National Survey of Lead and Allergens in Housing

DRAFT FINAL REPORT

Volume II: Design and Methodology

Revision 6.0

Prepared for:

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TABLE OF CONTENTS

List of Appendices

List of Tables

List of Figures

1. INTRODUCTION

The National Survey of Lead and Allergens in Housing was conducted under the sponsorship of the U.S. Department of Housing and Urban Development (HUD) and the National Institute of Environmental Health Sciences (NIEHS) to assess children's potential household exposure to lead and allergens, i.e., estimate the levels of lead in dust, soil, and paint, the prevalence of hazardous levels of lead, and levels and patterns of various indoor allergens in dust in homes. Sections 2.4 and 2.5 describe the sample design and weighting, respectively, for a subset of 481 homes at which play area soil was sampled.

1.1 Background

Volume II presents a detailed description of the design and methodology of the National Survey of Lead and Allergens in Housing.

For background information on prior studies and surveys related to lead hazards in homes, a discussion of the purpose and use of this survey data, the major lead hazard findings, and sources of error in the data, refer to Volume I of this report.

For a detailed description of the survey data files, including file formats and layouts, definitions of variables, algorithms for derived variables, and data dictionary, the reader is referred to the *Survey Data Documentation Report*.

Allergen results were reported to HUD in a separate report, *Report on Allergens in Beds*.

Before the survey was implemented, the plan for the survey was submitted to the applicable authorities required by Federal law for their review and approval. All required approvals were received before the survey was implemented. Specifically, the proposed information collection was submitted to the Office of Management and Budget (OMB) for review, as required by the Paperwork Reduction Act of 1995 (44 U.S.C. Chapter 35). In addition, the survey plan was reviewed and approved by the NIEHS and Westat Institutional Review Boards, in compliance with the Public Health Service Act (45 CFR 46, Protection of Human Subjects). The review processes are described in Chapter 3.

1.2 Report Organization

The report for the National Survey of Lead and Allergens in Housing consists of two volumes: Volume I presents the major lead hazard findings and Volume II presents the survey design and methodology.

There are six chapters in Volume II, including the introduction. Descriptions of each chapter are as follows:

- Chapter 2 presents the survey objectives and the multi-stage statistical sampling design, including a discussion of weighting.
- Chapter 3 describes the procedures used for identifying, screening and recruiting respondents into the survey.
- Chapter 4 details the field data collection protocols, including staffing, questionnaire administration, environmental testing and sampling, and sample handling.
- Chapter 5 details the analytical methodologies used to analyze the various environmental samples collected.
- Chapter 6 summarizes each element of the quality assurance plan for the survey and describes the database developed for the survey data.

1.3 Objectives of Volume II

Volume II describes the design and field data collection protocols used in conducting the National Survey of Lead and Allergens in Housing. Volume II is intended for a technical audience who possess a general vocabulary and understanding of survey research and environmental data and sample collection. However, every attempt is made to clearly define and discuss the protocols. Readers are referred to Volume I for a summary of procedures and significant findings of the survey. Readers are referred to the *Data Documentation Report* for a detailed description of the data files.

2. SURVEY DESIGN AND WEIGHTING

In order to meet the study objectives, a nationally-representative sample of 1,984 housing units[1] was drawn and fielded in 75 clusters called *primary sampling units* (PSUs). Samples of dust and soil were collected, painted surfaces were tested, and a resident questionnaire was administered for each of the 831 qualified housing units (HUs) screened and recruited from the sample. A five-stage sample design was utilized to accomplish these goals as efficiently as possible. Each stage of sampling is discussed in Section 2.2. Section 2.3 describes the weighting for the survey estimates.

2.1 Survey Objectives

HUD's principal purpose for the National Survey of Lead and Allergens in Housing was to assess children's potential household exposure to lead and allergens, i.e., estimate the levels of lead in dust, soil, and paint, the prevalence of hazardous levels of lead, and levels and patterns of various indoor allergens in dust in homes. In addition, HUD desired that the survey data provide:

1. Estimates of the number and percent of homes with dust and soil lead levels with respect to selected thresholds, especially those in the 1995 HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* (the "*Guidelines*") and HUD's Lead Safe Housing Rule (24 CFR 35, etc. *Requirements for Notification, Evaluation and Reduction of Lead-Based Paint Hazards in Federally Owned Residential Property and Housing Receiving Federal Assistance, Subpart R – Methods and Standards for Lead-Paint Hazard Evaluation and Hazard Reduction Activities*, effective September 15, 2000).

2. Data to identify sources of lead in dust in housing: e.g., paint and soil.

3. Data to permit future analysis of lead hazard control strategies and costs: e.g., quantities of deteriorated, friction and impact painted surfaces.

4. Data to permit future analysis for regulation, policy and guidance that minimize regulatory and program implementation burden.

[1] A housing unit is defined as a house, apartment, mobile home, a group of rooms, or a single room that is occupied as separate living quarters. Separate living quarters are those in which the occupants live and eat separately from any other persons in the building and which have direct access from the outside or through a common hall.

The study was not intended to determine appropriate lead hazard control strategies or costs for each home. Instead, basic data necessary for selecting a lead hazard control strategy was collected (e.g., total area of contaminated surfaces within a home, area of damaged paint within a home, probable cause of paint damage, lead content of paint and soil, etc.) Cost data were not collected because data on unit costs are available and updated from other sources (NSLSH, 1998). Thus, if and when HUD wishes to estimate lead hazard control costs, the study data on existing lead hazards would be combined with the most current unit cost data to generate required estimates.

NIEHS's principal purpose for the survey was to develop a scientific description of the existing allergen types and levels on floors and furniture in the Nation's housing. In addition, NIEHS desired the survey of allergens in homes to provide:

1. Estimates of the number and percent of homes with allergen levels above selected thresholds (e.g., dust mite allergen above 2 μg/g dust and 10 μg/g dust; cockroach allergen above 10 units/g dust).

2. Data to facilitate evaluation of regional, ethnic, socioeconomic, and/or housing characteristic differences in allergy burden.

