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COMPREHENSIVE ABATEMENT PERFORMANCE PILOT STUDY

VOLUME II: MULTI-ELEMENT DATA ANALYSES

Technical Programs Branch
Chemical Management Division
Office of Prevention, Pesticides, and Toxic Substances
Office of Pollution Prevention and Toxics
U.S. Environmental Protection Agency
Washington, DC 20460

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AUTHORS AND CONTRIBUTORS

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Battelle Memorial Institute (Battelle)

Battelle was responsible for the design of the study, for identifying the elements that were selected for analysis, for producing the design documentation and the Quality Assurance Project Plan, for developing training for the field teams, for recruiting cooperators for the study, for providing team leaders for the field teams, for auditing the field teams, for data management of combined study data, for auditing the study data, for conducting the statistical analysis of the data, and for writing the final report. Key staff included: Bruce Buxton, Steve Rust, Tamara Collins, Fred Todt, John Kinateder, Nancy McMillan, Matt Palmgren, Nick Sasso, Robin Hertz, and Casey Boudreau.

Midwest Research Institute (MRI)

Midwest Research Institute was responsible for participating in the planning for the study, for identifying the elements that were selected for analysis, for writing certain chapters and appendices in the Quality Assurance Project Plan, for designing and producing a vacuum device for collecting field samples, for developing training for the field teams, for providing the technicians who collected the field samples, for auditing the field teams, for conducting the laboratory analysis of the field samples, for managing the data associated with the field samples, for auditing the laboratory results, and for producing the multi-element data on which this report is based. Key staff included: Gary Dewalt, Paul Constant, Jim McHugh, and Jack Balsinger.

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The Environmental Protection Agency was responsible for managing the study, for reviewing the design and the Quality Assurance Project Plan, for assessing the performance of the recruiters and the field teams, for reviewing audit reports, for reviewing draft reports and for arranging the peer review of the draft final report. The EPA Work Assignment Managers were Ben Lim and John Schwemberger. The EPA Project Officers were Gary Grindstaff, Joe Breen, Jill Hacker, Phil Robinson, and Sineta Wooten.

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EXECUTIVE SUMMARY

This report presents the results of the statistical analysis of multi-element data collected during a pilot study that preceded the Comprehensive Abatement Performance (CAP) Study. The goal of the CAP Study was to assess the long-term impact of lead-based paint abatement. The pilot study was conducted to test the sampling and analysis protocols for the full study.

For the multi-element analysis, concentrations of lead, as well as of aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc in dust and soil samples were measured. Barium, cadmium, chromium, titanium, and zinc concentrations were measured because they are often components of paint. Aluminum, calcium, magnesium, nickel, and potassium concentrations were measured because they are present in soil.

The multi-element analysis was undertaken to determine whether relationships among these elements could provide a "tracer" for identifying the sources and pathways of lead in households. Pilot study data were used to 1) characterize the concentrations of lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc samples in household dust and soil; 2) determine the effect of renovation and lead-based paint abatement on the concentrations of these elements in household dust and soil; and 3) investigate the relationship among the elements by sample type (i.e., samples of different media taken from different locations).

Dust and soil samples from six houses in Denver, Colorado were studied. Two houses were unabated (previously identified as relatively free of lead-based paint). The remaining four houses were abated using removal methods and/or encapsulation or enclosure methods. One house was abated using primarily removal methods on the interior and primarily encapsulation or enclosure

methods on the exterior. Another house was abated using predominantly encapsulation or enclosure methods on the interior and predominantly removal methods on the exterior. The other two houses were abated by primarily the same method on the interior as the exterior (one removal, the other encapsulation or enclosure). Most of the lead levels in the paint in the houses studied were less than 1.0 mg/cm^2.

A total of 109 vacuum dust samples was collected. Between 16 and 22 dust samples were collected at each house from window channels, window stools (often referred to as "sills"), air ducts, floors, bedcover/rug/upholstery, and entryways. Forty-eight (48) soil samples were collected. Eight samples were collected from each house: from just outside the front and back entryways, at different locations along the foundation, and at different locations on the property boundary.

Analysis of the samples showed that the highest concentrations of the elements analyzed were of calcium in the indoor dust samples and of aluminum in the outdoor soil samples. Lead concentrations were highest in air duct, window stool, and window channel samples, and they were higher in foundation soil samples than in boundary soil samples. Except for titanium and aluminum, dust samples from floors and interior entryways had similar concentrations of elements. After controlling for abatement and renovation effects, relative concentrations of the elements suggested grouping the following sample types: a) air duct, window stool, and window channel dust; b) floor, interior entryway, and bedcover/rug/upholstery dust; and c) foundation, exterior entryway, and boundary soil.

Little difference, in general, was observed between levels of the elements studied in abated and unabated units. Regardless of the method of abatement, there were significantly higher lead levels in interior entryway dust and exterior entryway soil in abated houses. There were also significantly higher levels of

zinc in the soil outside the entryways of abated houses. There were significantly lower levels of calcium in the dust on window stools and significantly lower levels of chromium in the dust on floors of abated houses. Lead concentrations in dust and soil near the interior and exterior entryways of abated houses were three to five times the levels in unabated houses. The concentrations of lead in dust from floors and interior entryways of renovated houses were about five times those in unrenovated houses. Calcium concentrations in the dust of renovated houses were significantly higher than in dust of unrenovated houses for window stools, bedcover/rug/upholstery, floors, and interior entryways. The difference was tenfold for bedcover/rug/ upholstery and interior entryways.

Zinc was the element most frequently correlated with lead. Based on visual observation of correlation scatter plots, similar bivariate relationships among the eleven elements were found in a) floors, interior entryways, and exterior entryways; b) boundary and foundation soil; and c) window channels and stools. Multivariate principal component analysis showed similarities among the concentrations of elements in a) exterior entryway, foundation, and boundary soil samples and b) floor, interior entryway, bedcover/rug/upholstery, window stool, and air duct dust samples.

Study Conclusions

The data collected in this pilot study were analyzed to determine sample sizes and test sampling protocols for the full CAP study. This report focuses on a multi-element analysis of the data collected in the pilot study. It was not possible to determine definitively from the data collected in the pilot study whether lead dust in the houses studied came primarily from paint or soil. However, bivariate relationships among the elements in soil outside entryways were more similar to those in interior

floor dust (including entryway dust) than they were to those in soil samples taken near the foundation and boundary. This suggests that soil near the entryways is transported indoors and constitutes a portion of interior floor dust.

COMPREHENSIVE ABATEMENT PERFORMANCE PILOT STUDY: MULTI-ELEMENT DATA ANALYSES

1.0 INTRODUCTION

This report presents the results of a multi-element analysis of data obtained during a pilot study that preceded the Comprehensive Abatement Performance (CAP) Study. This represents Volume II of the CAP Pilot report. Volume I dealt exclusively with the statistical analysis of observed levels of lead (US EPA, 1995). The goal of the CAP Study was to assess the long-term impact of lead-based paint abatement. The pilot study was conducted to test the sampling and analysis protocols that were intended for the full study. These protocols called for determining the levels of lead in dust and soil samples collected at residential units.

1.1 STUDY DESIGN

In the CAP Pilot study, six houses of differing abatement histories were sampled. These houses were located in Denver, Colorado. Two houses were unabated (previously identified as relatively free of lead-based paint). The remaining four houses were abated using removal methods and/or encapsulation or enclosure methods. One house was abated using primarily removal methods on the interior and primarily encapsulation or enclosure methods on the exterior. Another house was abated using predominantly encapsulation or enclosure methods on the interior and predominantly removal methods on the exterior. The other two houses were abated by primarily the same method on the interior as the exterior (one removal, the other encapsulation or enclosure). Most of the lead levels in the paint in the houses studied were less than 1.0 mg/cm^2. For easy reference, Table 1 displays the abatement and renovation history of each of the six houses sampled. (Renovation is described later.)

Table 1. Abatement and Renovation History by House

House	Interior Abatement History	Exterior Abatement History	Renovation
17	Abated: Removal	Abated: E/E	None
19	Unabated	Unabated	Partial
33	Unabated	Unabated	None
43	Abated: Removal	Abated: Removal	None
51	Abated: E/E	Abated: Removal	Full
80	Abated: E/E	Abated: E/E	None

Along with the determinations of lead obtained in the study, levels of ten other metals were measured within dust and soil samples taken at these houses: aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc. Five of these metals (barium, cadmium, chromium, titanium, and zinc) have been used in the composition of paint. The other five elements are present primarily in other sources such as soil (Tisdale, Nelson, and Beaton, 1985). For example, magnesium is found in clay, which is often observed in soil samples. The purpose of measuring the levels of these other metals in the samples was to identify groups of sample types that appear to have come from similar sources, with the ultimate goal of identifying prominent sources of lead found in household dust.

The major objectives addressed in the analysis of the multi-element data from the pilot study were to:

(1) Characterize the concentration levels of lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc in samples of household dust and soil,

(2) Determine the effect of renovation and abatement on the concentration of these elements in household dust and soil, and

(3) Investigate the relationships among these elements by sample type (e.g., household dust, exterior soil, dust

from air ducts, and dust from bedcover/rug/ upholstery).

The intention of this examination was to identify analysis methods for evaluating multi-element data and to apply these methods to pilot study data to identify any strong relationships. With data available for only six housing units, few relationships were strongly detectable.

Subsection 1.2 describes the data and gives a summary of the outlier analysis. Section 2 describes the analyses performed, and the results are discussed in Section 3. Section 4 provides conclusions. Section 5 lists the references cited in this report. Appendix A is a summary of the multi-element data collected, and Appendix B is the outlier analysis.

1.2 DATA

The study design required the collection of 25 vacuum dust samples and 8 core soil samples from each of the six houses in the study, for a total of 150 dust samples and 48 soil samples. The vacuum dust samples were collected from six different locations (window channels[1], window stools[2], air ducts, floors, bedcover/rug/ upholstery, and entryways). Core soil samples were taken from just outside the front and back entryways, at different locations on the foundation, and at different locations on the property boundary. Table 2 contains a description of the acronyms used throughout this report in the tables and figures to denote the building components from which samples were collected (referred to hereafter as "sample types").

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[1]Window channel: The surface below the window sash and inside the screen and/or storm window.

[2]Window stool: The horizontal board inside the window that extends into the house interior—often called the window sill.

Table 2. Abbreviations for Sample Types Used in Tables and Figures

Media	Mnemonic	Component/Sample Type
Vacuum Dust Samples	ARD	Air ducts
	BRU	Bedcover/rug/upholstery
	EWY (-I)	Entryway (-Inside)
	FLR	Floor
	WCH	Window Channel
	WST	Window Stool
Soil Samples	BDY	Boundary
	EWY (-O)	Entryway (-Outside)
	FDN	Foundation

The number of dust samples actually collected from each house varied from 16 to 22 for a total of 109 vacuum dust samples. Fourteen of these 109 samples were side-by-side duplicates. Eight soil samples were collected from each house for a total of 48 soil samples. Twelve of the soil samples were side-by-side duplicates.

The dust and soil samples collected during the pilot study were analyzed to determine the amount of eleven different elements present. Listings of the raw element concentration data are displayed in Tables A-1a through A-1f of Appendix A. Each table displays concentrations from a given house for each of the eleven elements by sample medium, sample type, location, and sample ID. House number and sample ID uniquely identify each sample. Only element concentrations ($\mu g/g$) were analyzed for this report. Element loadings ($\mu g/ft^2$) were also measured for dust samples, but were not considered in this analysis.

Univariate and multivariate outlier detection tests were applied to the multi-element concentration data. Lists of potential outliers were sent back to the laboratory for verification. The results for all but one of the potential

outliers were confirmed and included in the analysis as originally reported. The sample for which an error was reported was updated and the corrected value was used in the analysis. This sample is documented in the footnotes to Table A-1b. Details regarding the statistical approach to the outlier analyses and their respective results are provided in Appendix B.

Twenty-three samples had zinc concentrations above the calibration range of the measuring instrument. One sample had a cadmium concentration above the calibration range. For the 23 samples with elevated zinc concentrations, the maximum detectable concentration was corrected for the dilution factor[3] associated with each sample. These adjusted values were used in the statistical analysis and are identified by superscripts in the appendix tables. Because only one sample had a cadmium concentration above the calibration range, it was excluded from the statistical analysis, rather than adjusted by its dilution factor.

Results for seven dust samples were excluded from the statistical analyses. No soil samples were excluded. One of the seven dust samples omitted was the sample with the elevated cadmium concentration described in the previous paragraph (sample 7 in house 19, see Appendix A-1 for a data listing by house and sample number). Another sample (sample 12 in house 19) was dropped in the laboratory. Four samples (samples 3, 9, and 17 in house 19 and sample 19 in house 43) were eliminated because only lead concentrations were available due to calcium interference. Finally, sample 12 in house 51 was excluded due to sampling problems; the cartridge filled with sawdust prior to completion of the sample collection. Thus, 102 of the designed 150 vacuum

[3]The maximum detectable concentration was 5 μg/mL. The reported concentration depended on the actual amount of dilution prior to chemical analysis.

dust samples and 48 of the designed 48 core soil samples were available for the multi-element statistical analyses.

2.0 ANALYSIS

The analysis is divided into three parts corresponding to the three major objectives introduced above. Section 2.1 contains a characterization of the concentration levels of the different elements in the various sample types. Section 2.2 describes the estimated effects of abatement and renovation, and Section 2.3 examines the relationships among the elements and sample types.

2.1 CHARACTERIZATION OF ELEMENT LEVELS

Due to the general lack of room-level effects found in the analysis of the CAP pilot lead data, the basic experimental unit considered in the multi-element data analysis is the house. House geometric mean concentrations of the eleven elements were the basic quantities used in the statistical analyses. These are tabulated in Table A-2 of Appendix A by sample type and house for each of the eleven elements.

Levels of each of the eleven elements observed varied by sample type. Figures 1a through 1k display geometric mean sample concentrations by house and building component for lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc. These figures display all the data considered in the analysis. Mean sample concentrations for each house are plotted with different symbols. The grand means over all houses are plotted with a circle and connected by a solid line across sample types. Note that the last three sample types in each plot represent soil samples, while the other sample types represent dust samples.

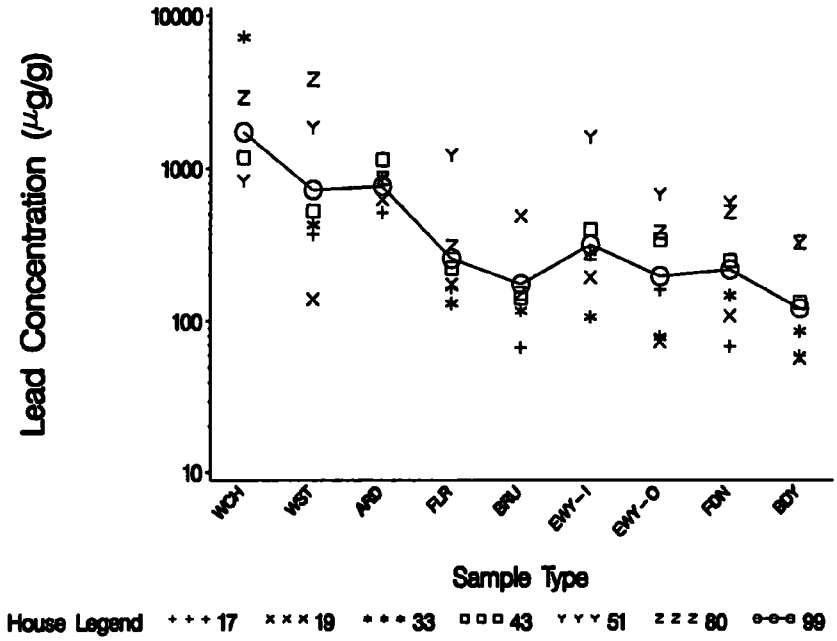

Figure 1a. Lead Concentration vs. Sample Type (Geometric House Mean).

