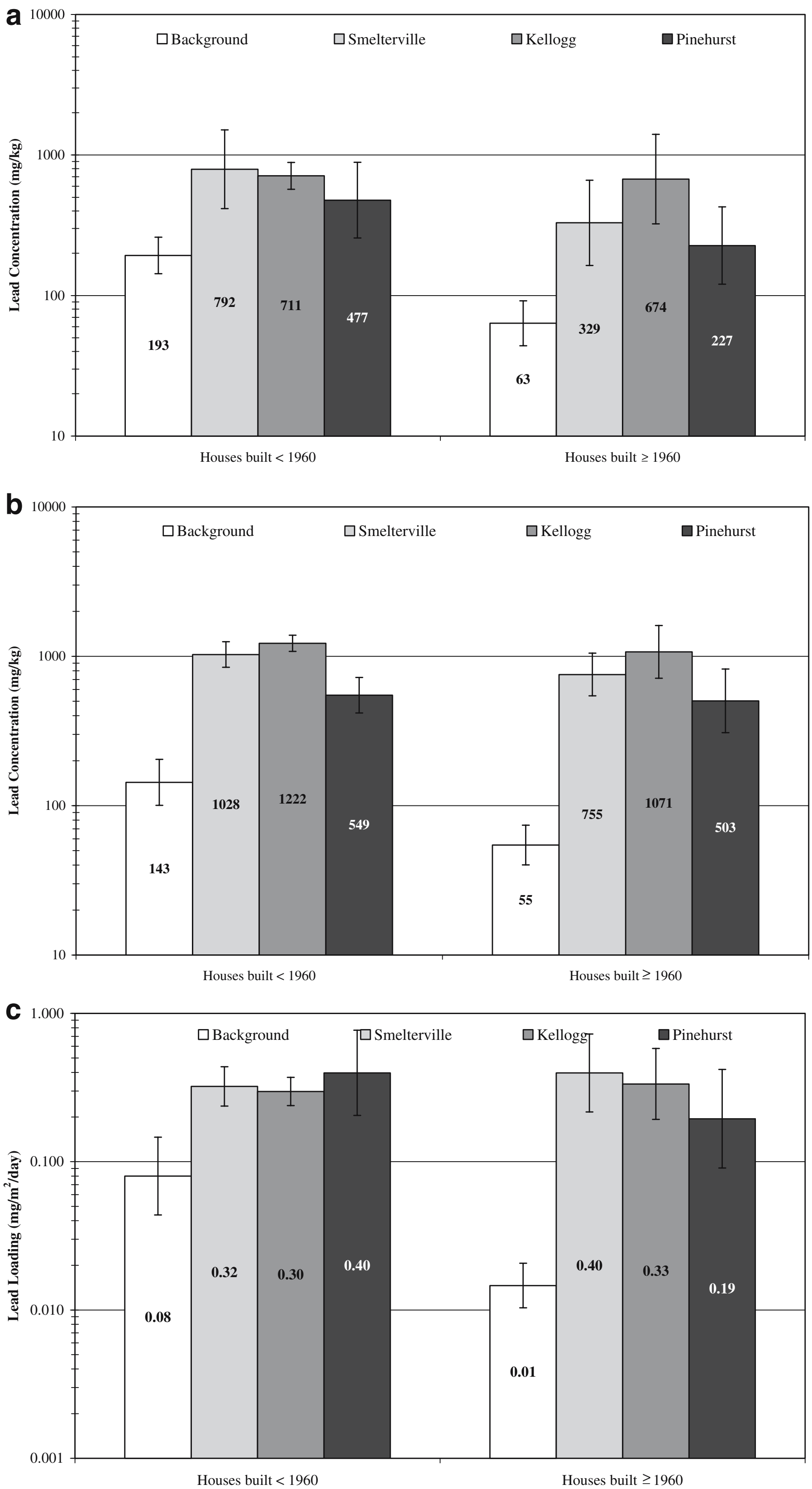