3. Baseline data to be used as a reference point for future allergen surveys.

The study was not intended to determine appropriate allergen control strategies or costs. Instead, basic data necessary for selecting and applying allergen strategies were collected (e.g., distribution of allergens within homes, geographic differences in the allergen burden).

2.1.1 Measures of Interest

In order to develop the statistical sampling design, the general study objectives stated above were translated into specific statistical objectives, i.e., specific parameters to be estimated from the data. The following parameters were of interest to HUD and NIEHS in meeting the stated objectives:

- Percentage of homes with dust lead loadings and soil lead concentrations above selected thresholds, especially the interim standards in the HUD Lead Safe Housing Rule and in the HUD *Guidelines*.

- Percentage of homes with loadings of specified allergens: *Der f* I, *Der p* I, *Bla g* I, *Fel d* I, *Can f* I, *Mus m* I, *Rat n* I, and Alternaria above selected thresholds for sensitization and disease (if known).

- Arithmetic means and standard deviations and geometric means and standard deviations, median, 75th percentile and 90th percentile of dust lead loadings, and bare and covered soil lead concentrations in and around homes.

- Arithmetic and geometric means and standard deviations, median, 75th percentile and 90th percentile of allergen loadings in an array of sites in survey homes (bedroom, kitchen, TV/family room, basement).

- Estimates of the floor area, and area of painted surfaces, for each component and room type, and area of deteriorated paint, for each component and room type, and each type of paint deterioration.

- Percentage of homes with paint lead loadings above selected thresholds, especially the interim standards in the HUD Lead Safe Housing Rule and in the HUD *Guidelines*.

- Arithmetic and geometric means and standard deviations, median, 75th percentile and 90th percentile of paint lead loadings in homes, by component type.

- Estimates of the potential biases in the above estimates.

- Estimates of impact of measurement error on above estimates.

2.1.2 Subpopulations of Interest

The estimates described above were needed for the full national housing stock. In addition, estimates were needed for subpopulations of the housing stock, including:

- Housing units occupied by children under age 6 years.

- Housing units occupied by children under 18 years.

- Single family and multi-family housing units.

- Owner-occupied and renter-occupied housing units.

- Housing units built in selected ranges of years. Ranges for reporting include pre-1940, 1940-1959, and 1960-1998; pre-1950, 1950-1977, and 1978-1998; and pre-1940, 1940-1949, 1950-1959, 1960-1969, 1970-1977, 1978-1989, and 1990-1998.

- Housing units occupied by households in different socio-economic statuses, defined by income levels, housing unit market value or monthly rent.

- Measures of urbanization, e.g., urban, suburban, and rural.

- Housing units occupied by individuals with asthma and/or allergies.

When it is known in advance of conducting a survey that certain subpopulations are especially important, it is advantageous to try to incorporate them into the design. This helps to ensure adequate numbers of the subpopulations in the sample and, consequently, the efficiency of the resultant estimates and significance tests. This also requires that information on respondents' membership in the subpopulations be available before conducting the survey. As will be detailed later, prior information was available on a number of important respondent characteristics, and this information was utilized to construct an efficient design.

2.1.3 Exclusions and Inclusions

As stated above, the target population for this study was the full national housing stock of over 110 million housing units. In field household surveys, it is common to examine certain subsets of the US population to determine whether or not they should be included in the study. The decision to include or exclude a subset is usually based on such factors as relevancy to the study objectives, availability of data from other sources, and effort required to obtain the study data. Based on these considerations, the following subsets of the housing stock were **excluded** from the survey:

- Housing where children are not permitted to live (elderly housing, nursing homes, college dormitories, etc.).

- Group housing – both institutional (prisons or jails, detention centers, hospitals, military housing, etc.) and non-institutional (dormitories, fraternities, orphanages, rooming houses, missions, work camps, convents, etc.). There are a number of reasons for excluding this type of housing. Some of the sub-types, e.g., prisons and hospitals, tend to exclude children as long-term residents. The Department of Defense has active lead hazard control programs for military housing. Many of HUD's programs do not apply to these types of housing. Finally, the nature of the institutions that own and manage this housing make gaining access to this housing more difficult than typical owner-occupied or renter-occupied housing.

- Vacant housing. To gain access to vacant housing, the homeowner or manager must be identified, located, contacted, and persuaded to permit access to the vacant housing unit. All of these tasks are more difficult and less certain of success than with occupied housing. Consequently, the response rates will be lower for vacant housing than for occupied housing. Nationally, approximately 11% of the housing stock is vacant at any one time (1997 AHS). Much of this is short-term housing. This category includes homes which are not the resident's sole or permanent home, and in which the resident present at the time of field data collection spends less than three months per year. This includes seasonal, occasional use, recreational, and second homes, as well as homes for migrant workers.

- Hotels and motels. While some hotels and motels have long term occupants, including families, the average stay at these types of accommodations is 3.3 nights (Travel Industry Association of America, 1999 Travel Study).

The following subsets of the housing stock were reviewed because they have sometimes been excluded from prior studies. However, they were **included** in this study for the reasons stated.

- Housing built after 1977 - These homes should be included for a variety of reasons. Because lead-based paint was no longer available does not mean that lead-contaminated dust or soil will not be present. Also, HUD and EPA need reliable data for excluding these homes from possible future regulations. Finally, these homes may actually have *higher* allergen levels due to environmental factors that promote higher allergen levels (e.g., having more carpeting, being less well ventilated).

- Housing units in multi-family buildings - These housing units should be included since they comprise a significant portion of the homes in which people live (12%, according to the 1997 American Housing Survey). Also, characteristics of multi-family housing which may impact lead and allergen levels in dust may be different than single-family housing, e.g., multi-family housing may be more often rented rather than owned, and may have different maintenance schedules.

- Manufactured housing units, i.e., mobile homes and trailers - These homes comprise 5 to 6 percent of US homes, comprise a socioeconomic group of interest, and are no more difficult to access than other categories of housing. Thus, they were not excluded from the survey.