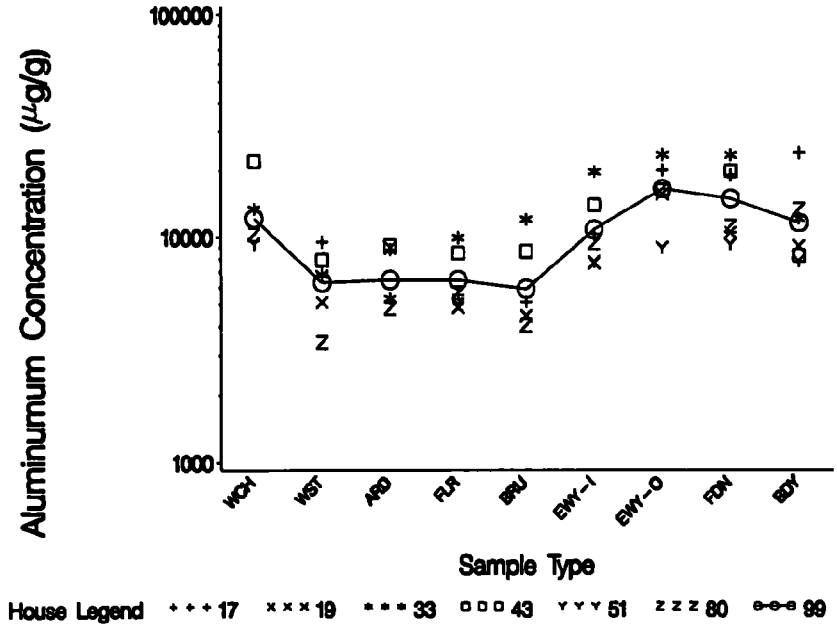

Figure 1b. Aluminum Concentration vs. Sample Type (Geometric House Mean).

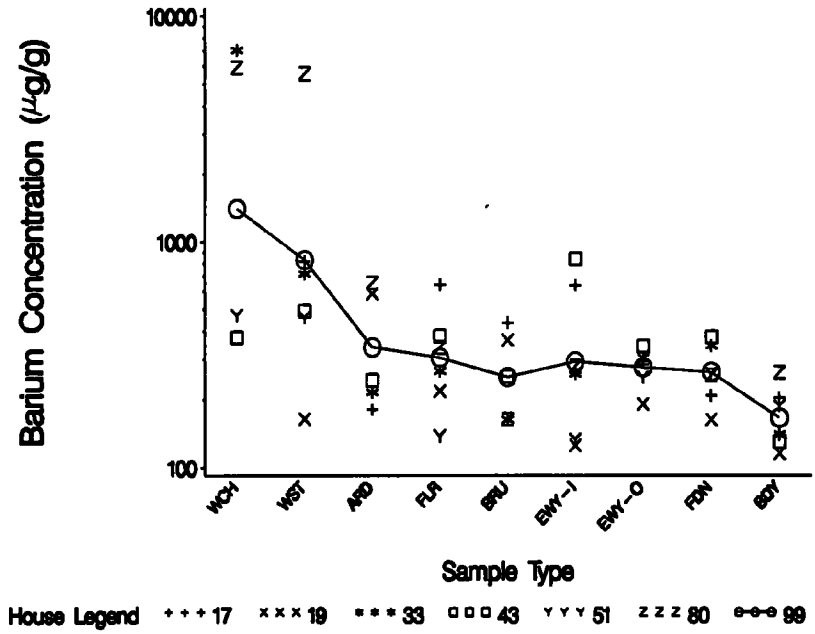

Figure 1c. Barium Concentration vs. Sample Type (Geometric House Mean).

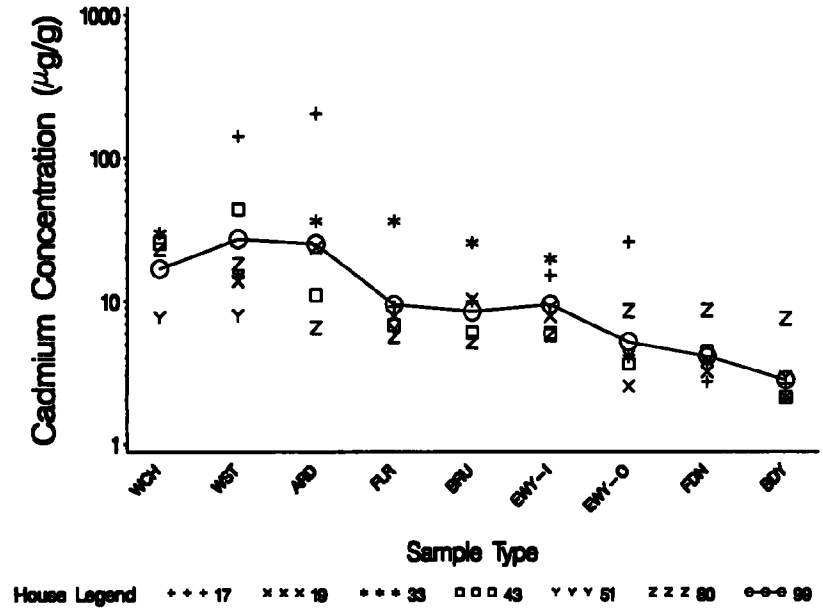

Figure 1d. Cadmium Concentration vs. Sample Type (Geometric House Mean).

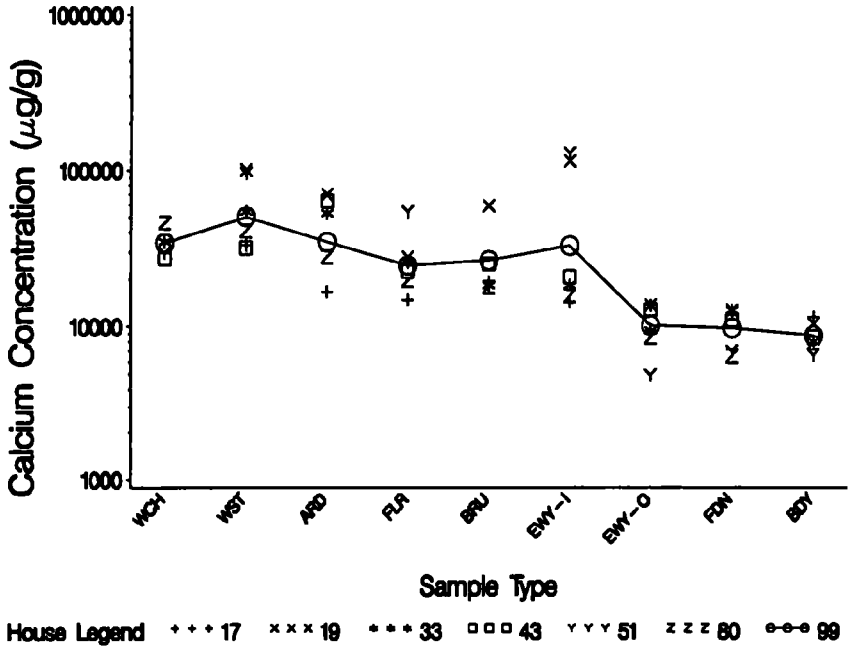

Figure 1e. Calcium Concentration vs. Sample Type (Geometric House Mean).

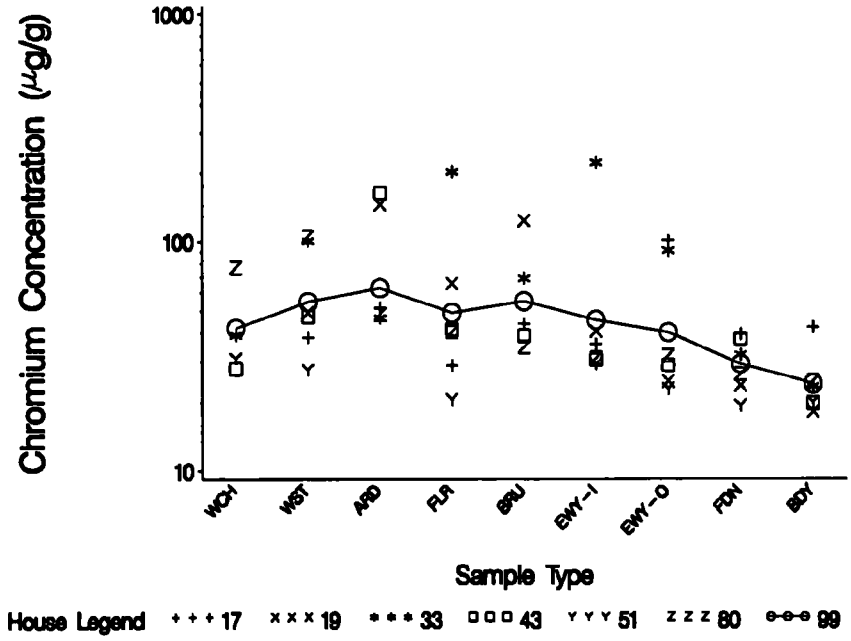

Figure 1f. Chromium Concentration vs. Sample Type (Geometric House Mean).

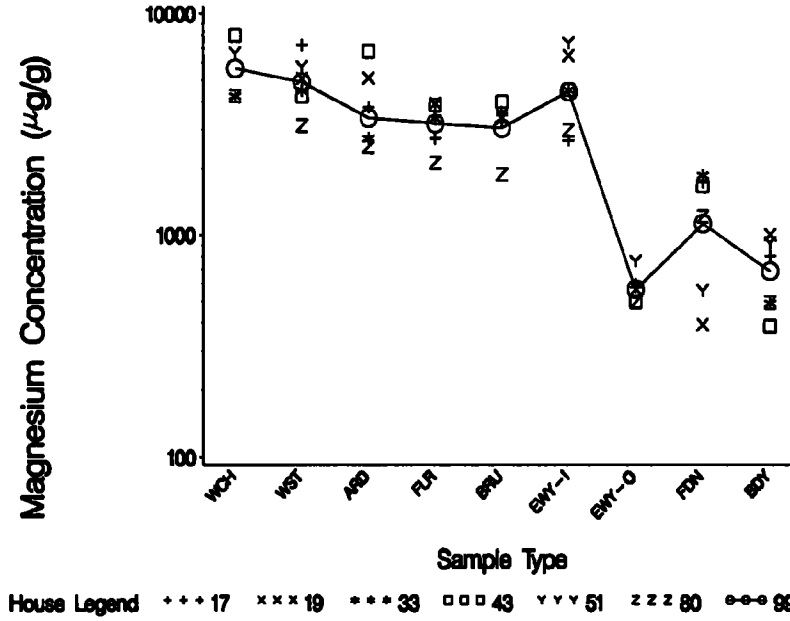

Figure 1g. Magnesium Concentration vs. Sample Type (Geometric House Mean).

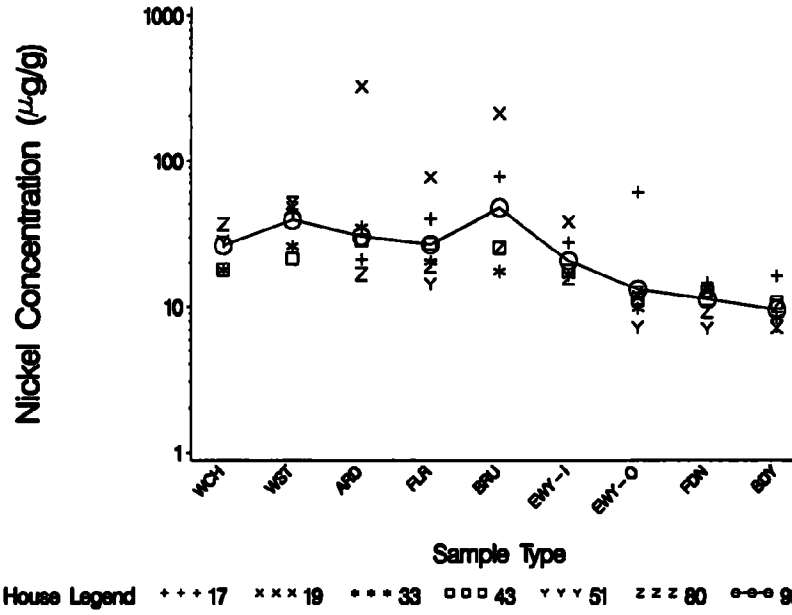

Figure 1h. Nickel Concentration vs. Sample Type (Geometric House Mean).

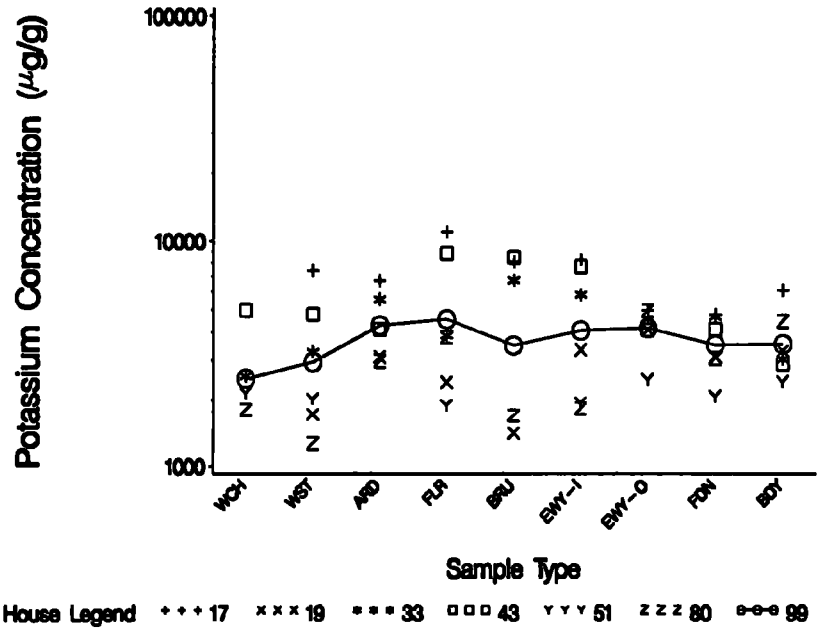

Figure 1i. Potassium Concentration vs. Sample Type (Geometric House Mean).

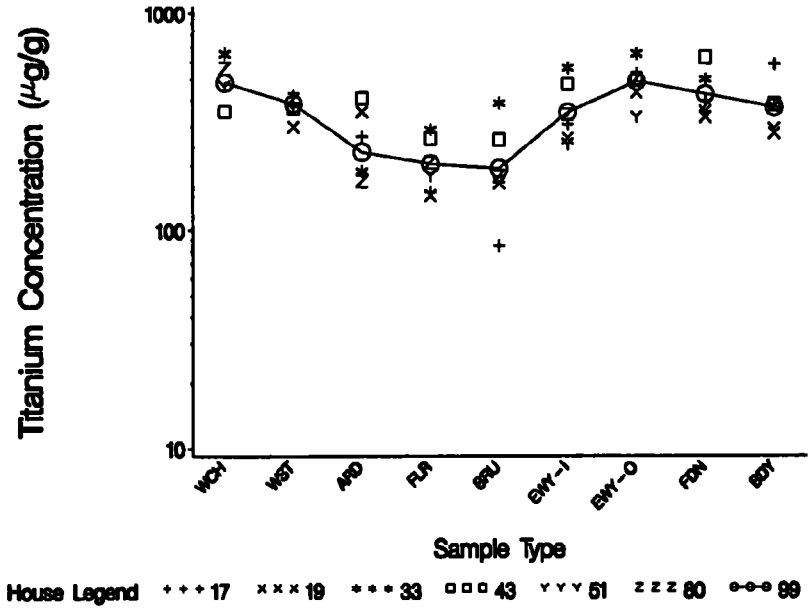

Figure 1j. Titanium Concentration vs. Sample Type (Geometric House Mean).

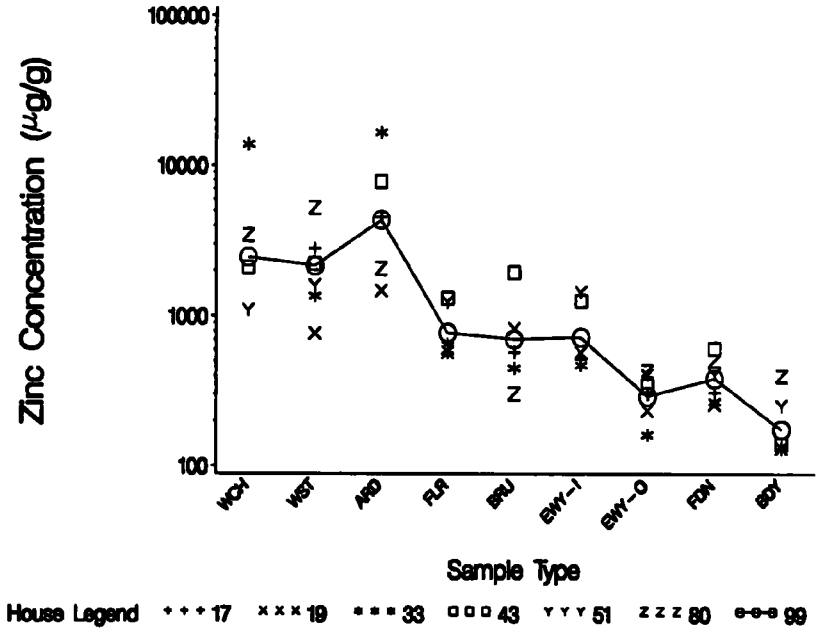

Figure 1k. Zinc Concentration vs. Sample Type (Geometric House Mean).