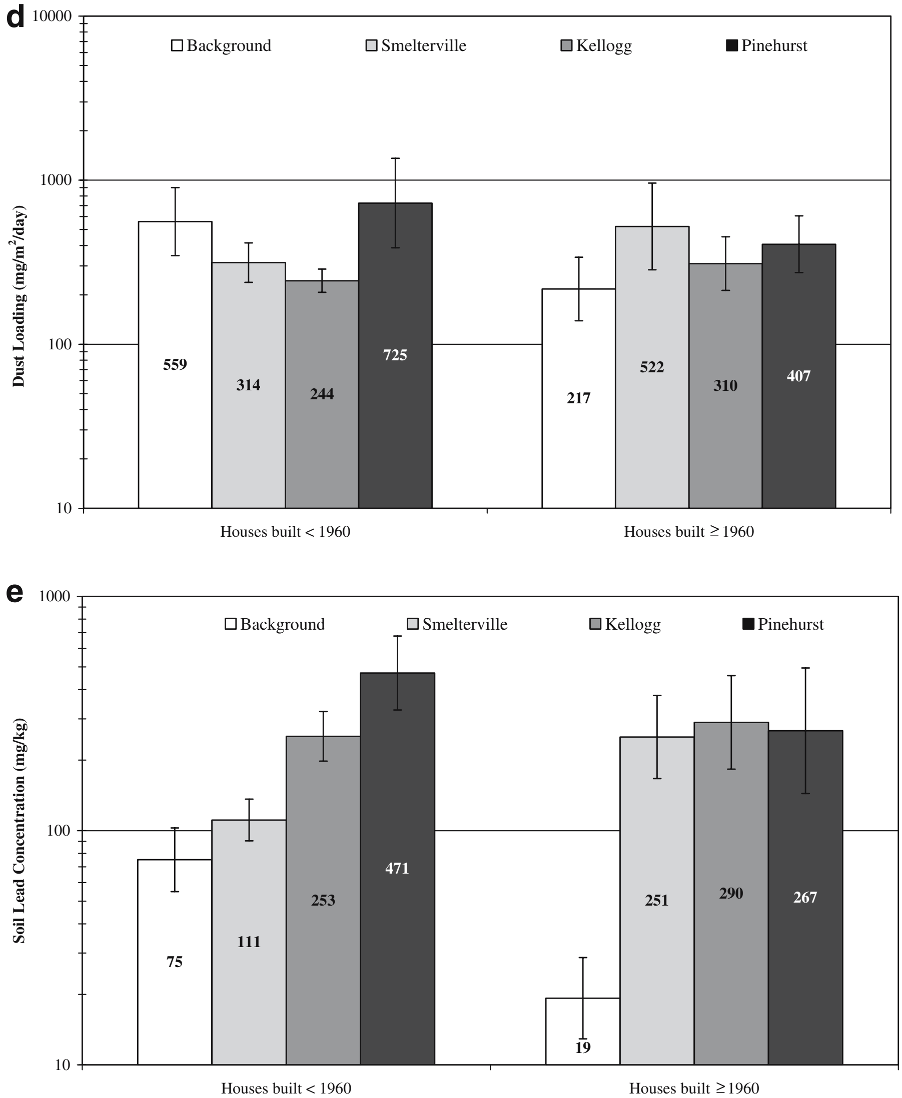