2.2 Sampling Stages

The most cost-effective method of sampling for a national survey requiring in-person visits is some form of multistage sampling with clustering at one or more stages. For example, a simple random sample of over 800 housing units in the United States might result in housing units selected in several hundred counties. A multistage design, on the other hand, might use clusters of housing units in a much smaller number of counties, such as 60 to 100, thereby concentrating the household visits in a smaller number of areas, decreasing the time and travel cost of the field visits. A complex, multistage design would, however, result in loss of precision relative to a simple random sample because the housing units are likely be correlated to some extent within these clusters. A multistage, clustered design would therefore require more housing units in the sample to achieve the same precision as a simple random sample. However, this tradeoff is necessary in large-scale, national surveys to contain travel costs, and because a national list of housing units from which to sample does not exist.

While some form of multistage, clustered sampling is required for national in-person surveys, the degree of clustering employed is open to choice. For instance, a sample of 800 housing units could be spread across 80 counties with an average of 10 households per county, or it could be concentrated in 40 counties with an average of 20 households each. The optimum degree of clustering in a survey depends on how homogeneous the housing units are with respect to lead and allergen levels within the clusters, and also on the cost of travel, listing, and screening relative to the cost of collecting measurements and laboratory processing. As a rule, survey variables exhibit some degree of homogeneity within clusters, but the extent of homogeneity can vary greatly from one variable to another. This homogeneity, or correlation between individuals in the cluster has the effect of reducing the precision of the survey estimates, compared to a simple random sample of the same size. On the other hand, clustering allows a larger sample of households to be taken for the same survey budget. When this increase in sample size more than offsets the loss of precision caused by clustering, then clustering should be used.

Based on the above considerations, the National Survey of Lead and Allergens in Housing included five stages of sampling (see Figure 2.1):

1. Selection of PSUs, which were *Metropolitan Statistical Areas* (MSAs)[2]; counties, or groups of counties;
2. Selection of segments within sampled PSUs (see section 2.2.2 for definition of a segment);
3. Selection of housing units within sampled segments;
4. Selection of rooms within housing units;
5. Selection of surface components within rooms.

These stages of sampling are described in more detail in the sections below. For a detailed description of the power analysis, expected precision, and design effect calculations that motivated the sample design, as well as the decision to use an existing PSU sample, see Appendix A.

[2] See Chapter 13 of the U.S. Census Bureau's Geographic Areas Reference Manual, November 1994, available electronically at www.census.gov/geo/www/garm.html.

2.2.1 First-Stage: Sampling PSUs

As shown in Figure 2.1, the first stage of selection was geographic primary sampling units (PSUs). The PSUs consisted of Metropolitan Statistical Areas (MSAs), counties, or groups of counties. Because of its size, the New York MSA was divided into three PSUs. For the same reason, the Los Angeles-Long Beach and Chicago MSAs were each divided into two PSUs. Miami-Hialeah, FL was joined with Fort Lauderdale-Hollywood-Pompano Beach, FL and Oakland, CA was joined with San Francisco, CA. The remaining MSAs each comprised a single PSU.

The sample of PSUs was drawn from a sampling frame, or list, of PSUs that was created by grouping contiguous counties to create PSUs that have a minimum population of 15,000 and do not cross the boundaries of the four Census regions.[3] Beginning with the 3,141 counties (or county-equivalents) in the United States, the grouping led to the construction of 1,404 PSUs. Every area in the 50 states and the District of Columbia was assigned to a PSU, thus every area in the country had a chance of selection. A random sample of 100 PSUs was drawn for use in area frame surveys of the general population.

The frame of 1,404 PSUs was stratified by the four Census regions, MSA vs. non-MSA status, population size class, percent Black or African-American, percent Hispanic or Latino, and Per Capita Income, using county-level data from the 1990 Census and the Bureau of Economic Analysis. The Census data file provided county-level population counts by race and Hispanic origin, while the Bureau of Economic Analysis file provided 1988 per capita income. The population size classes differed according to region and MSA status. A noncertainty PSU whose Black or African-American population exceeded 20 percent or whose Hispanic or Latino population exceeded 13 percent was placed in a "high Black or African-American" or "high Hispanic or Latino" stratum. There were a total of 62 strata. The precise definitions of the 38 noncertainty strata are given in Appendix B in Table B-1. The 24 certainty strata are given in Appendix B in Table B-2.

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[3] The four Census regions are:

Northeast: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.