As can be seen in the figures, the highest geometric mean concentrations were observed for calcium in the indoor samples. For the outdoor samples, the highest levels were observed for aluminum. Of the different components sampled, lead concentrations were highest in air duct, window stool, and window channel samples (Figure 1a). Levels of barium and zinc appear to be similar to levels of lead across sample types. On average, titanium was the least variable of the eleven elements within each sample type. For each of the elements except titanium and aluminum, dust samples taken from floors and entryways had similar concentrations. However, the concentrations for these two elements were higher for entryways on average than for floors. The levels of aluminum and titanium observed in entryway dust samples were more consistent with those observed in soil samples.

This could indicate that soil is being tracked into the homes through the entryways, or it could be a reflection of the presence of these elements in the construction of the entryways. Levels of aluminum and titanium were also high in window channel samples.

The highest mean chromium concentration was observed in house 33 for regular floor dust samples and entryway dust samples. The entryway soil samples from this house also had high chromium concentrations. The individual dust and soil samples obtained from the back side entrance to this home and a floor dust sample collected from the adjoining room (kitchen) had the highest chromium concentrations observed in the study (see Table A-1c), suggesting a possible relationship between exterior and interior chromium levels.

Two exceptionally high zinc concentrations were observed on window channels and one high concentration on a window stool. However, each of these three measures came from different houses.

When grouping the profiles in Figures 1a through 1k based on similarity, three groups of elements are formed. Lead, barium, and zinc seem to have similar contours and comprise one group. Aluminum and titanium make up a second group, while cadmium, calcium, and chromium make up the third group.

To quantify the degree of variation in the concentrations of each element across sample types, an analysis of variance was performed on the geometric means plotted in Figures 1a through 1k. The results of this ANOVA are summarized in Table 3. For all elements except potassium and chromium, the differences across sample types were statistically significant. The strongest differences were seen for magnesium and calcium, with lower levels observed in soil than in dust.

Also included in Table A-2 are indicators of the primary method of interior and exterior abatement for each house. A "U" indicates that no abatement was performed in the house because no significant lead-based paint was present, an "R" indicates that

the house was abated primarily by removal methods, and an "E" indicates that the house was abated primarily by encapsulation/ enclosure methods. Table A-2 also contains the number of samples for which concentrations were determined for all eleven elements.

Table 3. Results of Analysis of Variance to Test for Significant Differences Among Sample Types, by Element

Element	Root Mean Squared Error	F value	P value	Comment
Pb	1.14	4.47	.0006	
Al	0.48	6.55	.0001	
Ba	0.95	3.83	.0019	
Cd	1.01	5.54	.0001	
Ca	0.67	9.71	.0001	Soil all lower than dust
Cr	0.78	1.59	.1570	Insignificant differences
Mg	0.48	31.27	.0001	Soil all lower than dust, EWY lower than FDN
Ni	0.77	4.83	.0003	
K	0.74	0.55	.8096	Insignificant differences
Ti	0.38	8.44	.0001	
Zn	0.76	16.40	.0001	ARD, WST, WSL higher than rest

Any sample in Tables A-1a through A-1f for which at least one element had a missing value was not included in the Table A-2 summary.

Grand geometric mean concentrations for each element by sample type are displayed in Table 4. These were obtained by taking the geometric mean of the entries in Table A-2 across all houses for each sample type and element. Thus, each house where a sample was taken (for a particular sample type) is given equal weight in these averages. These grand means are plotted in Figures 1a through 1k by the circles connected by a solid line. Each geometric mean is followed by its log standard deviation.

Table 4. Geometric Mean Concentration and Log Standard Deviation Across Houses by Sample Type

Sample Medium	Sample Type	No. of Units Sampled	Dust Loading (mg/ft²)	Lead		Aluminum		Barium		Cadmium		Calcium		Chromium	
				Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev
Dust	WCH	4	738	2128	0 97	12940	0 39	1647	1 58	19 1	0 61	33730	0 23	40 1	0 46
	WST	6	46 8	658	1 20	6266	0 36	703	1 16	23 9	1 03	53230	0 51	54 3	0 54
	ARD	5	352	771	0 31	7136	0 32	325	0 60	26 3	1 32	40465	0 61	77 3	0 64
	FLR	6	58 3	260	0 81	6331	0 30	295	0 52	9 3	0 68	25042	0 44	48 7	0 80
	BRU	5	41 6	152	0 72	6248	0 47	254	0 45	9 7	0 62	24598	0 51	55 0	0 52
	EWY-I	6	71 8	314	0 91	10761	0 37	294	0 78	9.5	0 49	32709	1 03	45 4	0 79
Soil	EWY-O	6		208	0 90	16058	0 33	276	0 21	5 6	0 85	9814	0 40	40 8	0 67
	FDN	6		209	0 87	14491	0 40	257	0 31	4.0	0 41	9812	0 31	28 7	0 28
	BDY	6		126	0 79	11373	0 42	166	0 31	2 8	0 51	8576	0 20	23 6	0 31

Sample Medium	Sample Type	No. of Units Sampled	Dust Loading (mg/ft²)	Magnesium		Nickel		Potassium		Titanium		Zinc	
				Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.	Geo Mean (µg/g)	Log Std. Dev.
Dust	WCH	4	738	5553	0 32	24 0	0 35	2651	0 444	496	0 27	3226	1 07
	WST	6	46 8	4807	0 29	38 0	0 37	2818	0.67	376	0 13	1939	0 66
	ARD	5	352	3877	0 42	40 7	1 17	4260	0 36	262	0 38	4458	0 98
	FLR	6	58 3	3222	0 25	27 8	0 60	4311	0 70	199	0 29	770	0 39
	BRU	5	41 6	3094	0 29	45 0	1 02	4046	0 89	191	0 57	656	0 70
	EWY -I	6	71.8	4419	0 40	20 7	0 36	4045	0 67	351	0 33	722	0 49
Soil	EWY -	6		574	0 16	13 9	0 74	4069	0.26	482	0 23	296	0 37
	FDN	6		1054	0 66	11 4	0 27	3476	0 32	421	0 24	372	0 35
	BDY	6		636	0 39	9 7	0 30	3504	0 33	372	0 26	178	0 46

This represents a measure of the between-house variation for that response without controlling for abatement or renovation effects.

2.2 ABATEMENT AND RENOVATION EFFECTS

2.2.1 Abatement and Renovation Effects by Element

The impact of abatement and renovation on the multi-element data was assessed by fitting a statistical model containing both renovation and abatement effects to the data in Appendix A. The model fitted to data for each element was

$$C_j = m + aI_j + rR_j + E_j \qquad j = 1,\ldots,6$$

where

- C_j represents the observed (arithmetic) average log-concentration in house j,
- m represents the average log-concentration in unrenovated unabated houses,
- a represents the added effect of abatement,
- I_j= 1 if house j was abated
0 if house j was an unabated house,
- r represents the added effect of a full renovation,
- R_j is the degree of renovation house j was undergoing at the time of sampling (see below), and
- E_j represents house-to-house variation

House 51 was assigned an R_j value of 1 indicating "full renovation" and House 19 a value of 0.5 indicating "partial renovation". The other four houses were assigned R_j values of zero, indicating that no renovation was being performed.

In the analysis of the lead data, the method of abatement (E/E or removal) was also considered as a factor in the statistical model. No significant effect was found; and

therefore, this effect was not included in the above lead model applied to all elements.

Estimates of the model parameters are reported in Tables 5, 6, and 7. Table 5 contains estimates and log-standard errors of the geometric mean concentration of each element in unrenovated, unabated houses, by sample type. Tables 6 and 7 contain estimates and standard errors of the multiplicative effects of renovation and abatement, respectively, by sample type. In Tables 6 and 7, a multiplicative effect of 1.0 implies no effect. A multiplicative effect less than 1.0 indicates that lower levels were observed in renovated (abated) houses, while a multiplicative effect greater than 1.0 indicates that higher concentrations were observed in renovated (abated) houses. Those multiplicative effects that were significantly different from 1.0 at the 0.05 significance level are denoted by asterisks.

Figures 2a, 2b, and 2c display block charts of the estimates in Table 5 (portrayed on a log scale). A distinction between sample types was observed in the average levels displayed in these figures. Therefore, the sample types were purposely presented in three groups. Figure 2a displays the estimated average log-concentration in unrenovated, unabated houses for air ducts, window stools, and window channels. Figure 2b displays the corresponding estimates for bedcover/rug/upholstery, entryway, and floor samples. Figure 2c shows the estimates for soil samples (boundary, entryway, and foundation). Air ducts, window stools, and window channels typically had the highest baseline levels of lead, calcium, and zinc. Soil samples had the lowest concentrations of these elements. Notice the relatively similar behavior of these estimates across the different elements within each of the three sample groups. For example, the ratio of lead to aluminum is smallest for soil samples, and largest for window channels, window stools, and air ducts. Another distinction was observed in the relationship between lead, titanium, and zinc.

Table 5. Model Estimates and Log Standard Errors of Geometric Mean Concentrations in Unrenovated Unabated Houses

Sample Medium	Sample Type	# Houses	Lead		Aluminum		Barium		Cadmium		Calcium		Chromium	
			Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.
Dust	WCH	4	7238	0 64	13346	0 54	7058	1 95	29.7	0 07	34866	0 37	39	0 72
	WST	6	226	1 17	5808	0 39	478	1 11	21 4	0.89	57057	0 12	87	0.46
	ARD	5	875	0 41	5341	0 36	216	0 68	36 0	1 84	53114	0 68	46	0 69
	FLR	6	102	0 33	7687	0 30	313	0.31	19 1	0 59	20998	0 25	141	0 36
	BRU	5	117	0 45	11954	0.39	163	0 49	25 4	0 34	18230	0 18	69	0 12
	EWY-I	6	96	0 19	14146	0 34	255	0 47	13 0	0 57	25873	0 35	109	0 63
Soil	EWY-O	6	63	0 43	22668	0 10	261	0 15	3.9	0 81	13126	0.36	60	0 68
	FDN	6	102	0 89	18568	0 33	252	0 37	3 6	0 48	13395	0.27	32	0.18
	BDY	6	53	0 81	11492	0 44	128	0 30	2 1	0 57	9977	0 25	21	0.33

Sample Medium	Sample Type	# Houses	Magnesium		Nickel		Potassium		Titanium		Zinc	
			Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.	Geo Mean (µg/g)	Log Std. Err.
Dust	WCH	4	4237	0 45	17 9	0 50	2563	0 72	656	0 33	13783	0 35
	WST	6	4501	0 35	31 3	0 41	2784	0 77	370	0 13	1229	0 37
	ARD	5	2719	0 50	35 2	0 27	5553	0 41	188	0.44	16504	0 67
	FLR	6	3337	0 25	41.2	0.69	4184	0 46	222	0 33	555 2	0 40
	BRU	5	3558	0 39	17 6	0 64	6723	0 92	387	0 57	447 8	0 94
	EWY-I	6	4400	0 23	24 6	0 43	5575	0 70	444	0.28	439 1	0 40
Soil	EWY-O	6	535	0.11	13.3	0 81	4955	0 12	601	0 08	183 1	0.19
	FDN	6	1175	0 43	14 9	0 20	4458	0.19	443	0 26	269 5	0 29
	BDY	6	703	0 45	8 47	0 21	3500	0 33	338	0 22	120 8	0 52

Table 6. Estimates and Log Standard Errors of Multiplicative Renovation Effects

Sample Medium	Sample Type	Lead		Aluminum		Barium		Cadmium		Calcium		Chromium	
		Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.
Dust	WCH	0 45	0 62	0 62	0 44	0 31	5.70	0 32*	0 01	0 84	0 21	0 67	0 78
	WST	1.34	1 57	0 96	0 24	0 27	1 40	0 21	0 91	2 83*	0 02	0 43	0 24
	ARD	0 51	1 32	2 81	1 05	7 37	3 66	0 43	27 17	1 72	3 66	9 89	3 84
	FLR	4 67*	0 12	0 66	0 10	0 35	0 11	0 59	0 39	2 55*	0 07	0 44	0 15
	BRU	17 08	1 64	0 14	1 20	5 01	1 92	0 17	0 92	10 45*	0 26	3 19	0 11
	EWY-I	4 87*	0 04	0 57	0 13	0 25	0 25	0 84	0 37	9 80*	0 14	0 56	0 45
Soil	EWY-O	2 12	0 21	0 50*	0 01	0 72	0 03	0 43	0 75	0 54	0 15	0 38	0 53
	FDN	2 29	0 91	0 49	0 13	0 78	0 16	0 78	0 27	0 77	0 09	0 57	0 04
	BDY	1 87	0 67	0 57	0 22	0 93	0 10	0 86	0 37	0 81	0 08	0 71	0 12

Sample Medium	Sample Type	Magnesium		Nickel		Potassium		Titanium		Zinc	
		Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.
Dust	WCH	1 14	0 30	1 10	0 38	0 72	0 78	1 04	0 16	0 41	0 18
	WST	1 27	0 14	1 59	0 19	0.52	0 67	0 85	0 02	0 47	0 16
	ARD	3 52	1 98	79 23*	0 58	0 31	1 34	3 48	1 55	0 01	3 61
	FLR	1 38	0 07	0 84	0 54	0 28	0 25	0 74	0 12	1 45	0 18
	BRU	0 88	1 22	141 04	3 23	0 04	6 74	0.18	2 61	3.35	7 14
	EWY-I	2 21*	0 06	1 09	0 21	0 39	0 55	0 58	0 09	1 91	0 18
Soil	EWY-O	1 36	0 01	0 44	0 74	0.56*	0 02	0 62*	0 01	1 25	0 04
	FDN	0 27	0 21	0 63	0.05	0 52*	0 04	0 72	0 08	0 90	0 09
	BDY	1 95	0 14	0 62	0 05	0 63	0 13	0 65	0 05	1 24	0 30

*Indicates effect was significant at p= 05 level

Table 7. Estimates and Log Standard Errors of Multiplicative Abatement Effects

Sample Medium	Sample Type	Lead		Aluminum		Barium		Cadmium		Calcium		Chromium	
		Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.
Dust	WCH	0 26	0 62	1 13	0 44	0 21	5 70	0 82	0 01	1 02	0 21	1 19	0.78
	WST	4 45	1 03	1 09	0 16	2 93	0 92	2 11	0 60	0 61*	0 01	0 68	0 16
	ARD	0 91	0 22	1 36	0 17	1 42	0 61	0 68	4 53	0 58	0 61	1 60	0 64
	FLR	2 27	0 08	0 87	0 07	1 36	0 07	0.41	0 26	0 92	0 05	0 27*	0 10
	BRU	0 96	0 27	0 47	0 20	1 61	0 32	0 27	0 15	1 11	0 04	0 56	0 02
	EWY-I	3 25*	0 03	0 82	0 09	2 08	0 16	0 67	0 24	0 60	0 09	0 33	0.30
Soil	EWY-O	4 51*	0 14	0 77	0.01	1 22	0 02	2 41	0 49	0 81	0 10	0 81	0 34
	FDN	2 13	0 60	0 90	0 08	1 13	0 10	1.30	0 18	0 69	0 06	1 07	0 02
	BDY	2 42	0 44	1 14	0.14	1 49	0 07	1.58	0 25	0 92	0 04	1 23	0 08

Sample Medium	Sample Type	Magnesium		Nickel		Potassium		Titanium		Zinc	
		Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.	Effect	Log Std. Err.
Dust	WCH	1 37	0 30	1 44	0.38	1 17	0 78	0 68	0 16	0 19	0 18
	WST	1 01	0 09	1 12	0.12	1 30	0.44	1 09	0.01	2 63	0 10
	ARD	1 46	0 33	0 62	0.10	0 78	0 22	1 41	0 26	0.25	0 60
	FLR	0 84	0 05	0 59	0.36	1 69	0 16	0 95	0 08	1 42	0 12
	BRU	0 81	0 20	2 10	0 54	0 72	1 12	0 41	0 44	1 55	1.19
	EWY-I	0.75	0 04	0 75	0 14	0 88	0 36	0.86	0 06	1 65	0 12
Soil	EWY-O	0.99	0 01	1 46	0 49	0 92	0 01	0.86	0 00	1 89*	0.03
	FDN	1 38	0 14	0.80	0 03	0 88	0.03	1.05	0.05	1 68	0 06
	BDY	0 88	0 09	1.37	0 03	1 17	0.08	1.23	0.03	1 55	0 20