Figure 2 (Continued)



trations but also dust and Pb loading rates in towns where residual anthropogenic sources of Pb (i.e., paint, solder, gasoline, etc.) exist. Background dust and soil concentrations reveal significantly higher Pb concentrations in homes built before 1960. Although the number of people residing in the home exhibited a significant effect only in Pb loading rate, higher dust Pb averages were seen in older homes when more than four people reside in the home. A less distinct difference occurred in newer homes, most likely due to less Pb mass in and around the home from residual sources.

Inside and outside paint conditions were insignificant factors. However, the ANOVAs represent two cases where unbalanced data create difficulty in interpretation. In both cases, only one new home had either poor inside or outside paint condition and conclusions should not be drawn from these results. No quantitative analysis was performed to determine Pb paint concentrations and conditions in the houses sampled. A standard qualitative method was employed where visual paint chips and chalk on a finger would result in that house being categorized with bad paint conditions. Subjectivity is inherent using this method and may be affecting these factors. Paint Pb levels in combination with paint conditions would be a better measure of a Pb paint hazard.

Remodeled houses had lower dust loading rates than houses that had not been remodeled. It is likely that, as the inside of a house is being remodeled, more awareness to dust and debris results in more cleaning. On the other hand, Pb concentrations and Pb loading rates were all highest in older, remodeled homes. Homes built in and after 1960, conversely, do not show much of a difference in Pb concentrations and Pb loading rates between remodeled houses and houses that have not been remodeled. Higher dust concentrations and Pb loading rates in remodeled houses is an effect of old Pb-based paint, explaining the differences observed in older homes. The ANOVAs performed on three factors – number of people residing in the home, paint conditions, and whether remodeling had occurred – were more exploratory than confirmatory analyses.

Blood Pb studies show increased blood Pb levels in children residing in older houses, supporting the significant house age effects observed in the northern Idaho background survey. The National Health and Nutrition Examination Survey (NHANES III 1991–1994) reports average blood Pb levels of children between the ages of 1–5, by the year in which their houses were built. The levels are 3.8 μg/dl for houses built prior to 1946, 2.8 μg/dl for houses built between 1946 and 1973, and 2.0 μg/dl for houses built after 1973 (Pirkle et al., 1998).

Houses built prior to 1960 may contain Pb-based paint (HUD, 1995), and may have had more fallout from leaded gasoline, prior to its phase out in the 1980s. These are all anthropogenic (or residual) sources of Pb to the home environment that are typical of old residential areas in the US. Pb-based paint was phased out in the 1960s, first regulated in residential paint in 1972, and banned in 1978 (HUD, 1995). For these reasons, the older houses sampled in the background survey showed higher Pb concentrations and loading rates than did newer houses. However, many conditions and factors cause differences in Pb concentrations and loading rates. Occupations and personal hobbies may also contribute to Pb contamination of a house. Workers may bring Pb particles home on their boots and clothing; hobbies, such as soldering stained glass, can cause releases of Pb particles.

4.3 Bunker Hill towns versus background towns

House age did not show a significant effect in the 1998 Bunker Hill data. This effect may be due to a more narrow variation in house age at Bunker Hill compared to a wider variation in house age in the background survey. However, significant differences for vacuum and floor mat Pb concentrations and dust loading rates were observed among towns. Therefore, each of the three Bunker Hill towns was analyzed separately compared to the background data.

Vacuum and floor mat dust Pb concentrations and Pb loading rates were all significantly higher in Smelterville, Kellogg, and Pinehurst compared to the background towns sampled in this survey for both house age categories. Dust loading rate was not significantly different between the studies because older background homes typically had higher dust loading rates than older Bunker Hill homes, whereas newer background homes had lower dust loading rates than newer Bunker Hill homes. Although the dust mass entering background towns was higher than those in Bunker Hill towns, the Pb mass entering the homes in the BHSS is significantly higher than background. The time of year at which the background and Bunker Hill data were collected may be important. Background data were collected in spring while Bunker Hill samples have historically been collected in late summer and early fall. The difference in season could affect the dust and lead loading rates because spring may be a wetter season than summer. Sampling at the homes participating in this background survey continued in order to examine seasonal effects of Pb in house dust (Petrosyan et al., 2006). Another survey of seasonal effects of blood Pb levels in Boston showed floor dust Pb variation throughout the year (USEPA, 1995b). However, the sampling methods were different from the techniques used for the northern Idaho background survey and Pb levels were reported as a mass (in micrograms) rather than as a concentration.