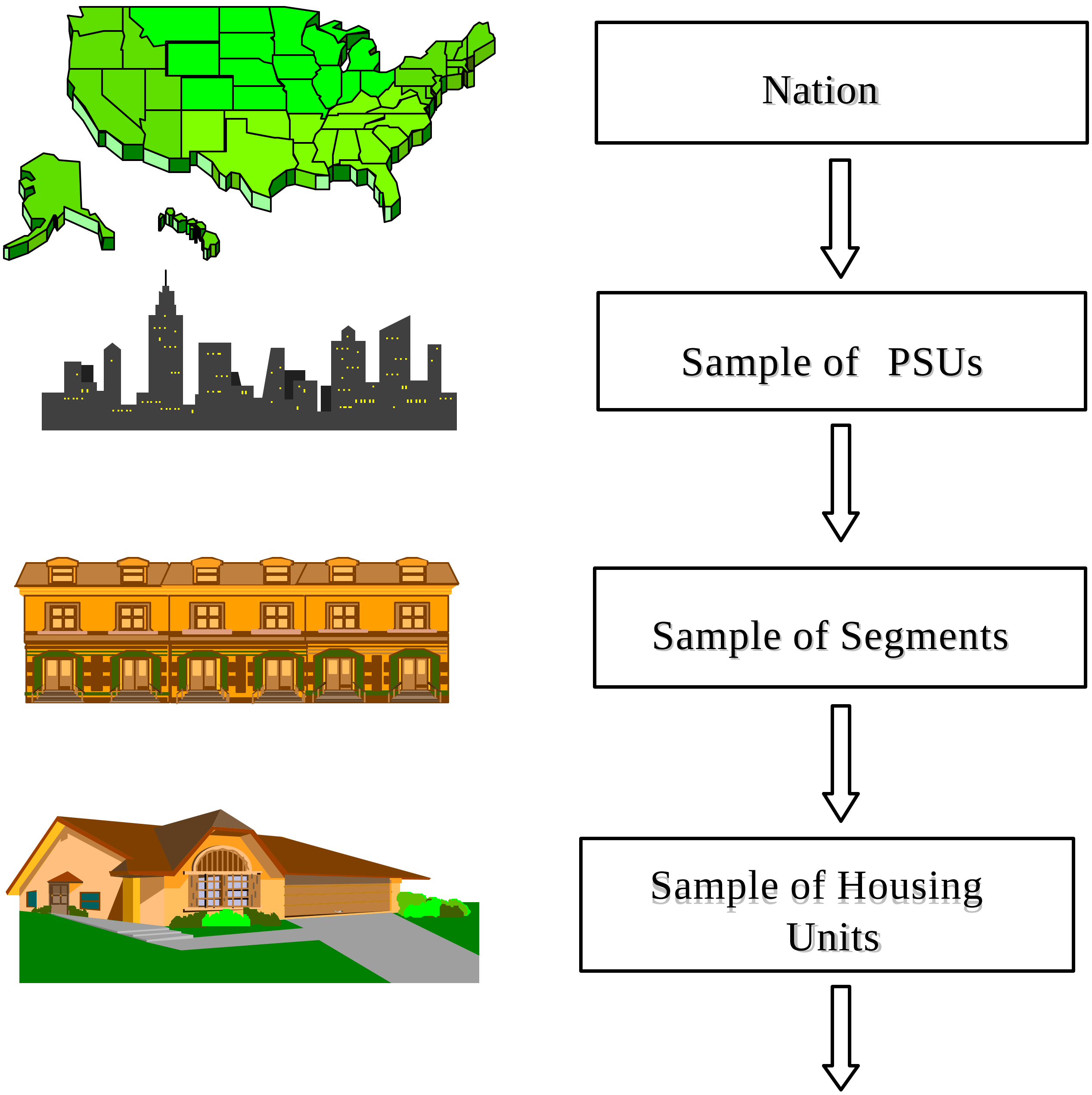
South: Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, Washington, D.C., West Virginia.

Midwest: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin.

West: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming.

The 24 largest PSUs in the nation each formed their own stratum because their populations were so large that their probability of selection was 1 (or nearly 1 in the case of Phoenix, AZ); hence they were selected with certainty into the sample.[4] The certainty PSUs were identified by an iterative process.

Figure 2.1 Multi-Stage Area Probability Sample



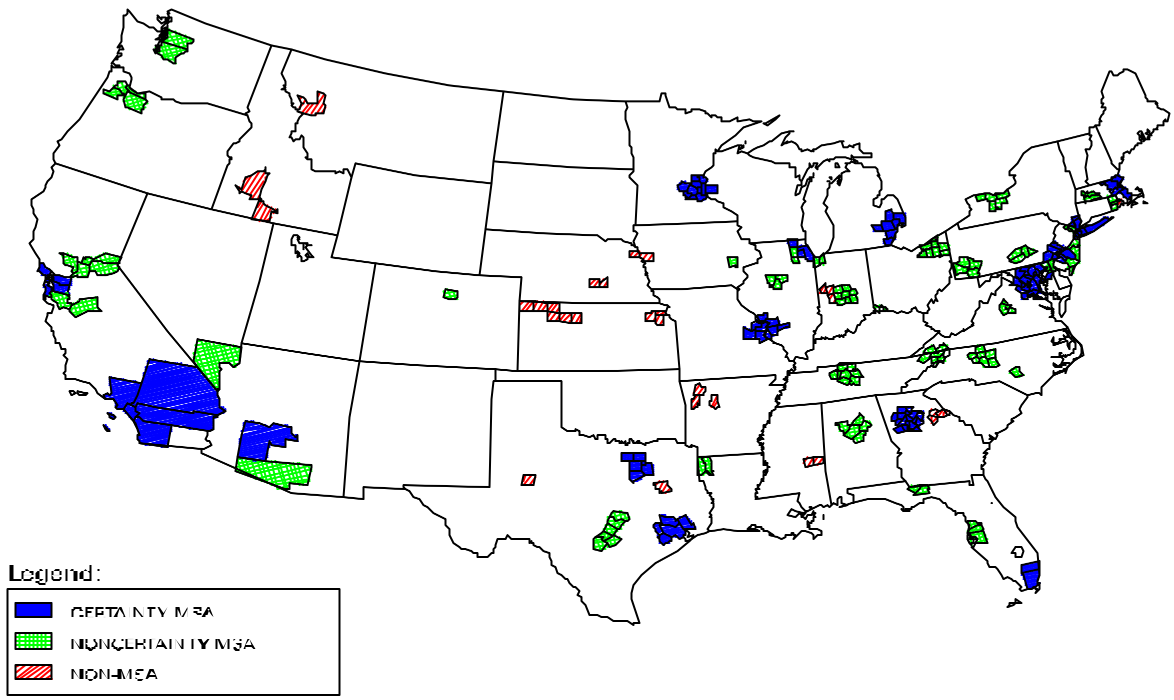
[4] In systematic probability proportional to size sampling, a certainty PSU is one whose measure of size exceeds the sampling interval. This means its probability of selection is one because it will be sampled with certainty. The sampling interval is equal to the sum of the measures of size for the PSUs in the stratum divided by the number of PSUs to be sampled.

An initial sampling interval was calculated by dividing the total 1990 U.S. population by the number of PSUs to be selected (248,709,881/100 = 2,487,098). Eighteen PSUs whose 1990 population exceeded this sampling interval of 2,487,098 were identified as certainties and removed. A new sampling interval was calculated and an additional six PSUs were identified as certainties because their population exceeded the new sampling interval; these were removed. A new sampling interval was calculated, after which no more certainty PSUs were identified. The sampling interval at that point was 2,278,212. In each of the remaining 38 strata, 2 PSUs were randomly selected with each PSUs probability of selection proportional to its 1990 population. These constituted a sample of 100 PSUs. Because of budgetary constraints, a subsample of 75 of these 100 PSUs was selected for this survey. The 75 PSUs included all 24 of the certainty PSUs and at least one of the PSUs from each of the noncertainty strata. A map of the 75 PSUs is displayed in Figure 2.2, and a list of the 75 PSUs is provided in Appendix B in Table B-2.