*Indicates effect was significant at p= 05 level

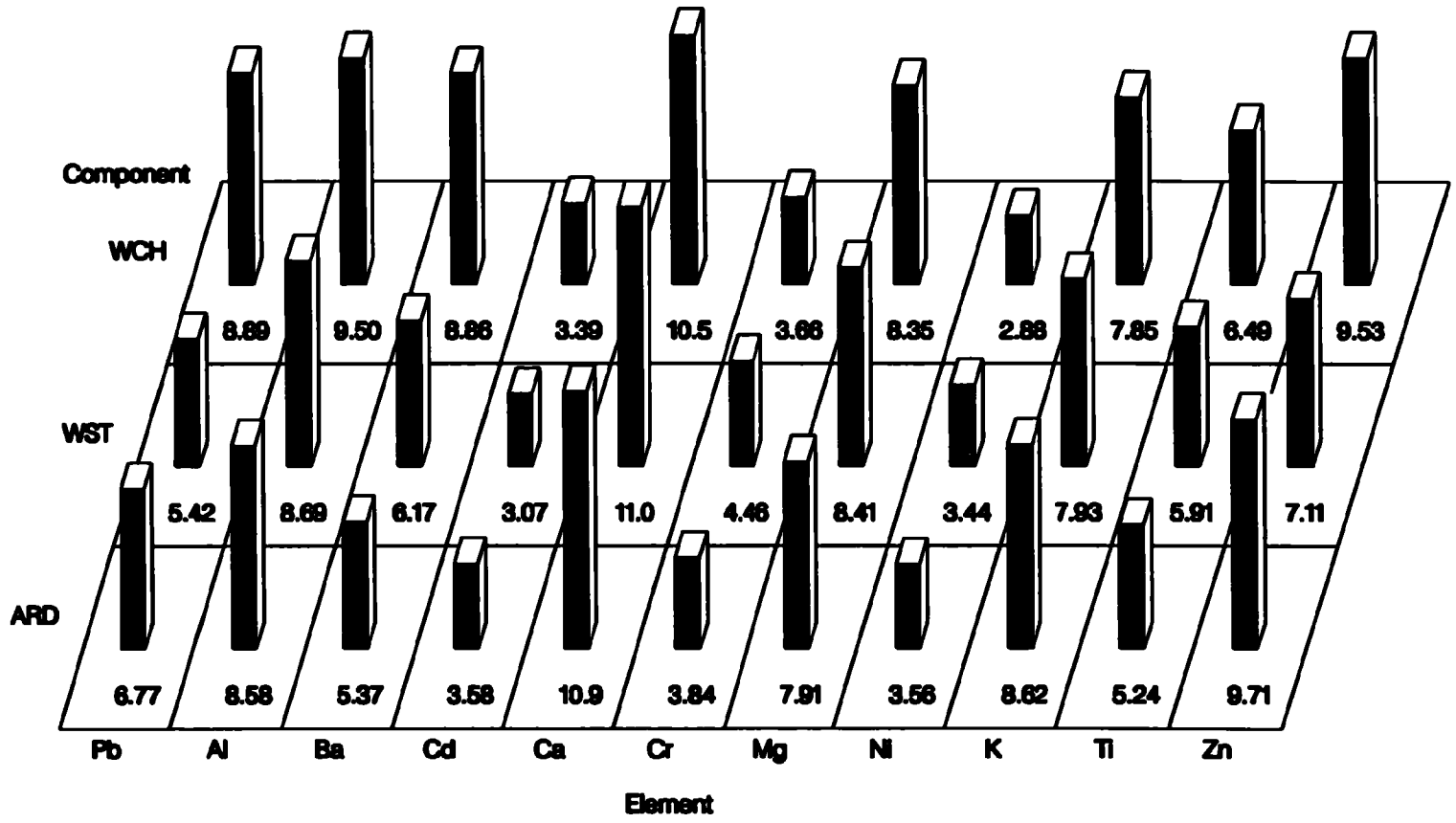

Figure 2a. **Block Chart of Estimated Average Log-Concentration in Unrenovated, Unabated Units for Window and Air Duct Dust Samples.**

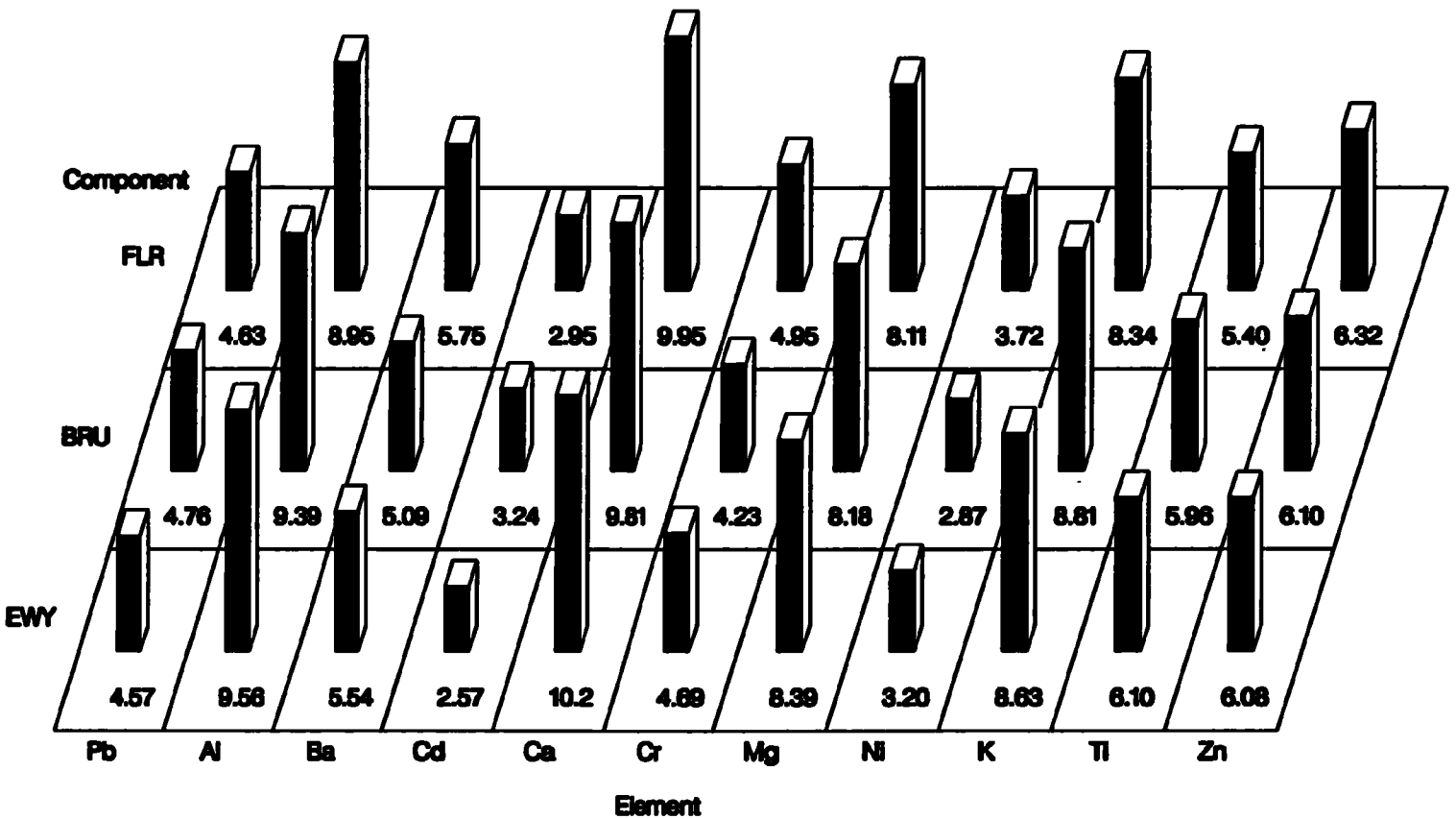

Figure 2b. Block Chart of Estimated Average Log-Concentration in Unrenovated, Unabated Units for Floor and Bedcover/rug/upholstery Dust Samples.

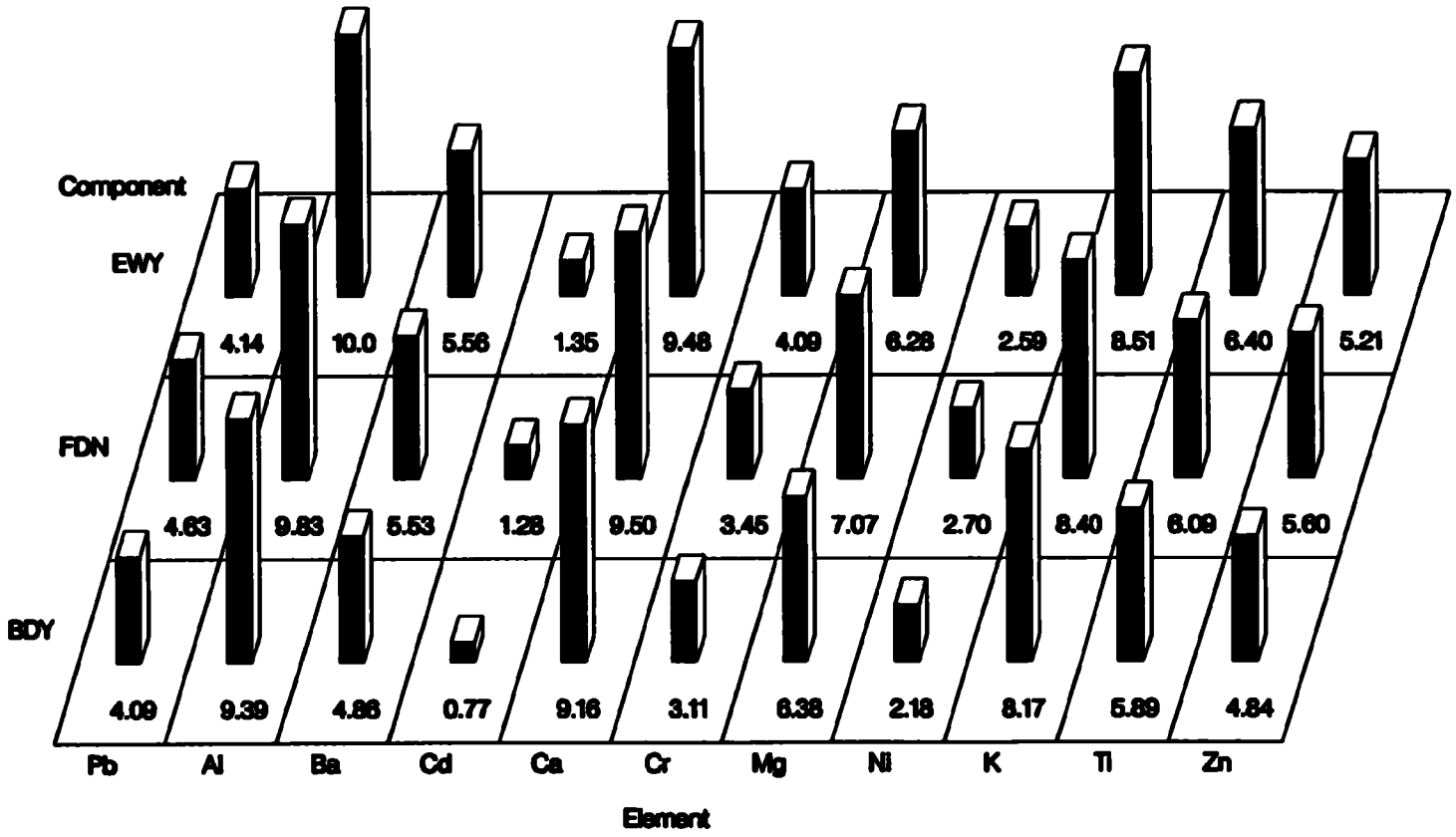

Figure 2c. **Block Chart of Estimated Average Log-Concentration in Unrenovated, Unabated Units for Soil Samples.**

Figure 2a depicts a lower titanium level than lead or zinc for air ducts and window channels. On the other hand, levels portray a general rise as one moves from lead to titanium to zinc for floor, entryway, and bedcover/rug/upholstery samples in Figure 2b. Finally, in Figure 2c, titanium was the element with the highest concentration among lead, titanium, and zinc in each of the soil samples.

In trying to identify the source of dust on floors, the relationship among levels of the different elements for window stools appears more similar to those for floors, entryways, and bedcover/rug/upholstery samples than to those for window channels and air ducts. This is likely a reflection of the general composition of these dust samples. Figure 2a indicates that the window channel samples have especially high concentrations of barium and lead relative to the concentrations of the other elements. In this manner, window channel samples seem to differ from the other types of samples.

Close attention should be given to the log standard errors of the estimates in Tables 6 and 7. Most of these are very large in comparison to the logarithm of the multiplicative estimates. Note that a total of 198 statistical tests were performed in the analysis supporting the results in Tables 6 and 7. Each test was performed at the 5% level. Therefore, even if there were no effects of abatement or renovation on any of these element concentrations, we would still expect 9 or 10 sample type/element/factor combinations to be significant. A total of 18 combinations were found to be significant. Of these, calcium was involved in five cases, lead was the element involved in four cases, potassium was involved in two cases, while aluminum, cadmium, chromium, magnesium, nickel, titanium, and zinc were each involved in one case. Entryways were involved in 9 cases of significance (5 soil and 4 dust), floors in 3 cases, and window stools in two cases.

One case of significance was observed for air duct, bedcover/rug/ upholstery, window channel, and foundation samples.

Thus, although more cases of significance were observed than would be expected if there were no real effects, the number of statistically significant results was small relative to the number of tests performed. This, along with the limited data set associated with the pilot study, makes it difficult and perhaps inadvisable to draw general conclusions from the estimates reported in Tables 6 and 7.

2.2.2 Abatement and Renovation Effects Across Elements

A principal components analysis was performed to determine whether the relationships in element concentrations among the houses (or houses with a similar abatement/renovation history) were similar for the different sample types. This analysis is an attempt to simplify the interpretation of the data by reducing the number of elements characterized from eleven to perhaps two or three "element classes". These element classes represent weighted averages of the eleven elements. Ultimately, this may provide insight into the following source-assessment question: "Where does the lead in household dust come from?" This analysis, was performed on mean log-concentrations for each element and house by sample type.

The purpose of this analysis was two-fold. A principal components analysis provides a mathematical tool for estimating the approximate dimensionality of the responses. Also, plotting the higher-order principal components against each other affords an objective means of identifying clusters of houses with similar dust and soil element compositions. The ultimate goal is a reduction in the complexity of the multivariate data analysis.

Principal component analyses can be performed based on either correlations or covariances. Analyses based on correlations standardize the range of each of the elements' concentrations.

This prevents the most widely fluctuating elements from dominating the analysis and gives equal attention to all variables regardless of their range. Covariance-based analyses leave all element concentrations in their original scale. Since the scales observed varied substantially by element, and a priori there was no reason to weight more heavily the elements with greater absolute variation, the principal component analyses were performed based on correlations.

Table 8 displays estimates of the first two principal components (i.e., the two principal components explaining the most variability in the data) by sample type, followed by the cumulative proportion of total variation explained by these components. Figures 3a and 3b display plots of the relationship between the first and second principal components by sample type. Figure 3a is for dust samples; Figure 3b is for soil samples. Houses are distinguished by different plotting symbols in these figures. Refer to Table 3 for a synopsis of abatement and renovation history of these houses.

For many of the sample types, more than 70% of the total variation is explained by the first two principal components. A similar weighting pattern was applied to the elements for floor and entryway dust and entryway soil samples. The weights are assigned to the different elements to maximize the variation. Therefore, if two elements are negatively correlated, then the weights of the high-order principal components of the two elements will likely be of opposite signs. For example, as will be seen in Section 2.3, aluminum and calcium concentrations are negatively correlated in entryway dust. Table 8 shows that their coefficients in the first principal component are of an opposite sign for entryway dust. Obviously, when considering so many elements, it is impossible for this relationship between correlation and principal component coefficients to hold for all pairs of elements.