The greater Pb concentrations and quantities in BHSS towns suggest that there is still a significant source of Pb contaminating house dust above background concentrations. In a town such as Smelterville where soil remediation is complete, higher Pb concentrations and loading rates may be due to either reservoirs of Pb inside the house (e.g., the attic or deeply embedded in the carpet) or recontamination of outside sources, such as right-of-way or gravel driveways (TerraGraphics, 2000). Another possibility is a time-lag factor. Soil remediation in Smelterville was completed in 1997 but it may take more time to determine if dust Pb concentrations will fall below the RAOs or if interior remediations will be necessary to reduce dust Pb concentrations in homes where levels remain high.

5 Conclusions and Recommendations

The overall purpose of this survey was to determine background house dust Pb levels for demographically similar towns unaffected by the mining industry in northern Idaho and to compare those levels with concentrations and loading rates observed at the BHSS. One of the objectives was to also evaluate underlying factors contributing to house dust Pb concentrations.

- House age was determined to be the most significant factor affecting background Pb levels in house dust. In the BHSS towns where past smelting and mining operations created a source of Pb, the house age effect was not as strong because Pb contaminated all media in and around these towns.
- The background Pb levels measured in this survey are significantly lower than the 1998 Pb levels observed at the BHSS.
- The RAOs established for the BHSS need to be clarified and updated. The house dust sampling method was not stated in the RAO and it has been observed, not only with BHSS data but also with background data, that results differ with sampling methods.
- Further laboratory analysis, such as fingerprinting or speciation, would help to determine the sources of house dust in the background house samples versus those in the BHSS samples. It would also further characterize the house dust observed at the BHSS today by differentiating between background concentrations and increased concentrations associated with past mining and smelting activities.

Acknowledgements The authors acknowledge all participants in the background survey and those BHSS residents who continue to participate in the annual surveys. We are grateful for funding provided by the Idaho Department of Environmental Quality and TerraGraphics Environmental Engineering, Inc. The authors also acknowledge the input from Gregory Möller, Maxine Dakins, and Phil Druker, professors at the University of Idaho.

References

Adgate, J. L., Weisel, C., Wang, Y., Rhoads, G. G., & Lioy, P. J. (1995). Lead in house dust: Relationships between exposure metrics. *Environmental Research, 70*(2), 134–147.

Adgate, J. L., Willis, R. D., Buckley, T. J., Chow, J. C., Watson, J. G., Rhoads, G. G., et al. (1998). Chemical mass balance source apportionment of lead in house dust. *Environmental Science & Technology, 32*, 108–114.

Agency for Toxic Substances and Disease Registry (ATSDR) (1997). *Toxicological profile for lead*. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Bero, B. (1994). *Characterization of lead contaminated soils and evaluation of vacuuming and X-ray fluorescence techniques for sampling carpeted surfaces*. PhD Dissertation, University of Idaho, Moscow, Idaho.

Bero, B., von Braun, M., von Lindern, I., Hammel, J., & Korus, R. (1997). Evaluation of six vacuum techniques for sampling lead-contaminated carpeted surfaces. *Advances in Environmental Research, 1*, 333–344.

Bornschein, R. L., Succop, P. A., Kraft, K. M., Clark, C. S., Peace, B., & Hammond, P. B. (1986). Exterior surface dust lead, interior house dust lead and childhood lead exposure in an urban environment. In D. D Hemphill (Ed.), *Trace substances in environmental health-XX. Proceedings of University of Missouri's 20th Annual Conference* (pp. 322–332). June 1986, Columbia, Missouri.

Butte, W., & Heinzow, B. (2002). Pollutants in house dust as indicators of indoor contamination. *Reviews of Environmental Contamination and Toxicology, 175*, 1–46.