2.2.2 Second-Stage: Sampling Segments

To further reduce travel costs and the cost of listing housing units within the sampled PSUs, the second stage of selection was segments. A segment consisted of one or more contiguous blocks, depending on the number of housing units in the block. Segments were therefore generally smaller than Block Groups, as defined by the Census Bureau. To control listing costs, very large segments were split into chunks and one chunk was subsampled with probability proportional to size. A fixed number of segments in each PSU was sampled with probability proportional to the number of housing units in each segment, as reported in the 1990 Census. The number of segments sampled in each PSU was fixed, but the fixed sample size depended on two factors. The first was how homogeneous the housing units were expected to be with respect to lead and allergen levels within segments. The second was the ratio of the cost of obtaining a sampled household (including listing housing units within a segment and traveling to the sampled housing unit) to the cost of collection and processing data within the household. The larger the tendency of housing units within the same segment to have similar lead and/or allergen levels, the less information gained from sampling additional housing units in the segment, and the smaller the within-segment sample size.

Figure 2.2 Map of 75-PSU Sample



In general, it is best from a statistical standpoint to keep clustering to a minimum because it usually increases the standard errors of the survey estimates. This would argue for sampling as many PSUs and as few housing units within each PSU as the data collection budget will permit. It would also argue for spreading the within-PSU sample over as many segments as possible. However, some clustering is necessary to control travel and other data collection costs, such as listing housing units. To keep the workload relatively equal across the PSUs and to limit the clustering of housing units, ten segments per PSU were sampled, and a sample size of one eligible, responding housing unit within each segment was targeted. In a few PSUs, the number of segments was modified (to between 8 and 13) to reduce variation in selection probabilities. Analysis showed that the optimal sample size of cooperating housing units per segment was 1 (the smallest possible). With 75 PSUs and a total target sample size of about 800 housing units, this implied 10 cooperating housing units per PSU; 1 cooperating housing unit per segment implies 10 segments per PSU. The initial sample size of housing units was increased to 2 or 3 per segment to offset anticipated losses due to household nonresponse, refusal and ineligibility.

A frame of segments within each PSU was created from Census public use files, which contain detailed housing and population data at the Census block and block group level. (A Census block group consists of one or more contiguous blocks, and usually contains between 250 and 550 housing units.) For each segment, the total number of housing units was obtained by construction year decade, number of units in the building, percent of households in poverty, and percent minority population for the Census block group to which it belonged. This information was used in sampling segments. Data which were available only at the block group level were assumed to apply equally to all segments in that block group.

Within the 100 originally sampled PSUs, the segments on the frame were sorted by indicators of urbanicity, low-income households, high black population, and housing unit age prior to sampling. A probability proportional to size (PPS) systematic sample of segments was drawn in each PSU, where each segment's probability of selection was

$$P(\text{segment}_i \mid \text{PSU}) = \frac{M_i}{\left(\sum_{i=1}^{K} M_i / k\right)}$$

where k = number of segments to be sampled in the PSU,
K = number of segments on the frame in the PSU, and
M_i = number of housing units in the i-th segment from the 1990 Census.

The number of segments sampled was ten for most PSUs. In the six largest PSUs the sample size was increased to 11, 12, or 13 to prevent very large segment weights. The sample size was decreased to 8 or 9 in nine PSUs to keep the total number of sampled segments at 1,000. (See Table B-3 in Appendix B for a list of the PSUs with other than 10 selected segments.) After reducing the number of PSUs to 75, 754 segments remained in the sample.

Of the 754 segments in the sample, 732 were listed. Fifteen segments were not listed because they contained only senior housing, businesses, a military base, or condemned housing. Seven segments were not listed because the lister could not gain access. Of these seven, two were gated communities and two were Indian reservations where the tribal authorities were very suspicious and told the lister she should leave. This lister also visited the county police chief, who was unable to locate the segment due to unmarked roads and housing units. (A third segment in this reservation was successfully listed, since it was in a business district with numbered streets and addresses.) In two segments, the lister was threatened and left for personal safety reasons. There was an additional segment where the lister could not locate the segment housing units due to very unsafe, hilly and winding dirt roads.

2.2.3 Third-Stage: Listing and Selecting Housing Units

Within each of the sampled segments, a list of all eligible housing units was developed. Units that were clearly ineligible, such as senior retirement homes, military bases, or businesses were not listed. If the eligibility of a housing unit was in doubt, the housing unit was included in the list and its eligibility status was determined during recruitment and screening. In approximately one-sixth of the segments, the segment contained so many housing units that it was not practical to list the entire segment (see Table B-4 in Appendix B). As described in Section 3.1, the lister cruised each segment by automobile to estimate the number of units on each street. When the estimated number was very large (e.g., upwards of hundreds of housing units), the lister reported the counts to the Field Office. Using this information the Field Office split the segment into geographic chunks of approximately equal numbers of housing units, and randomly selected one of those chunks. The interviewer then listed that one chunk of the segment. This "chunking" controlled the listing effort by preventing the listing of very large numbers of housing units in segments in which two or three housing units would be sampled.

In the original sample of 100 PSUs, 50,224 housing units were listed. In the 75 PSUs, 39,071 housing units were listed. The lists were sent to the Field Office for sampling of housing units, and a sampling interval was calculated as the number of housing units on the list divided by the desired sample size. An equal probability sample of housing units was drawn from each list using systematic sampling. The sampled housing units were screened at recruitment, after which 95 percent or higher were expected to be eligible for the survey. Of the eligible housing units, about 50 percent were expected to cooperate. In the 1990 Lead-Based Paint survey, 47 percent of eligible housing units completed inspection visits. These assumptions, combined with the projected target of one completed housing unit per segment, suggested that the initial sample size should be 2 units (for some PSUs this was increased to 3 housing units per segment). Cooperation was sought from all sampled housing units in the segment. If multiple housing units cooperated, data were collected from each housing unit (see Chapter 3 for a full description of the field contact methodology).