Table 8. Principal Components for Unit Mean Log-Concentration by Sample Type

Sample Medium	Sample Type	Principal Component	Principal Component Coefficients											Cumulative Explained Variability
			Pb	Al	Ba	Cd	Ca	Cr	Mg	Ni	K	Tl	Zn	
Dust	ARD	1	0 15	0.29	0.11	-0.23	0.37	0 45	0.40	0 29	-0 27	0.40	-0.14	0 44
		2	-0.14	0 41	-0 49	0.43	-0 08	0 08	0.25	-0.10	0 46	0.28	0 11	0 71
	BRU	1	0 40	-0 33	0 25	-0.17	0 40	0.33	-0 08	0 43	-0 31	-0.27	-0.05	0 44
		2	0 22	0 39	0 00	0 37	0 26	0 37	0.48	0.16	0 13	0 37	0 21	0 70
	EWY-I	1	-0.32	0 38	0 22	0.28	-0 39	0 29	-0.31	-0 10	0.31	0 37	-0 23	0 47
		2	0 16	0 28	-0 47	0 34	0.24	0 50	0.35	-0 16	-0 26	0 19	-0 01	0.67
	FLR	1	-0.44	0 32	0 30	0.29	-0.43	0.29	-0.23	0 01	0.26	0.24	-0.27	0.36
		2	0.12	0 38	-0 34	0 37	0.24	0 37	0.22	-0 26	-0.25	0 42	0.20	0 68
	WCH	1	0 29	-0.26	0 38	0.13	0.34	0.30	-0 40	0.17	-0.31	0 38	0.24	0.57
		2	0.36	0.33	0 17	0 42	-0.17	-0 22	-0.02	-0 47	0.28	0 12	0 41	0.88
	WST	1	0 41	-0 37	0 43	-0 19	-0 06	0 33	-0 34	0.17	-0.28	0 11	0.35	0 45
		2	0 02	0.10	0.14	0.41	-0.53	0 12	0 07	-0 21	0 42	0 45	0 29	0.74
Soil	BDY	1	-0 10	0 43	0.22	0 08	0 19	0 42	-0 12	0.42	0.42	0 42	-0.01	0 48
		2	0 46	-0 03	0 41	0.44	-0 36	-0 02	-0 24	-0 02	0 00	-0 02	0 48	0 84
	EWY-O	1	-0 36	0 40	0 15	0 22	0 29	0.33	-0.25	0.24	0 37	0 36	-0.25	0 52
		2	0 29	-0.13	0 19	0 58	-0 07	0 21	0 14	0.52	0.04	-0 16	0.40	0 70
	FDN	1	-0 33	0 38	0 16	-0 17	0.32	0 36	0.33	0 36	0 39	0 27	-0 06	0.57
		2	0 29	0 13	0 45	0 34	-0 28	0 13	0.25	-0 18	0.00	0.37	0 50	0 85

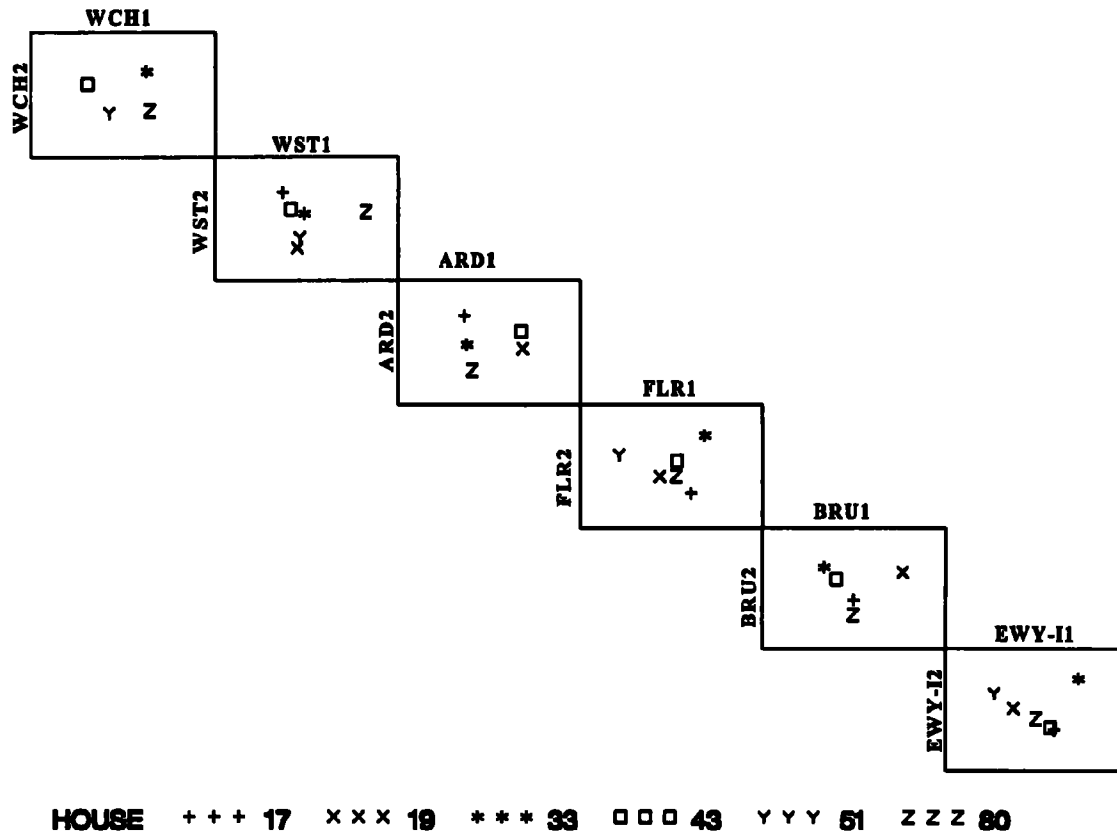

Figure 3a. **Plot of First Two Principal Components of Mean Log-Concentrations for Dust Samples.**

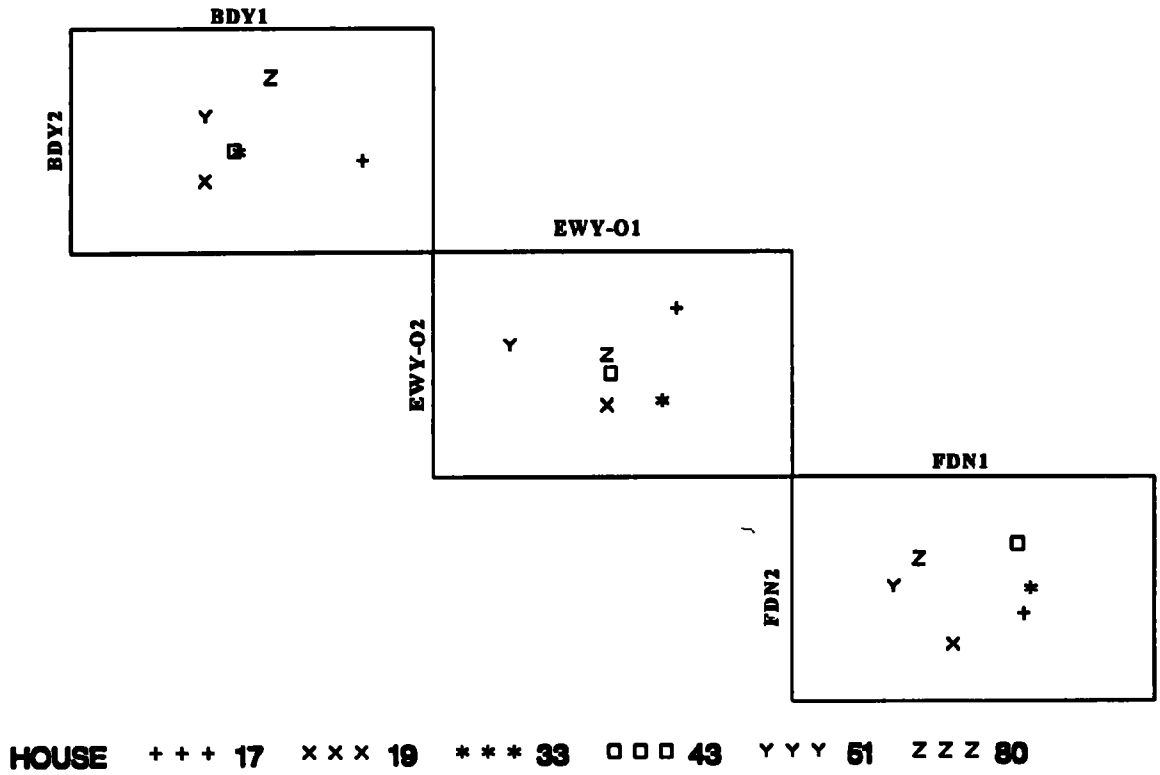

Figure 3b. **Plot of First Two Principal Components of Mean Log-Concentrations for Soil Samples.**

If patterns in the relationships of these eleven elements were affected by abatement or renovation history, then homes with similar histories would be clustered in Figures 3a and 3b. The figure allows inspection for such relationships separately by sample type. However, comparing the proximity of the houses to each other in Figures 3a and 3b, there do not seem to be any consistent groupings of houses across sample types. Substantive conclusions would require data from more than six houses.

2.3 RELATIONSHIPS AMONG THE ELEMENTS

2.3.1 Bivariate Relationships (Correlations)

Displays portraying the bivariate relationships among the eleven elements are provided in Figures 4a through 4i. For each sample type, average log-concentrations for each house are plotted for each pair of elements. Ellipses are drawn on each plot that represent 95% of the estimated bivariate distribution. Those plots for which the ellipse is narrow represent pairs of elements for which there was a strong observed correlation. Pairs of elements which are negatively correlated have an ellipse with the major axis running from upper left to lower right. The magnitude of the correlation can be inferred from the shape of the ellipse by comparing it to the key in Figure 5.

On the plots in Figures 4a-4i, each house is identified with a different symbol. This permits determining whether certain houses have similar characteristics with respect to the various elements and/or sample types.

The strongest relationships among the elements across houses were observed in foundation and boundary soil samples (Figures 4h and 4i). These correlations were strongest among aluminum, chromium, nickel, potassium, and titanium. Strong relationships were also observed among lead, calcium, chromium, and nickel in samples taken from bedcover/rug/upholstery (Figure 4e).

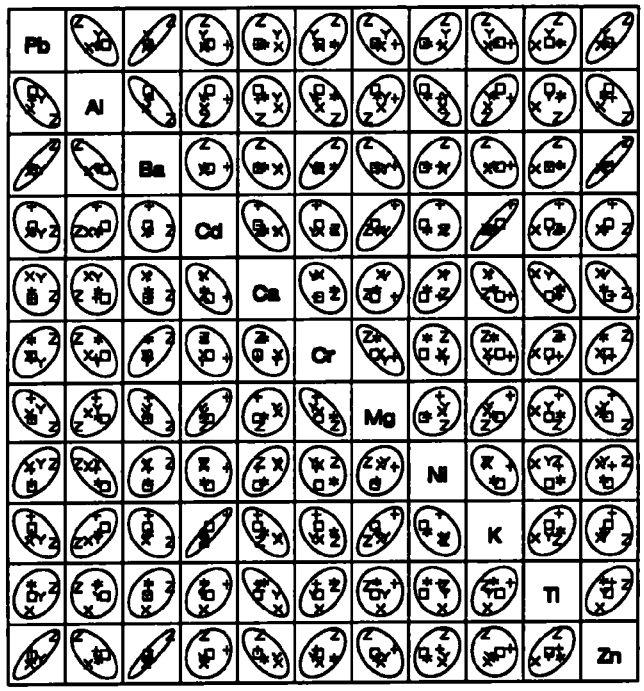

Figure 4a. Window Channel House Mean Correlation Scatterplot.

House Legend: * = 17 □ = 19 + = 33 X = 43 Z = 51 Y = 80

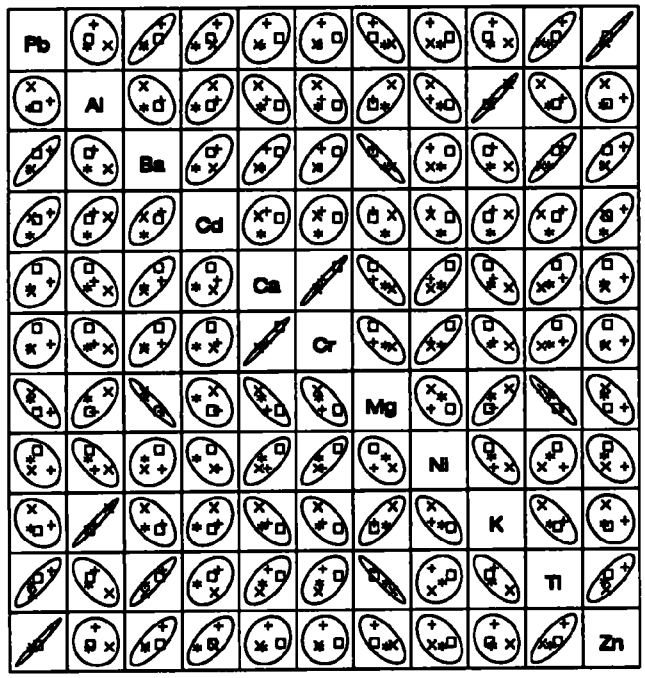

Figure 4b. Window Stool House Mean Correlation Scatterplot.

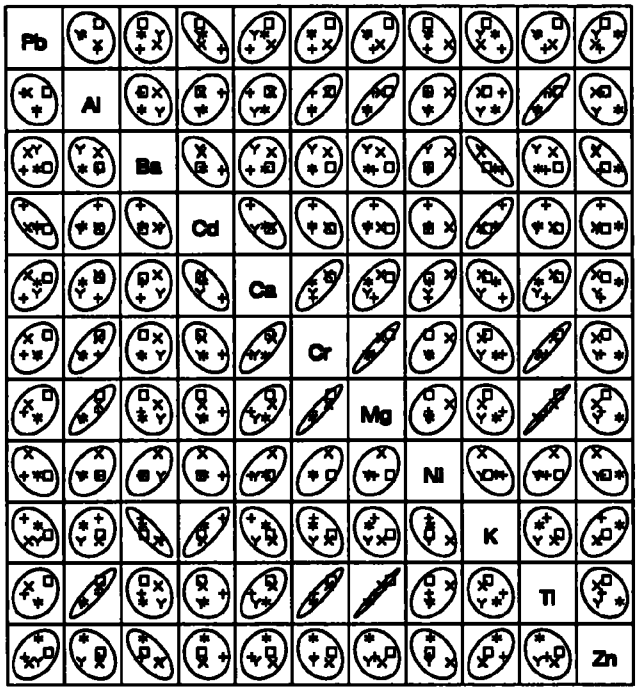

Figure 4c. Air Duct House Mean Correlation Scatterplot.

House Legend: * = 17 □ = 19 + = 33 X = 43 Z = 51 Y = 80

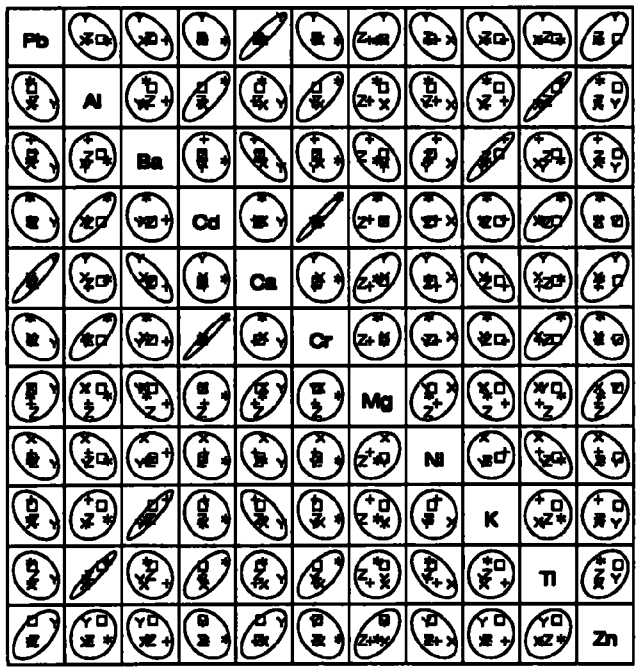

Figure 4d. Floor House Mean Correlation Scatterplot.

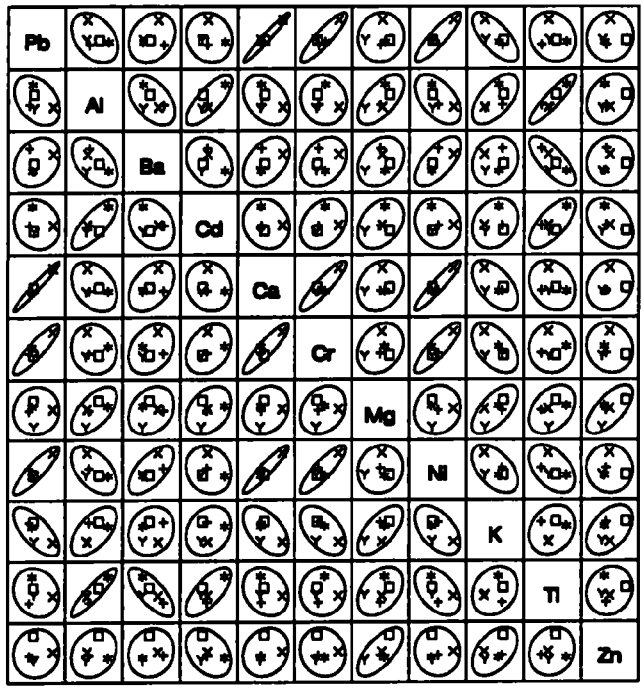

Figure 4e. Bedcover/Rug/Upholstery House Mean Correlation Scatterplot.