Centers for Disease Control (CDC) (1991). *Preventing lead poisoning in young children: A statement by the centers for disease control – October 1991*. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Centers for Disease Control (CDC) (1997). *Screening young children for lead poisoning*. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

CH2M Hill (1991). *Final House Dust Remediation Report for the Bunker Hill CERCLA Site Populated Areas RI/FS* (Technical Report BHPA-HDR-F-R0-052091). Idaho Department of Health and Welfare.

Colt, J. S., Zahm, S. H., Camann, D. E., & Hartge, P. (1998). Comparison of pesticides and other compounds in carpet dust samples collected from used vacuum cleaner bags and from a high-volume surface sampler. *Environmental Health Perspectives, 106*(11), 721–724.

Fergusson, J. E., & Schroeder, R. J. (1985). Lead in house dust of Christchurch, New Zealand: Sampling, levels and sources. *Science of the Total Environment, 46*, 61–72.

Friendly, M. (1999). *SAS macro programs for statistical graphics: STARS*, Version 1.6.

Hunt, A., Johnson, D., Watt, J., & Thornton, I. (1992). Characterizing the sources of particulate lead in dust by automated scanning electron microscopy. *Environmental Science & Technology, 26*, 1513–1522.

Idaho Department of Health and Welfare (IDHW) (1976). *Shoshone lead health project*. Summary Report. Boise, Idaho.

U.S. Environmental Protection Agency (USEPA) (1991).

Bunker Hill populated areas: Record of decision. Kellogg, Idaho.

Johnson, D. E. (1998). *Applied multivariate methods for data analysts*. Pacific Grove, CA: Duxbury Press.

Landrigan, P. J., & Baker, E. L. (1981). Exposure of children in heavy metals from smelters: Epidemiology and toxic consequences. *Environmental Research, 25*(1), 204–224.

Lanphear, B. P., Dietrich, K., Auinger, P., & Cox, C. (2000). Cognitive deficits associated with blood lead concentrations <10 microg/dL in US children and adolescents. *Public Health Report, 115*(6), 521–529.

Lanphear, B. P., Matte, T. D., Rogers, J., Clickner, R. P., Dietz, B., Bornschein, R. L., et al. (1998). The contribution of lead-contaminated house dust and residential soil to children's blood lead levels. A pooled analysis of 12 epidemiologic studies. *Environmental Research, 79*(1), 51–68.

Lewis, R. G., Fortune, S. R., Willis, R. D., Camann, D. E., & Antley, J. T. (1999). Distribution of pesticides and polycyclic aromatic hydrocarbons in house dust as a function of particle size. *Environmental Health Perspectives, 107*, 721–726.

Lioy, P. J., Freeman, N. C., & Millette, J. R. (2002). Dust: A metric for use in residential and building exposure assessment and source characterization. *Environmental Health Perspectives, 110*(10), 969–983.

Marcus, A. H., & Elias, R. W. (1994). Estimating the contribution of lead-based paint to soil lead, dust lead, and childhood blood lead. In: M. E. Beard & S. D. Allen (Eds.), *Lead in paint, soil, and dust: Health risks, exposure studies, control measures, measurement methods, and quality assurance*. ASTM STP 1226, Philadelphia.

Murgueytio, A. M., Evans, R. G., & Roberts, D. (1998). Relationship between soil and dust lead in a lead mining area and blood lead levels. *Journal of Exposure Analysis and Environmental Epidemiology, 8*(2), 173–186.

Panhandle Health District (PHD) (1986). *Kellogg revisited – 1983: Childhood blood lead and environmental status report* (Technical Report). Kellogg: Idaho Department of Health and Welfare.

Petrosyan, V., von Braun, M. C., Spalinger, S. M., & von Lindem, I. H. (2006). Seasonal variations of lead concentration and loading rates in residential house dust in northern Idaho, *Journal of Hazardous Materials, 132* (1), 68–79.