2.2.4 Fourth-Stage: Sampling Rooms within Housing Units

Within each eligible housing unit that was recruited, a stratified sample of rooms was drawn by Westat. The basis for the room sampling frame within each housing unit was the Room Inventory

Form. The room strata were defined as given below in Tables 2.1a and 2.1b, depending on whether a child's bedroom was present or not.

Table 2.1a Housing Units Containing a Child's Bedroom:

Stratum	Room Type
1	Kitchen, Kitchen/Living Room Combinations
2	Living Room, Sitting Room, Parlor, Den, Family Room, Recreation Room, Florida Room, Great Room, Efficiency
3	Child's Bedroom
4	Adult and Guest Bedrooms, Dining Room, Study/Office, Sewing Room, Laundry Room, Bathroom, Additional Rooms

Table 2.1b Housing Units Not Containing a Child's Bedroom:

Stratum	Room Type
1	Kitchen, Kitchen/Living Room Combinations
2	Living Room, Sitting Room, Parlor, Den, Family Room, Rec Room, Florida Room, Great Room, Efficiency
3	Adult Bedroom
4	Guest Bedrooms, Dining Room, Study/Office, Sewing Room, Laundry Room, Bathroom, Additional Rooms

An equal probability sample of one room was selected within each room stratum, with the exception of Stratum 4. If Stratum 4 contained seven or more rooms, the sample size was increased to two rooms to prevent excessively large room weights.

2.2.5 Fifth-Stage: Sampling Components within Rooms

Within each sampled room, one window and one door were subsampled by the Technician from among the existing windows and doors (if any) with equal probability. Walls and other components were not subsampled. The protocols for this activity are described in more detail in sections 4.4.1 and 4.4.2.

2.3 Weights

2.3.1 Housing Unit Weights

Each housing unit received a weight that permitted the final sample of 831 housing units to be expanded to represent the population of all private, noninstitutional, nonvacant U.S. housing that allow resident children. The weight for a particular sampled housing unit is the number of housing units it represents. First, a weight was calculated that is equal to the inverse of the housing unit's overall probability of selection. This is called the *base weight*. The housing unit's overall probability of selection is the product of the probability of selection at each of three stages; that is

$$p(HU) = p(PSU)*p(segment|PSU)*p(HU|PSU,segment) \qquad (1)$$

where

- HU = housing unit,
- Segment = a block or group of small blocks,
- PSU = primary sampling unit,
- p(HU) = final probability of selection for the housing unit,
- p(PSU) = probability of selection for the PSU,
- p(segment|PSU) = probability of selection for the segment given the PSU was selected, and
- p(HU|PSU,segment) = probability of selection for the housing unit given the segment and PSU were selected.

This formula applies to the general situation where it is not necessary to split a segment into "chunks" and subsample one chunk within the segment. When "chunking" and subsampling were necessary, there was an extra term in the expression for p(HU), where

p(HU|PSU,segment) is replaced by p(CHUNK|PSU,segment)* p(HU|PSU,segment, chunk).

One further complication was that a few segments could not be listed because access was denied (e.g., Indian reservations or gated communities). A small nonresponse adjustment was made at the segment level to account for this rare occurrence (less than one percent of all segments). The nonresponse adjustment factor was calculated as:

$$F = \frac{\sum_{\substack{i \in \text{eligible sampled} \\ \text{in cell}}} \text{segment base wt}_i}{\sum_{\substack{i \in \text{eligible listed} \\ \text{in cell}}} \text{segment base wt}_i}$$

where the i-th segment base weight = 1/p(segment$_i$). The factor was calculated within cells formed by the PSU ID, a low-income indicator for the segment, and by housing unit age categories based on the 1990 Census. The factor was applied to the segment base weights of the listed, eligible segments. Thus, p(segment|PSU) in equation (1) is replaced by p(segment|PSU)* F.

There were missing data at the housing unit level due to nonresponse. A nonresponse adjustment was performed to compensate for unit response by inflating the base weights of the eligible responding households so that they represent the eligible nonresponding households sampled as well as the eligible nonsampled housing units (Sarndal, 1992, chapter 15). This was necessary to permit estimation of total housing units from the sample. A responding household was defined as one in which any physical measurements were taken and paperwork was completed. To help control for nonresponse bias caused by differential response rates among the different types of housing units, a separate nonresponse adjustment factor was calculated within nonresponse adjustment cells. Nonresponse adjustment cells were formed by cross-classifying housing units by region, income, high/low minority, and age of housing unit—factors which are correlated with the response rates and with the propensity to have high lead or allergen levels. Nonresponse adjustments were first done for nonresponding housing units of unknown eligibility, then for those known to be eligible.

After adjusting the housing unit base weights for unit nonresponse, the weights were reviewed and a few (less than 25) excessively large weights were trimmed to improve the overall accuracy of survey estimates. By trimming a few extreme weights, it is possible to greatly reduce the variance of survey estimates. While the trimming may introduce some bias, it is anticipated that the overall accuracy will be increased (Potter, 1988 and 1990). These trimmed weights were then poststratified to 1997 American Housing Survey housing counts to improve the accuracy of the sample estimates (for a description of poststratification, see Cochran (1977), pages 134, 135; Kish (1965), pages

90-92; Sarndal (1992), pages 264-268). The trimmed weights were post-stratified by region, age of housing construction (pre 1940, 1940-59, 1960-77, and 1978 or newer), and whether or not a child under 18 lived in the house (control totals were not available for younger age categories).

The AHS does not exclude housing that cannot be used by families with children (senior housing). Therefore housing units considered ineligible for this survey because they were senior housing were included in the post-stratification. The six segments that were not listed because they contained only senior housing were assumed for these purposes to have the number of units reported in the 1990 Census.

The final HU weight (FINHUWT) can be expressed as the product of the HU base weight and the weighting adjustment factors:

FINHUWT = HU base weight x HU screener nonresponse adjustment factors x
trimming factor x poststratification factor
= BW x (NR1 x NR2) x TR x PS.