House Legend: * = 17 □ = 19 + = 33 X = 43 Z = 51 Y = 80

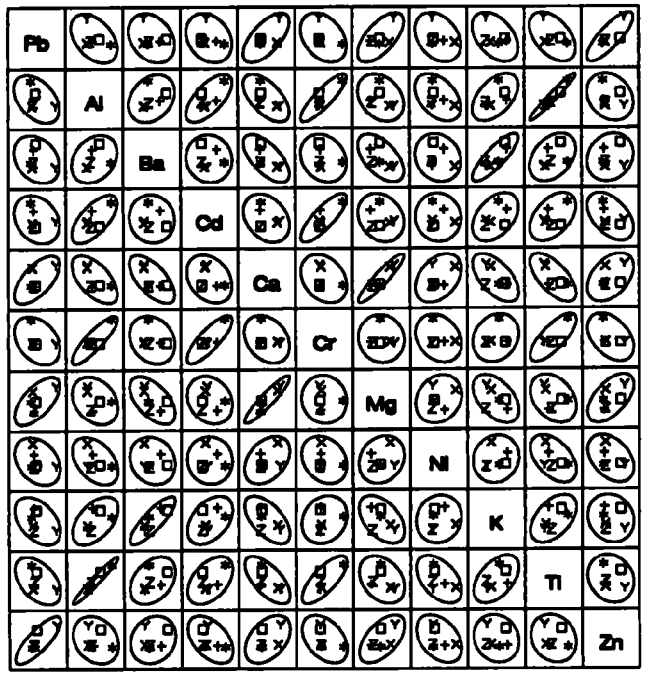

Figure 4f. Entryway Dust House Mean Correlation Scatterplot.

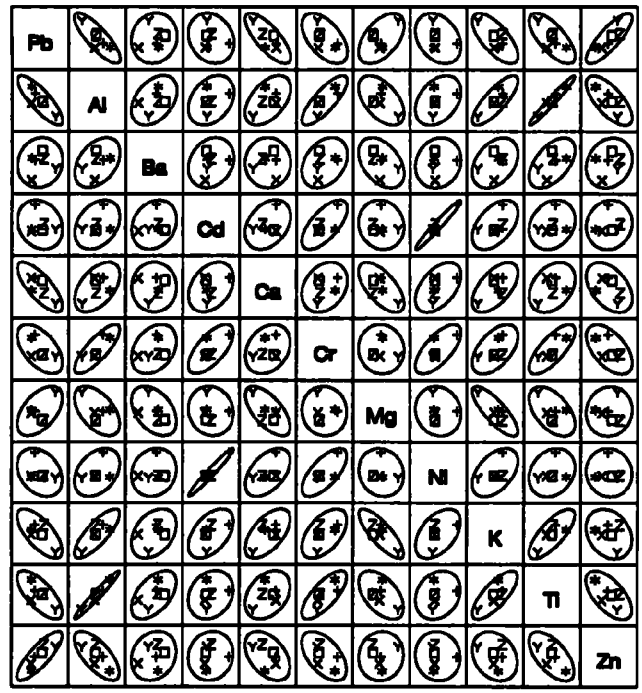

Figure 4g. Entryway Soil House Mean Correlation Scatterplot.

House Legend: * = 17 □ = 19 + = 33 X = 43 Z = 51 Y = 80

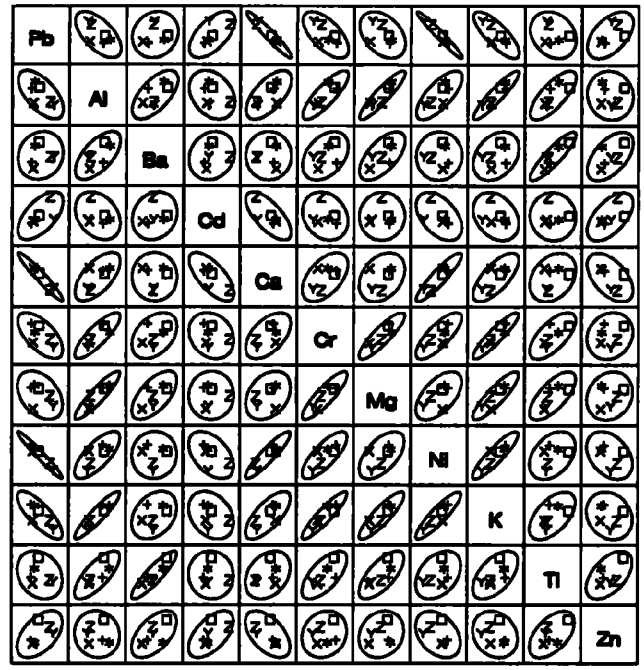

Figure 4h. Foundation Soil House Mean Correlation Scatterplot.

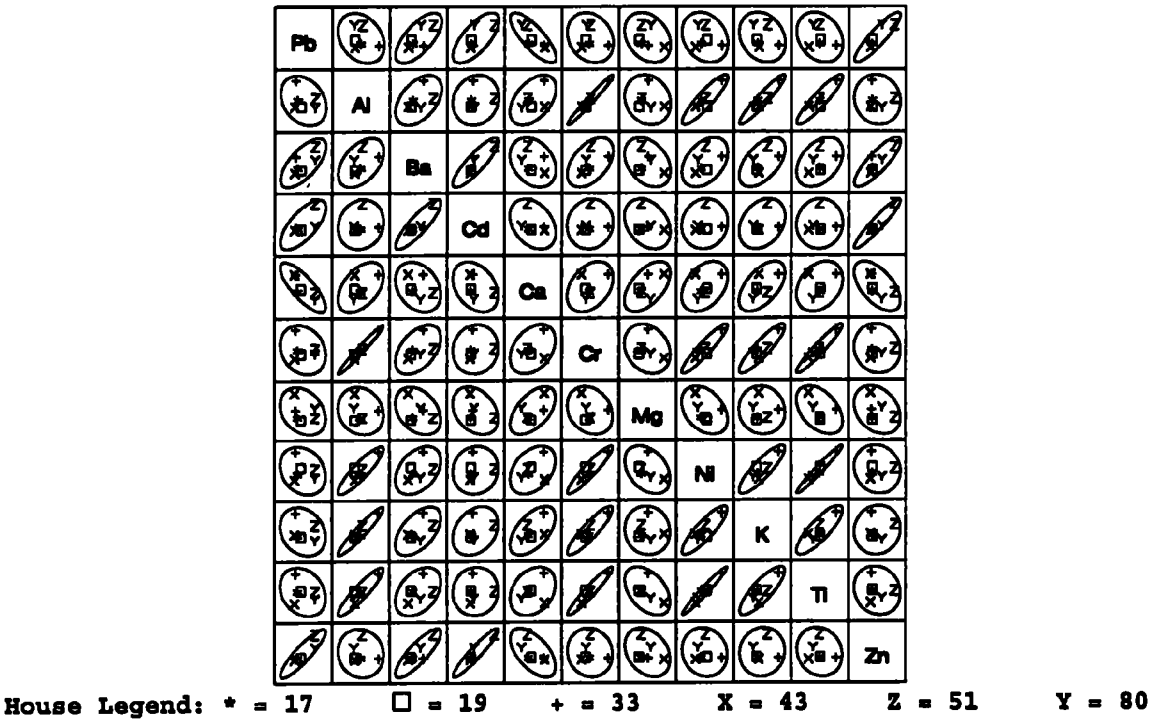

Figure 4i. Boundary Soil House Mean Correlation Scatterplot.

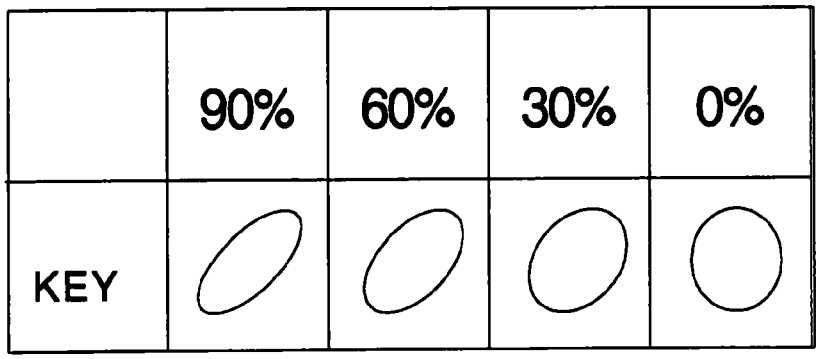

Figure 5. Key to Relation Between Shape of Ellipse and Observed Correlation in Figures 4a Through 4i.

Lead concentrations were most frequently correlated with zinc concentrations. High correlations were also observed on window stools among lead, titanium, barium, and zinc (Table 4b).

A slightly different categorization of sample types could be made based on the patterns observed in these scatter plots. Relatively consistent sets of bivariate plots were observed for the following groups of sample types: floor, interior entryway, and exterior entryway; boundary soil and foundation soil; and window stool and window well. Air ducts and bedcover/rug/upholstery samples do not appear similar to any of the groups mentioned nor to each other. These groupings of the sample types do not appear particularly surprising although one might have expected exterior entryway samples to be more like the other two soil samples than like interior floor dust samples.

The floor, interior entryway, and exterior entryway group displays consistent, strong bivariate relationships between aluminum and titanium, cadmium and chromium, and barium and potassium. As introduced above, the boundary and foundation soil group displays the strongest bivariate relationships, suggesting consistent correlations between lead and calcium; aluminum and chromium; nickel, potassium, and titanium; chromium and nickel; potassium and titanium; and nickel and potassium. The window channel and window stool group has consistent bivariate relationships among lead, barium, and zinc; chromium and magnesium (negative correlation); and titanium and zinc.

2.3.2 Multivariate Relationships (Principal Components)

For the estimated model parameters displayed in Tables 5, 6, and 7 (average log-concentrations in unrenovated unabated houses, increments in log-concentration associated with renovation, and increments in log-concentration associated with abatement), a second principal components analysis was performed across the nine sample types. The purpose of this analysis was not only to

identify consistent patterns in the composition of dust across different sample types (unrenovated, unabated house analysis), but also to determine whether abatement or renovation impacts different components in different ways.

The numerical results of the principal components analyses and plots of the first two principal components are displayed in Table 9 and Figure 6. Table 9 displays estimates of the coefficients for the first two principal components followed by the cumulative proportion of total variation explained by these components. Figure 6 displays the relationship between the first two principal components (the orthogonal directions in which the greatest variability was observed).

The first two principal components generally accounted for at least 68% of the total variability in the model parameter estimates. This means that although eleven elements were measured (lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc), most of the variation among the nine sample types occurred within a two-dimensional space (i.e., two linear combinations of the eleven element concentrations).

For averages in unrenovated, unabated houses it can be argued that the three soil sample types are grouped into one cluster; floor, entryway, window stool, bedcover/rug/upholstery, and air duct dust sample types form another cluster; and window channels stand alone. For the renovation effect, all samples are grouped into one cluster except for air ducts and bedcover/rug/ upholstery, which stand alone. One must recognize that air ducts and bedcover/rug/upholstery were not sampled in the fully renovated house. Therefore, the estimated impact of renovation on these sample types is less meaningful than on the other sample types which were sampled in the fully renovated house.

Table 9. Principal Components for Unrenovated, Unabated Home Averages, Abatement Effects, and Renovation Effects

Response	Principal Component	Principal Component Coefficients*											Cumulative Explained Variability
		Pb	Al	Ba	Cd	Ca	Cr	Mg	Ni	K	Ti	Zn	
Unrenovated Unabated Unit Means	1	0.20	-0.37	0.17	0.43	0.41	0.15	0.37	0.36	-0.09	-0.17	0.32	0.40
	2	0.48	0.20	0.48	0.04	-0.00	-0.32	-0.00	-0.28	-0.27	0.43	0.25	0.71
Abatement Effect	1	0.34	-0.37	0.30	0.11	0.07	-0.43	-0.43	0.16	0.09	-0.23	0.42	0.36
	2	0.35	0.29	0.31	0.31	-0.46	0.07	0.06	-0.34	0.10	0.44	0.22	0.68
Renovation Effect	1	0.02	0.40	0.43	-0.13	0.03	0.46	0.34	0.30	-0.22	0.40	-0.10	0.43
	2	0.47	-0.22	0.13	-0.15	0.40	-0.01	-0.15	0.33	-0.37	-0.23	0.45	0.83

*Coefficients are applied to the estimated parameters for each sample type to obtain maximum spread among sample types in two dimensions.

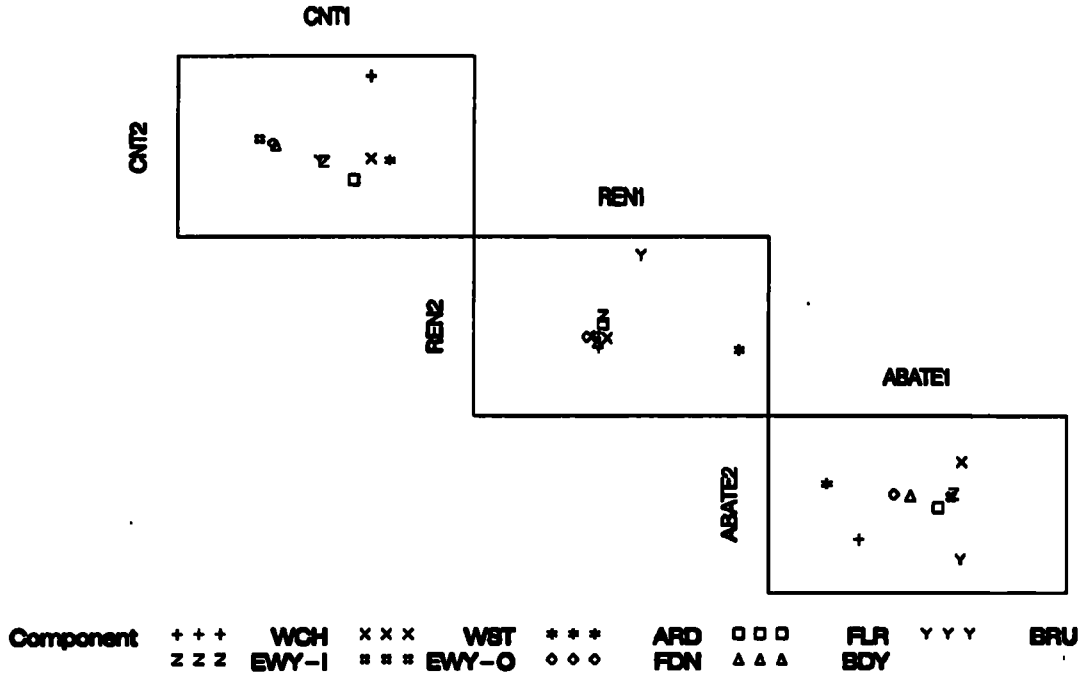

Figure 6. First Two Principal Components for Each Building Component, Plotted versus Each Other for Unrenovated, Unabated Unit Mean Log-Concentrations, Renovation Effects, and Abatement Effects.

For the abatement effects, there were no clear clusters or outlying sample types, but the three soil sample types appear close together in Figure 6, and interior entryway samples were right on top of exterior entryway samples, with floor dust samples nearby. This may be an indication that even after lead-based paint abatement, the composition of the soil near the foundation and entryway is similar to that of the soil at the boundary.

3.0 RESULTS OF ANALYSIS

The following results were obtained from statistical analyses of the multi-element data.

Characterization of multi-element concentration

1. Of those elements analyzed, calcium and aluminum had the highest concentrations in indoor dust and outdoor soil.

2. After controlling for abatement and renovation effects, concentrations of the elements provide for the following groupings of sample types:

   - air duct, window stool, and window channel dust;
   - floor, entryway, and bedcover/rug/upholstery dust; and
   - foundation, entryway, and boundary soil.

Effects of abatement and renovation on multi-element concentrations

3. Lead concentrations in dust and soil near the entryways of abated houses were three to five times the levels in unabated houses. The concentrations of lead in dust from floors and entryways of renovated houses were about five times those in unrenovated houses.

4. Calcium concentrations in the dust of renovated houses were significantly higher on window stools, floors, bedcovers/rugs/upholstery, and interior entryways. This difference was tenfold for bedcover/rug/upholstery and interior entryways.

5. Several other statistically significant effects were estimated for the remaining elements, but with little consistency across elements or across sample types.

Relationships among element concentrations for sample types

6. Of the ten elements measured besides lead, concentrations of zinc were most positively correlated with lead, both within sample types and across sample types.

7. The strongest bivariate relationships among the elements were observed in boundary and foundation soil samples; three groups of sample types were identified as having similar bivariate relationships among many of the elements; floor, interior entryway, and exterior entryway; boundary and foundation soil; and window channel and stool. The relationships among element concentrations in entryway soil are more similar to those in entryway dust and floor dust than to relationships among element concentrations in boundary and foundation soil.