Pirkle, J. L., Kaufmann, R. B., Brody, D. J., Hickman, T., Gunter, E. W., & Paschal, D. C. (1998). Exposure of the U.S. population to lead, 1991–1994. *Environmental Health Perspectives, 106*(11), 745–750.

Roberts, T. M., Hutchinson, T. C., Paciga, J., Chattopadhyay, A., Jervis, R. E., VanLoon, J., et al. (1974). Lead contamination around secondary smelters: Estimation of dispersal and accumulation by humans. *Science, 186* (4169), 1120–1123.

Sayre, J. W., & Katzel, M. D. (1979). Household surface lead dust: its accumulation in vacant homes. *Environmental Health Perspectives, 29*, 179–182.

Stern, A. H., Fagliano, J. A., Savrin, J. E., Freeman, N. C., & Lioy, P. J. (1998). The association of chromium in household dust with urinary chromium in residences adjacent to chromate production waste sites. *Environmental Health Perspectives, 106*(12), 833–839.

TerraGraphics Environmental Engineering, Inc. and Panhandle Health District (TerraGraphics and PHD) (1996). *Final Work Plan* (Technical Report). Moscow: Idaho Department of Health and Welfare.

TerraGraphics Environmental Engineering, Inc. (TerraGraphics) (1997). *Bunker Hill NPL site: Summary of lead health intervention and source removal efforts, 1985–1996* (Technical Report). Moscow: Idaho Department of Health and Welfare.

TerraGraphics Environmental Engineering, Inc. (TerraGraphics) (1999). *1998 annual summary: Blood lead absorption and exposure survey* (Technical Memo). Moscow, Idaho.

TerraGraphics Environmental Engineering, Inc. (TerraGraphics) (2000). *Five year review of the Bunker Hill Superfund Site* (Technical Report). Moscow: Idaho Department of Health and Welfare.

TerraGraphics Environmental Engineering, Inc. (TerraGraphics) (2001). *Human Health Risk Assessment for the Coeur d'Alene Basin extending from Harrison to Mullan on the Coeur d'Alene River and Tributaries: Remedial Investigation/Feasibility Study* (Technical Report). Moscow: Idaho Department of Health and Welfare and Idaho Department of Environmental Quality.

Terragraphics Environmental Engineering, Inc. (TerraGraphics) (2004). *Human Health Risk Evaluation (HHRE)* (Technical Report). Moscow: Idaho Department of Environmental Quality.

U.S. Census Bureau (1997). *1990 census data*. http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=DEC&_lang=en.

U.S. Department of Housing and Urban Development (HUD) (1995). *Guidelines for the evaluation and control of lead-based paint hazards in housing*. Washington, D.C.

U.S. Environmental Protection Agency (USEPA) (1995a). *Sampling house dust for lead: Basic concepts and literature review* (Technical Report). EPA 747-R-95-007).

U.S. Environmental Protection Agency (USEPA) (1995b). *Seasonal rhythms of blood-lead levels: Boston, 1979–1983* (Technical Report). EPA 747-R-94-003.

U.S. Environmental Protection Agency (USEPA) (1995c). Contract laboratory program statement of work for inorganics analysis. ILM04.0, EPA 540-R-95-121. Washington, DC.

U.S. Environmental Protection Agency (USEPA) (2001). Lead; Identification of dangerous levels of lead, 40 CFR Part 745. *Federal Register, 66*(4), 1206–1240.

von Lindern, I. H., Spalinger, S. M., Bero, B. N., Petrosyan, V., & von Braun, M. C. (2003). The influence of soil remediation on lead in house dust. *Science of the Total Environment, 303*(1–2), 59–78.

Washington State Department of Health (WSDH) (1997). Residential environmental lead survey: Yakima, Tacoma, Spokane, and Bellingham (Technical Report).

Yankel, A. J., von Lindern, I. H., & Walter, S. D. (1977). The silver valley lead study: the relationship between childhood blood lead levels and environmental exposure. *Journal of the Air Pollution Control Association, 27*(8), 763–767.