NR1 is the adjustment factor for unknown eligibility and was calculated within cells formed by Census region, a low-income indicator, and a high minority indicator. NR2 is the adjustment factor for screener nonresponse among eligible HUs and was calculated within cells formed by Census region and HU age category. The poststratification factor PS was calculated by Census region, HU age category, and an indicator of the presence of children under age 18. For PS, the reported HU age was used to create adjustment cells when available. Otherwise, the modal HU age for the block group from the 1990 Census was used. For NR2, only the modal HU age for the block group from the 1990 Census was used. Formulas for these factors are given below.

$BW_i = 1/P(HU_i)$ where P(HU) was described previously in this section,

$$NR1 = \frac{\sum_{\substack{i \in \text{sampled} \\ \text{in cell}}} BW_i}{\sum_{\substack{i \in \text{elig.status} \\ \text{known in} \\ \text{cell}}} BW_i}, \quad NR2 = \frac{\sum_{\substack{i \in \text{elig.status} \\ \text{known in cell}}} (BW_i \text{ x } NR1)}{\sum_{\substack{i \in \text{elig.resp.} \\ \text{in cell}}} (BW_i \text{ x } NR1)},$$

$$TR = \min(1, \frac{300{,}000}{BW_i \text{ x } NR1 \text{ x } NR2}),$$

$$PS = \frac{\text{1997 AHS Total HUs in cell}}{\text{Sample Estimate in cell}}$$

$$= \frac{\text{1997 AHS Total HUs in cell}}{\sum_{\substack{i \in \text{elig.resp.} \\ \text{in cell}}} (BW_i \text{ x NR1 x NR2 x TR}) + \sum_{\substack{i \in \text{senior} \\ \text{housing} \\ \text{in cell}}} (BW_i \text{ x NR1}) \text{ x } \sum_{\substack{j \in \text{segment} \\ \text{containing} \\ \text{only senior} \\ \text{housing in cell}}} (\text{seg wt}_j \text{ x \#HUs}_{1990\ \text{Census}})}$$

Of the 1,984 housing units sampled, 831 were eligible respondents, 229 were found to be ineligible, 149 were eligible nonrespondents, and the remaining 775 were of unknown eligibility. Unknown eligibility usually resulted from failure to make contact with the household or a refusal on the part of the household to complete enough of the screener to establish eligibility. Nonresponding HUs received a zero final weight, since they are represented by the 831 eligible respondents. The final housing unit weights were developed for the 831 eligible respondents. The eligibility status for these housing units was determined by the screening questionnaire. Their response status meets the final definition of a responding housing unit given in Section 2.3.1.

2.3.2 Room and Component Weights

Post-stratified housing unit weights were the basis for room weights. The post-stratified weights received a small nonresponse adjustment to account for four housing units in which no complete room data were collected. These weights were divided by the room probabilities of selection to produce room base weights. A nonresponse adjustment was then made to account for noncompleted rooms. A room was only considered completed if some environmental samples and questionnaire data were collected in the room. The room nonresponse adjustment factors were calculated within cells formed by the segment ID, room stratum, and housing unit age category within the PSU. By doing this, completed rooms could represent noncompleted rooms of the same type from housing units of similar age within the same segment.

The nonresponse-adjusted room weights were trimmed to prevent a few extremely large room weights from having undue influence on the estimates and adversely affecting their precision. The trimming thresholds were determined separately for kitchens, living rooms, bedrooms, and "other" rooms since these are important categories for room level estimates (see Table 2.2). Since room weights are not poststratified, the weights of rooms not trimmed were ratio-adjusted upwards to preserve the original room weight total in each room category.

The trimmed room weights were then the basis for component weights. For all allergen samples and most lead samples, the component weight equaled the trimmed room weights since all components were sampled. The exceptions were for window dust wipe samples and XRF paint measurements on windows and doors. For these components, a sample of one window or door per room was selected. To complete component weights, the trimmed room weights were divided by the component probability of selection. The component probability of selection is simply one over the number of components of that type available in the room to sample; e.g., one out of four windows. No nonresponse adjustment was done for components.

The final component weight (COMPWT) can be written as:

COMPWT = FINHUWT x
nonresponse adjustment factor for HUs with no room data collected x
room base weight x room nonresponse adjustment factor x
trimming factor x within-room component weight,

= (FINHUWT x NR3 x ROOMBW x ROOMNR) x ROOMTR x RMCOMP
= W x ROOMTR x RMCOMP

where

$$NR3 = \frac{\sum_{\substack{i \in \text{elig. complete HU} \\ \text{in cell}}} FINHUWT_i}{\sum_{\substack{i \in \text{elig. complete HU w/} \\ \text{room data in cell}}} FINHUWT_i},$$

$$ROOMBW = \frac{\#\text{rooms inventoried in stratum in HU}}{\#\text{rooms sampled in stratum in HU}},$$

$$ROOMNR = \frac{\sum_{\substack{k \in \text{sampled rooms} \\ \text{in cell}}} ROOMBW_k}{\sum_{\substack{k \in \text{completed rooms} \\ \text{in cell}}} ROOMBW_k},$$

$$
\text{ROOMTR} = \begin{cases} \dfrac{\text{THRESHOLD}}{W_k} \text{ if } W_k > \text{THRESHOLD}, \\ \\ \dfrac{\sum\limits_{\substack{k \in \text{all rooms} \\ \text{in ROOMCAT}}} W_k - n \text{ x THRESHOLD}}{\sum\limits_{\substack{k \in \text{rooms not trimmed} \\ \text{in ROOMCAT}}} W_k} \text{ otherwise} \end{cases}
$$

where ROOMCAT is the room category for analysis, THRESHOLD is the trimming threshold for the ROOMCAT (see below), and n is the number of room weights trimmed in each room category.