8. A principal component analysis of estimated element concentrations in unrenovated, unabated houses by sample type suggested similarities in dust and soil composition within the following groups: 1) exterior entryway, foundation, and boundary soil, and 2) floor, interior entryway, window stool, air duct, and bedcover/rug/upholstery dust.

4.0 STUDY CONCLUSIONS

It was not possible to determine definitively from the data collected in the pilot study whether lead dust in the houses studied came primarily from paint or soil. However, bivariate relationships among the elements in soil outside entryways were more similar to those in interior floor dust (including entryway dust) than they were to those in soil samples taken near the foundation and boundary. This suggests that soil near the entryways is transported indoors and constitutes a portion of interior floor dust.

5.0 REFERENCES

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Tisdale, S. L., Nelson, W. L., and Beaton, J. D., Soil Fertility and Fertilizers, 4th edition, Macmillan Publishing Co., NY, 1985.

US EPA, 1996, "Comprehensive Abatement Performance Study, Volume I: Summary Report," EPA 230-R-94-013a.

US EPA, 1996, "Comprehensive Abatement Performance Study, Volume II: Detailed Statistical Results," EPA 230-R-94-013b.

APPENDIX A

SUMMARY OF MULTI-ELEMENT DATA

A-1. Multi-Element Data Listing

A-2. Geometric Mean Concentrations by Sample Type and Unit

Table A-1a. CAP Pilot Study Multi-Element Data, House 17

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	KIT	09	383	8970	187	16400	65.7	40 3	7740	3780	22.7	245	517[a]
		BD1	19	717	8660	173	16900	615	64 9	5790	3730	19.6	296	39900
	BRU	BD1	18	66.9	5140	434	19000	9.97	43 9	8100	3210	76.8	84.9	572
	EWY-I	EWY	20	282	10200	367	12300	19 6	36.5	8120	2290	27 3	285	426[a]
		EWY	21	259	10200	1100	16500	11.5	34.7	8420	3090	27 9	332	620[a]
	FLR	KIT	01	50 0	1690	742	14200	3.10	16.2	14400	2720	13.0	55.1	502
		KIT	03	254	6950	1840	23100	13.4	29 4	17200	3950	16.3	104	1340
		BD1	11	373	7290	742	15400	26.1	43 7	10000	2790	120	207	516[a]
		BD1	12	328	9280	875	8770	14.6	42 7	11500	2240	45.5	188	284[a]
		BD1	13	225	6090	698	33700	8.74	29 3	14900	4180	33 9	243	1750
		LVG	31	153	5170	442	13900	10.6	26 0	9870	2490	222	159	486[a]
		LVG	32	63.7	6460	165	7080	3.71	24 6	4600	1600	18 6	209	229[a]
	WCH	KIT	07	1140	268	915	22700	.[b]	45 0	481	4870	20 5	957	14900
	WST	KIT	06	221	6600	440	48000	114	23 6	31900	8460	159	323	1730
		BD1	14	727	16300	627	39100	198	35 8	3820	8040	23.1	552	10000
		BD1	16	338	12500	725	41700	191	38 6	4990	7360	22.2	368	4220
		LVG	36	506	4480	377	29700	39 5	42 9	8800	10900	188	243	2520
		LVG	39	270	12500	1820	21200	307	43 3	4920	3980	16 8	627	1310
		LVG	40	337	9770	2170	27200	146	50 8	6290	6380	27 1	505	1910[a]
Soil	BDY	LFT	26	52.2	26700	221	13100	2 68	44 6	6400	984	17 1	692	116
		BAC	27	70 5	20200	183	8260	2 33	38 5	5940	500	15.5	454	177
		LFT	28	56 4	25100	206	13300	2 61	43 8	5870	1030	16.4	643	108
	EWY-O	FRO	22	70 4	20400	196	12800	2.75	37 7	5360	540	15.1	486	181
		BAC	23	364	19600	440	14200	241	269	4570	614	238	582	499[a]
	FDN	LFT	24	70.2	20800	199	12200	2.81	40 9	5410	668	15 7	422	279
		BAC	25	69.4	18000	262	11300	2 62	39 2	4420	2570	13 9	391	345
		BAC	29	65.7	18200	171	11700	2.51	38.0	4460	2960	14.3	385	299

[a] Analysis result was greater than upper calibration limit; reported value is an estimated lower bound on the true Zn concentration
[b] Analysis result was greater than upper calibration limit for cadmium, sample excluded from data analysis.

Table A-1b. CAP Pilot Study Multi-Element Data, House 19

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	LVG	09[b]	69.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		BD1	19	624	8950	585	69600	23.7	146	3100	5100	313	351	1470
	BRU	LVG	08	482	6810	695	93800	12.7	187	1900	4600	389	265	1970
		BD1	18	485	2900	190	37000	8.51	81.4	1020	2430	112	104	341
	EWY-I	EWY	20	201	8660	275	140000	6.16	40.8	5400	6890	30.6	290	551
		EWY	21	184	6740	56.8	94800	10 1	40.1	2050	5990	47.6	241	583
	FLR	LVG	01	190	4560	179	177000	6.15	36.1	2890	7940	31.5	130	706
		LVG	03[b]	69 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		BD1	11	301	5500	598	20000	19.5	114	2470	3370	152	157	683
		BD1	12[c]	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00
		BD1	13	402	5690	831	58500	13.6	157	2140	3990	306	166	1520
		KIT	31	99.5	4250	103	9280	5.71	44.9	2290	2970	43.2	136	316[a]
		KIT	32	67 9	4330	53.1	8140	3.24	41.9	2270	2900	40.7	143	267[a]
	WCH	BD1	17[b]	368	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00
	WST	LVG	04	70.8	4130	74.1	149000	4.14	50.3	1200	12400	19.1	416	231
		BD1	16	215	7760	281	74200	37.4	77.8	2450	4050	116	385	2050
		KIT	36	177	4190	209	92700	17.0	30.3	1690	2620	47.3	166	944
Soil	BDY	FRO	26	98.2	10900	121	8320	2.30	24.6	3430	430	8.91	379[d]	161
		LFT	27	43.3	8340	116	11200	2.30	16.0	3490	1510	6.58	257	107
		LFT	29	44.2	8030	110	11700	1.63	15.3	2950	1510	6.49	223	130
	EWY-O	FRO	22	49.7	12800	131	12200	2.27	23.7	3430	491	10.3	383	161
		BAC	23	40.4	9280	128	13400	2.04	17.9	2840	370	11.7	285	278
		FRO	28	197	31300	409	15100	3.23	34.3	6980	985	13.8	753	281
	FDN	FRO	24	49.2	10200	116	12600	2.02	19.7	3010	403	8.01	295	143
		LFT	25	238	10500	228	12500	4.85	27.8	3190	378	21.0	374	461

[a] Analysis result was greater than upper calibration limit; reported value is an estimated lower bound on the true Zn concentration.
[b] ICP analysis hampered by calcium interference; no multi-element data reported.
[c] Sample dropped in lab, therefore, no multi-element data reported.
[d] The titanium concentration was originally reported as 0.38 µg/g This concentration was flagged in the outlier analysis, investigated, and revised to 379 µg/g. The outlier analysis is described in Appendix B.

Table A-1c. CAP Pilot Study Multi-Element Data, House 33

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	BD2	09	477	8030	206	76700	19.8	53.0	3670	3380	27.7	297	2620
		LVG	19	1610	3550	225	36800	65.6	40 7	8410	2190	44.6	120	104000
	BRU	LVG	18	117	12000	163	18200	25 4	69.1	6720	3560	17.6	387	448
	EWY-I	EWY	20	128	21700	226	21000	12 9	94.2	5800	5180	21.5	572	458
		EWY	21	88.4	17900	298	15900	30 0	523	5830	3870	12.7	558	482
	FLR	BD2	01	135	4910	357	42300	13 1	96.7	1830	3250	33.5	165	426
		BD2	03	183	4880	139	41800	40 9	85 2	1210	2940	15.1	195	646
		LVG	11	189	13100	300	20800	88 9	180	5100	3170	18.6	389	939
		LVG	12	128	12400	453	21500	66 1	190	5710	2950	19 6	314	866
		LVG	13	107	13400	167	23900	20 8	146	5850	4060	22 9	325	608
		KIT	31	116	13600	288	19000	35 7	516	5990	3490	20 9	386	609
		KIT	32	88.2	13200	301	20200	33.0	676	5600	3670	16.8	355	577
	WST	BD2	04	575	7040	488	37300	19.6	135	5960	4150	52.2	625	1180
		LVG	14	175	9740	594	26900	24.7	101	3730	3220	21.5	373	1500
		LVG	16	562	8050	1830	55800	11 0	87 0	3350	4440	24.6	480	1610
		LDY	36	581	3960	510	155000	10 1	85.8	1510	6780	17 1	283	1180
	WCH	LVG	17	7240	13300	7060	34900	29 7	39.1	2560	4240	17 9	656	13800
Soil	BDY	LFT	26	44 1	10900	121	12000	2 18	27.0	2980	474	9.59	321	165
		FRO	27	168	13200	161	5270	2 01	19 9	3060	497	7 58	443	112
	EWY-O	FRO	22	63 2	22800	252	8130	2 52	29 4	4190	495	10.8	730	140
		BAC	23	136	26200	401	12500	14 4	952	6240	849	13 1	667	243
		FRO	28	57	21500	280	8090	1.75	26.9	3530	494	6.78	575	122
	FDN	LFT	24	167	22000	356	12400	3.51	31.3	4960	3060	15.9	423	258
		FRO	25	108	22700	309	12900	3.27	28 4	3620	616	11.9	601	263
		LFT	29	176	25500	369	12300	4 17	36.8	5540	3350	13 3	498	285

Table A-1d. CAP Pilot Study Multi-Element Data, House 43

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Tl	Zn
Dust	ARD	LVG	09	1140	9150	243	63500	11.0	165	4100	6720	28.7	408	7810
	DIN	19[b]	611	.	.	.	.	.	.	.	.	.	.	
	BRU	LVG	08	102	6500	209	28000	6.00	40.0	9200	3860	25.6	198	2990
		DIN	18	195	11500	304	22100	6.15	37.6	7770	4100	25.8	344	1250
	EWY-I	EWY	20	263	13400	331	18200	5.26	35.3	9790	4530	18.9	486	763
		EWY	21	589	14300	2110	23300	6.91	26.2	6060	4460	16.5	467	2070
	FLR	LVG	01	147	6600	220	15100	4.71	33.8	7020	2940	23.7	198	1640
		LVG	03	205	7830	288	43300	7.26	30.2	31700	8090	26.1	257	989
		DIN	11	234	6920	420	30100	7.73	51.5	8610	3720	44.9	231	2870[a]
		DIN	12	256	8630	393	21900	8.12	42.0	6270	3450	21.5	237	1160
		DIN	13	149	7490	210	15000	4.59	44.1	6800	2920	15.0	262	1320
		KIT	31	308	10400	873	17800	8.23	47.0	7390	3150	20.4	291	949
		KIT	32	309	13400	593	25000	8.79	45.6	6910	4430	61.5	422	981
	WST	LVG	04	964	5170	521	47400	18.2	82.7	4590	4450	25.3	440	1340
		DIN	16	378	10500	512	20200	20.6	28.6	6630	4020	17.5	312	6950
		KIT	36	397	9170	443	33800	221	44.3	3550	4210	22 6	353	1160
	WCH	LVG	05	963	13700	384	56400	8.93	23.8	5340	14000	17.3	509	2540
		KIT	38	1430	35400	367	13100	72.3	32.5	4640	4540	18.8	244	1720
Soil	BDY	FRO	26	290	12600	203	12500	4.53	28.3	4780	491	12.1	473	221
		BAC	27	60.8	5340	83.2	5790	0 94	13.8	1740	301	9.57	314	88.7
	EWY-O	FRO	22	623	13800	374	12100	6.58	28.7	3810	494	11.8	326	492[a]
		BAC	23	205	19400	374	13100	2 83	32.1	4550	506	11.7	741	300
		BAC	28	304	15700	284	13000	2.45	25.9	3880	493	10.8	497	272
	FDN	FRO	24	337	18500	460	10000	5.39	41.8	3800	3070	12.6	601	812
		BAC	25	181	21600	339	15800	3.80	36.4	4740	610	14.1	723	561
		FRO	29	245	19400	337	8240	4.29	34.6	3800	2410	12.0	577	488[a]

[a] Analysis result was greater than upper calibration limit; reported value is an estimated lower bound on the true Zn concentration.
[b] ICP analysis hampered by calcium interference; no multi-element data reported.

Table A-1e. CAP Pilot Study Multi-Element Data, House 51

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	EWY-I	EWY	20	640	8490	234	130000	6.98	22.5	2320	7220	13.7	294	743
		EWY	21	4030	7110	75 5	127000	11 6	37.8	1630	7430	19.8	211	2760
	FLR	BAT	01	2450	4410	93 0	134000	8 78	20.7	1860	8590	36 0	149	3390
		BD3	11	966	6340	43 2	26400	7.50	25.8	2080	3010	15.3	188	966[a]
		BD3	12[b]	467	116	86 2	14800	1 72	5 59	815	1020	3 40	44.1	304
		BD3	13	712	5060	135	113000	5 30	16.8	1920	5590	13 5	175	782
		BD1	31	1780	5690	1430	91300	7 19	26 7	1690	3690	12.8	226	1440
		BD1	32	1760	6090	325	39300	6 44	22 9	2050	3140	11 9	260	1470[a]
		BD3	44	646	3290	27 0	17700	4.37	14 1	1760	2010	8 02	117	657[a]
	WST	BAT	06	6370	4020	679	154000	19 9	31.1	905	9290	165	259	4110
		BD3	14	774	7950	278	92300	4 73	22.9	2170	4730	90 4	345	835
		BD3	16	670	9160	314	77300	6 08	30.3	3110	4820	18 9	407	866
		BD1	40	3580	6950	746	77500	7 00	26.1	2780	5120	24.4	486	2170
	WCH	BAT	07	2730	4830	1190	123000	13 2	26 1	901	14500	52.5	362	3200
		BD3	15	421	13300	288	13500	6 71	33 6	3280	4390	22.0	485	753
		BD3	17	493	12500	300	15600	5 21	33 8	3410	4560	19.5	570	549
Soil	BDY	FRO	26	346	7760	207	5930	3.86	24 6	2220	304	11.2	306	314
		BAC	27	329	8190	177	6560	2.55	19 2	2600	1490	6 14	305	235
		BAC	29	300	7390	178	7070	2.40	16 9	2430	1690	5 83	271	217
	EWY-O	FRO	22	899	8710	232	4100	4.51	22 4	2290	1900	6 90	342	433
		BAC	23	505	9130	269	5800	3 74	23 1	2650	302	7 70	324	376
	FDN	FRO	24	938	9170	258	5450	4 13	15.9	1610	384	7 51	378	533
		BAC	25	539	9210	262	7960	3 81	22.5	2430	1520	7.10	343	377
		BAC	28	426	9320	257	7520	3 16	20 2	2310	295	6.90	346	340

[a] Analysis result was greater than upper calibration limit, reported value is an estimated lower bound on the true Zn concentration

[b] During initial sampling attempt, cartridge filled with sawdust prior to completion of sample collection. Sample was excluded from lead analysis and multi-element analysis.

Table A-1f. CAP Pilot Study Multi-Element Data, House 80

Sample Identification				Concentrations (µg/g)										
Medium	Type	Location	Sample ID	Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
Dust	ARD	BAT	09	1700	5810	1640	49700	6.65	84.0	2210	3760	37.6	225	5960
		BD3	19	965	5270	366	32200	7.79	78.8	3480	2280	12.4	209	1170*
		KIT	45	389	3610	470	13400	5.52	16.9	3420	1820	10.1	103	1240
	BRU	BAT	08	344	7780	263	41100	5 69	36.1	2510	2950	15.2	272	664
		BD3	18	66.3	2100	101	7620	4.79	33.3	1140	1180	42.5	117	136
	EWY-I	EWY	20	342	11800	303	25000	8.61	33.3	4990	3710	27.8	389	703
		EWY	21	222	7440	257	9620	4.00	28.9	670	2350	8.82	301	468
	FLR	BAT	01	1210	6870	1010	51000	5.37	31.2	3850	2990	14.6	226	1640
		BAT	03	649	8730	572	32800	4.37	32.4	4380	2860	18 5	198	1180
		BD3	11	180	3720	186	13900	9.25	46.1	3520	1510	51.2	155	436
		BD3	12	175	4810	176	18000	5.09	59.4	5050	1940	19 5	177	508
		BD3	13	243	6430	240	9710	5.33	44.3	3840	1720	14.8	224	326*
		KIT	31	182	4950	323	18200	4.23	25.4	2540	1890	10.6	239	436
		KIT	32	223	5510	350	15100	7.98	56.7	3840	2290	21.5	243	514
	WST	BAT	06	61600	610	30300	21300	30.8	151	1540	5080	42.4	181	35100
		BD3	14	680	6120	1380	38200	17.2	66.0	348	3160	99.3	426	1630
		PAN	36	535	5200	658	105000	7.85	60.1	2470	2740	15.9	630	2590
		KIT	39	7880	3830	29400	29300	23.3	104	745	2430	35.4	494	7560
		KIT	40	4660	6260	6560	45900	20.1	206	3150	2710	140	461	3470
	WCH	BD3	15	938	11600	846	51000	17.6	49.7	3340	5030	15.6	439	1850
		KIT	41	4550	8140	22500	65400	23.1	94.8	959	4060	21 5	715	4830*
		KIT	42	5790	11400	10900	29500	30.4	97.7	1810	3750	147	568	4510*
Soil	BDY	FRO	26	308	13000	246	8320	9.30	24.0	4220	489	9.51	437	394
		BAC	27	343	13400	279	7260	6.19	24.8	4660	493	11.0	326	396
	EWY-O	FRO	22	380	16400	282	6960	9.88	31.3	4970	489	12.3	486	385
		BAC	23	350	15200	288	10500	7.69	31.9	4710	502	11.5	501	417
		BAC	28	412	17600	340	8230	8.29	31.8	5220	487	13.8	528	492*
	FDN	LFT	24	942	17300	414	6940	14.0	32.9	4440	772	13.8	564	973
		BAC	25	459	8810	202	5160	6.06	23.0	2470	1510	7.43	322	345
		BAC	29	317	8890	198	7430	7.56	23.8	2570	1500	8.05	288	377

*Analysis result was greater than upper calibration limit; reported value is an estimated lower bound on the true Zn concentration.

Table A-2. Geometric Mean Concentration by Sample Type and Unit

Sample Type	House	Interior Abatement History	Exterior Abatement History	Renovation	Samples Taken in Unit	Geometric Mean Concentrations (µg/g)										
						Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
WCH	33	U	U	None	1	7238 3	13345.9	7057 8	34866 1	29.66	39.05	2563 4	4237.1	17.86	655.7	13782.9
	43	R	R	None	2	1174 9	22025.3	375 5	27181.3	25 40	27.82	4977.4	7979.5	18 02	352.5	2089 1
	51	E	R	Full	3	827.6	9305.9	469.3	29601.8	7.73	30 92	2158.1	6625.4	28.21	464.2	1097.5
	80	E	E	None	3	2913 6	10248.9	5915.2	46139.1	23.09	77.22	1794.5	4244.4	36.69	563 0	3426 6
WST	17	R	E	None	6	368 3	9505.7	817 6	33201.3	140.20	38.12	7410.0	7191 9	43.74	414.4	2781.5
	19	U	U	Partial	3	139.2	5120.0	163.3	100782.1	13.80	49.10	1708.4	5090 4	47 15	298.3	765.2
	33	U	U	None	4	425 4	6836.3	721 8	54305 9	15.22	100.43	3260 0	4478.2	26 21	422 0	1354.3
	43	R	R	None	3	525.1	7928.2	490 7	31861 3	43.54	47.14	4764.2	4222.3	21 50	364 5	2212.6
	51	E	R	Full	4	1854.4	6718.3	458.6	96019.2	7 96	27 40	2030.3	5742.0	51.21	364 8	1594.7
	80	E	E	None	5	3828 3	3416 5	5556.1	40917.9	18.10	105 18	1254.4	3105 9	50 58	406 3	5223.5
ARD	17	R	E	None	2	510 6	8813 8	179 9	16615.1	201.09	51 14	6695.5	3759.1	21 10	269.7	4537.5
	19	U	U	Partial	1	624 4	8948 0	585.1	69610.2	23.72	145 95	3097.1	5103.5	312.90	351.4	1465 9
	33	U	U	None	2	874 6	5340.9	215.5	53114 2	36.02	46.41	5553.4	2719.4	35 15	188.4	16503.7
	43	R	R	None	1	1137 7	9152 4	243.1	63535.5	11.03	164.75	4100.3	6724 6	28 70	408.4	7806 0
	80	E	E	None	3	861 2	4800 0	655.5	27795 2	6.59	48 20	2971 9	2497 4	16.77	169 6	2053 8
FLR	17	R	E	None	7	165 5	5548.9	642.6	14686 3	9.17	28 83	10974 0	2726.5	39.95	151.1	568 7
	19	U	U	Partial	5	173 1	4830.6	217.4	27470 5	7.87	65.56	2398.4	3911.9	76 26	145.9	573 1
	33	U	U	None	7	130 7	9921 4	267.2	25622 3	35 89	203.43	3854.7	3341.5	20 42	290 5	647 6
	43	R	R	None	7	220 9	8504.5	380.0	22451 7	6 86	41.41	8828.0	3844.8	27 29	264.2	1310 1
	51	E	R	Full	6	1227 1	5024 0	137 8	54204 6	6.43	20.63	1890.0	3870.5	14 44	179 6	1235 2
	80	E	E	None	7	304 8	5668 4	338 8	19605 1	5 71	40 40	3789 6	2109.9	19.03	206 6	609 7
BRU	17	R	E	None	1	66.9	5139 3	433 8	19032 9	9.97	43 85	8097 0	3210.0	76 84	84 9	572.3
	19	U	U	Partial	2	483.3	4444.6	363.7	58943 0	10 41	123 27	1395.4	3342.6	208.42	166 3	819.4
	33	U	U	None	1	116.9	11954 3	162 5	18229.9	25 44	69 06	6723.0	3558 3	17.55	387 4	447 8
	43	R	R	None	2	141.3	8630.5	252 1	24888 9	6 07	38 78	8456.8	3977.0	25.69	260 9	1931 2
	80	E	E	None	2	151.1	4040 3	163 2	17692 3	5 22	34.67	1688.3	1867.1	25.43	178 7	300.7
EWY-I	17	R	E	None	2	269.9	10232.5	636.0	14240 0	14 99	35 56	8268.5	2659.3	27 59	307.6	513.8
	19	U	U	Partial	2	192.6	7640.8	125.0	114992.3	7.88	40 40	3326.8	6423.5	38.19	264.3	566.6
	33	U	U	None	2	106 4	19721.0	259.4	18226.2	19 71	221.98	5812.2	4477.7	16.55	565 2	469 9
	43	R	R	None	2	394 0	13844.0	835.8	20562.2	6.03	30.42	7701.6	4497 6	17.63	476 5	1255 7
	51	E	R	Full	2	1605 4	7773 1	133.0	128563.4	9.00	29 12	1944.0	7325.5	16 46	249.1	1432.1
	80	E	E	None	2	275 4	9357.4	279.1	15521.7	5.87	30 99	1828 9	2953 4	15.66	341 8	573 6

U = unabated, R = removal, and E = encapsulation/enclosure

Table A-2. (Continued)

Sample Type	House	Interior Abatement History	Exterior Abatement History	Renovation	Samples Taken in Unit	Geometric Mean Concentrations (µg/g)										
						Pb	Al	Ba	Ca	Cd	Cr	K	Mg	Ni	Ti	Zn
EWY-O	17	R	E	None	2	160.1	19994.7	293.5	13488.9	25.75	100.69	4950.2	575.9	59.90	532.3	300.2
	19	U	U	Partial	3	73.3	15510.8	190 1	13527.8	2.46	24.38	4083.4	563.6	11.83	434.5	232.7
	33	U	U	None	3	78.8	23437.0	304.8	9360.6	3.99	90.97	4517.1	591.9	9.85	654.3	160.7
	43	R	R	None	3	338.4	16152.0	341.1	12687.1	3.57	28.76	4069.0	497.6	11.39	493.4	342.3
	51	E	R	Full	2	673.7	8916.5	249.5	4876.6	4.11	22.75	2461.6	757.7	7.29	333.0	403.5
	80	E	E	None	3	379.6	16376.5	302.3	8453.0	8.57	31.68	4962.2	492.6	12.51	504.5	429.4
FDN	17	R	E	None	3	68.4	18939.6	207.4	11734.0	2.64	39.32	4740.2	1718.7	14.63	398.8	306.6
	19	U	U	Partial	2	108.3	10368.0	162.2	12527.0	3.13	23.43	3096.0	390.2	12.96	331.9	257.1
	33	U	U	None	3	146.9	23354.5	343.9	12542.9	3.63	31.99	4632.8	1848.8	13.59	502.1	268.6
	43	R	R	None	3	246.0	19783.7	374.5	10929.7	4.45	37.50	4092.1	1652.2	12.88	630.4	605.7
	51	E	R	Full	3	599.4	9231.2	259.0	6884.4	3.68	19.34	2081.4	556.2	7.17	355.5	408.9
	80	E	E	None	3	515.4	11057.3	254.5	6432.2	8.62	26.19	3045.3	1204.9	9.38	374.2	502.1
BDY	17	R	E	None	3	59.2	23827.4	202.5	11296.0	2.54	42.19	6063.7	797.2	16.32	587.0	130.4
	19	U	U	Partial	3	57.3	9015.6	115.6	10270.8	2.05	18.17	3280.7	993.6	7.25	278.8	131.0
	33	U	U	None	2	86.0	11982.1	139.7	7961.7	2.09	23.19	3019.1	485.7	8.53	377.2	135 6
	43	R	R	None	2	132.6	8192.7	130.0	8519.8	2.06	19 74	2880.7	384.3	10.77	385.3	140.1
	51	E	R	Full	3	324.7	7773.8	186.7	6504.0	2.87	19.98	2413.1	914.8	7.37	293.8	252.1
	80	E	E	None	2	324.8	13198.4	261.9	7770.7	7.59	24.40	4435.5	491.3	10.25	377.5	395.2

U = unabated, R = removal, and E = encapsulation/enclosure.

APPENDIX B

OUTLIER ANALYSIS FOR THE CAPS PILOT MULTI-ELEMENT DATA

APPENDIX B

OUTLIER ANALYSIS FOR THE CAPS PILOT MULTI-ELEMENT DATA

B-1 INTRODUCTION

This appendix documents the statistical outlier analysis performed on the CAPS Pilot multi-element data. The statistical approach employed, the outliers identified, and the results of the laboratory review of the outlier data are discussed.

Two outlier tests were applied to the multi-element data. The first was a univariate outlier test, which evaluates one element at a time. This is the same test that was previously applied to the lead data. The test was applied to the natural logarithms of the concentrations for lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium, and zinc. The second test was a multivariate outlier test, which evaluates measurements for all eleven elements simultaneously. The multivariate test detects measurements which for a single element may not be an outlier, but when viewed in combination with the other elements is inconsistent with the majority of the data. Before performing the outlier tests, groupings of the data were defined.

B-2 DATA GROUPING

The following homogeneous groups of data were identified for each indicated sample type:

- Vacuum Cassette Samples (7 groups): air duct, upholstery (including bed coverings and throw rugs),

interior entryway, floor (excluding entryway), window stool, window channel, and floor (including entryway);

- Soil Samples (4 groups): boundary, foundation, exterior entryway, and all exterior samples combined.

Initially, data for all six units in the Pilot Study were combined before performing the univariate and multivariate outlier tests on these groups. When there were sufficient data, subsequent univariate outlier tests were also performed by segregating the data in each group by abatement method and by housing unit. Segregating by abatement method and unit was not done for the multivariate test due to the need for larger sample sizes with the increase in dimensionality.

B-3 METHODS

The details of the univariate and multivariate outlier tests are given in the following sections.

B-3-1 Univariate Outlier Test

Formal statistical outlier tests were performed on the natural logarithms of the concentrations for lead, aluminum, barium, cadmium, calcium, chromium, magnesium, nickel, potassium, titanium and zinc. Data were placed into groups of comparable values, and a maximum absolute studentized residual procedure was used to identify potential outliers. The SAS procedure GLM (SAS PC, ver. 6.08) was used to compute the studentized residual for each data value in a group by fitting a "constant" model (i.e., mean value plus error term) to the log-transformed data in each group. The absolute values of the studentized residuals were then compared to the upper .05/n quantile of a student-t distribution with n-2 degrees of freedom, where n is the number of data values in the group. If the maximum absolute studentized

residual was greater than or equal to the .05/n quantile, the corresponding data value was flagged as a potential outlier. When a potential outlier was identified, that value was excluded from the group, and the outlier test was performed again. This procedure was repeated until no more outliers were detected.

B-3-2 Multivariate Outlier Test

The multivariate outlier test is based on the Hotelling T-squared statistic, with one major difference. The Hotelling T-squared statistic is discussed in most multivariate statistics texts, such as Multivariate Statistical Methods, Second Edition, by Donald F. Morrison, copyright 1967, 1976 by McGraw-Hill, Inc., page 131. The difference in the statistic used here is that, in computing the statistic for the i^{th} observation, that observation is excluded from the computation of the mean vector and the variance-covariance matrix. This yields estimates of location and covariance that are unaffected by the observation in question and lead to a more robust outlier test. This is a multivariate extension of the univariate studentized residual used for the univariate outlier test. Under assumptions of normality, the resulting statistic has an F distribution, with numerator degrees of freedom equal to p (the number of elements) and denominator degrees of freedom equal to a function of p and the sample size, N. In this case, p was equal to eleven.

The observation corresponding to the maximum value of the statistic in a data group was declared a potential outlier if the statistic exceeded the (1-.10/N) quantile of the F distribution with appropriate degrees of freedom. When a potential outlier was identified, that sample was excluded from the group, and the outlier test was performed again. This procedure was repeated until no more outliers were detected.

B-4 RESULTS OF OUTLIER ANALYSIS

The potential outliers identified by these two tests were screened by a statistician to eliminate those that were merely numerical anomalies due to very small sample sizes. The remaining outliers identified by the univariate test are listed in Table B-1, and those identified by the multivariate test are listed in Table B-2. These lists of the remaining outliers were sent back to the laboratory for verification. One outlier was confirmed by the laboratory as an error and is documented in the footnote to Table A-1b. All remaining outliers were verified and declared by the laboratory to be correct as reported.

Table B-1. Univariate Outliers Detected by Univariate Methods

Sample Processing Batch	House ID/ Sample ID	Concentration (µg/g)						
		Al	Ba	Cd	Cr	Ni	Ti	Zn
CLS	33/20				94.18			
CRS	33/21				523.19			
SSS	33/23			14.43	951.74			
CSS	33/31				515.97			
CSS	33/32				676.48			
SSS	43/22			6.58				
SSS	43/26			4.53				
SSS	43/27			0.94	13.75			
CSS	43/11							2866.97
CSS	43/32						422.12	
CKC	43/36			220.60				
CKC	17/01				16.00		55.00	502.00
CLS	17/03						104.36	
SSS	17/23			241.07	268.94	238.11		
CLS	19/04							231.35
CLS	19/08				186.60			
CLS	19/13							1520.83
SSS	19/25			4.85				
SSS	19/26						0.38	
CLS	17/19			615.27				
SKI	43/24			5.39				
SSS	19/28						753.13	
CLS	19/36						165.58	
CRS	80/06	609.89	30315.04				181.30	35121.27
SSS	80/24			13.98			564.27	972.71
SSS	80/26			9.30				
SSS	80/27			6.19				
CLS	80/09							5963.48
CLS	80/45				16.92			
CSS	80/39		29402.19					
CSS	80/41		22466.22					
CRS	51/12			1 72	5.59		44 14	
CLS	51/20				22.45			
SSS	51/24							533.06
SSS	51/26			3 86				
CRS	33/19				99.07			
CRS	43/16							306.14

Table B-2. Outliers Detected by Multivariate Methods.

Sample Processing Batch	House	Sample ID	Concentration (µg/g)										
			Pb	Al	Ba	Cd	Ca	Cr	Mg	Ni	K	Ti	Zn
CLS	17	03	253.91	6949.83	1841.07	13 39	23113.58	29.35	3950.11a	16.27	17158.68	104.36a	1338.25
CKC	17	01	50	1694	742	3 1	14246	16.19	2724	13	14419	55 07	502
CRS	80	06	61573.85	609.89	30315.04	30.83	21251.35	151.36	5080.89	42.43	1536.03	181.3	35121.27
SSS	51	26	345.81	7761.56	206.56	3.86	5934.11	24.57	303.99	11.18	2224.18	306.4	313.77
SSS	17	23	363 88	19585.58	439.75	241.07	14160.18	268.94	614.15	238.11	4570.6	582.48	499.30
SSS	33	23	135.78	26178.44	401.46	14.43	12471.77	951.74	848.89	13.06	6241.22	667.37	243.15