Table 2.2 Trimming Thresholds for Room Weighting

ROOMCAT	Description	Threshold
1	Kitchen, Kitchen/Living Room combinations	508,760
2	Living Room, Sitting Room, Parlor, Den, Family Room, Rec Room, Florida Room, Great Room, Efficiency	903,008
3	Child or Adult's Bedroom	1,237,091
4	Dining Room, Guest Bedroom, Study/Office, Sewing Room, Laundry Room, Bathroom, Additional Rooms	2,250,357

RMCOMP = # components available in room to sample from

2.3.3 Variance Estimation

Estimates of population parameters obtained from the sample of housing units will differ from the true population parameters because they are based on a random sample rather than a complete census of all housing units. This type of error is known as *sampling error* and is measured by the variance of the estimate. The standard error of the estimate is defined as the square root of the variance. The calculation of standard errors must reflect not only the sample size on which the estimate is based, but the manner in which the sample was drawn. Sample design features that must be taken into account when calculating standard errors are stratification, clustering, and unequal probabilities of selection. Otherwise, the standard errors can be misleading and result in incorrect confidence intervals and p-values in hypothesis testing.

Replication methods such as the jackknife, balanced repeated replication (BRR), and the bootstrap are commonly used to estimate standard errors in the presence of complex survey designs. The jackknife method was chosen for the National Survey because of its greater stability when making estimates for small domains. In the jackknife method, one PSU at a time is dropped from the sample and the parameter of interest is estimated using the remaining PSUs. The weights of observations in the remaining PSUs are multiplied by a reweighting factor to create a replicate weight. This process is repeated over the set of PSUs to form replicates. The variability of the replicate estimates is an estimate of the sampling variability. For the stratified jackknife, the variance is estimated using the formula (Wolter, 1985):

$$\mathrm{Var}(\hat{q}) = \sum_{h=1}^{L} \frac{n_h - 1}{n_h} \sum_{g=1}^{n_h} \left(\hat{q}_{(g)} - \hat{q}\right)^2$$

where $\hat{q}$ is the full-sample estimate, $\hat{q}_{(g)}$ is the estimate based on the g-th replicate, n_h is the number of PSUs in stratum h, and L is the number of strata at the first stage of sampling. The stability of the variance estimate is measured by the *degrees of freedom*, which are calculated as the total number of PSUs minus the number of strata.

In practice, the PSUs may be grouped to reduce the number of replicates, and certainty PSUs are split into groups of second stage sampling units. The original sampling strata may also be collapsed or split to form "variance strata." Thus L and n_h may not be the actual number of sampling strata or PSUs.

For the National Survey, twenty-five of the original 38 noncertainty strata (see Appendix B-1) contained only one PSU in the 75-PSU design and had to be collapsed with adjacent strata for variance estimation purposes. The 24 certainty PSUs (see Appendix B-2) each formed a separate variance stratum. Together with the collapsed noncertainty strata, the total number of variance strata formed was 47. The 24 certainty PSUs were each split into two half-samples of segments to create 48 "pseudo-PSUs" or "variance units." Together with the remaining 51 noncertainty PSUs, this allowed for the creation of 99 jackknife replicate weights for each housing unit, room, and component measurement. Each time a PSU or pseudo-PSU was dropped from a variance stratum, the weights of the remaining observations in the variance stratum were multiplied by a factor of $n_h/(n_h-1)$, where n_h is the number of PSUs (or pseudo-PSUs) in variance stratum h. The degrees of freedom available for estimating standard errors for national estimates are 99 - 47 = 52. For regional estimates, the degrees of freedom will be less.

The replicate weights may be used with software packages such as WesVar or VPLX to estimate standard errors. WesVar is available from Westat (www.Westat.com/WesVar/index.html) while VPLX is available from the U.S. Bureau of the Census (www.census.gov/sdms/www/vwelcome.html). The data files are set up to use the JKn replication method in WesVar. When this is used for additional variance computation, it is important to include the JKn factors contained in the file JKNFAC.dat.

2.4 Sample Design and Selection for Play Areas

Soil samples were collected from children's play areas in a subsample of 40 of the 75 PSUs used in the National Survey of Lead and Allergens in Homes. The 40 PSUs were a random subsample of the 75 so as to allow for unbiased national estimates from the survey data. Other constraints in selecting the PSUs included maintaining regional representation and increasing the proportion of homes where high lead soils were likely to be found. Two steps were used to increase the proportion of homes with high soil lead levels: PSUs with the highest soil lead levels (among the main entrance, dripline and midyard samples) were retained with certainty; then among the remaining PSUs, those with the highest soil lead levels were oversampled relative to those with little soil lead. The final survey weights for the play area data were adjusted to take into account this oversampling. Thus, weighted totals provide unbiased national estimates.

All 15 PSUs that had at least one home with at least one soil lead sample above 5,000 ppm were retained with certainty. The 6 other PSUs that had at least 7 homes with soil lead values above 200 ppm were also included with certainty. This left 19 PSUs to be selected from the remaining 54 PSUs.

Table 2.3 shows the regional distribution of the 54 noncertainty PSUs. To proportionally include these regions in the sample of 19 PSUs (and thus minimize the increase in variance resulting from subsampling PSUs) required selecting 3, 4, 7, and 5 PSUs from the northeast, north central, south, and west regions, respectively.

Table 2.3 Regional Distribution of 54 Noncertainty PSUs

Region	Remaining Noncertainty PSUs	Percent of All Noncertainty PSUs	Number of Sampled Noncertainty PSUs
Northeast	8	15%	3
North Central	12	22%	4
South	19	35%	7
West	15	28%	5

Thirty-three of the 54 PSUs had 2 or fewer homes with at least 200 ppm soil lead in the sample, while 21 PSUs had 3 to 6 such homes. It was desirable to increase the probability of including PSUs that had higher numbers of homes with high soil lead. However, increasing this probability too much could adversely affect the overall survey efficiency since some homes in the remaining (undersampled) PSUs would also have high soil lead. It was therefore decided to double the probability of including PSUs from the higher-incidence stratum. This resulted in selecting 8 of the 33 PSUs with low soil lead and 11 of the 21 PSUs with higher lead.

The next step was to allocate the 19 PSUs to the 8 cells defined by region and soil lead, given the marginal totals determined above. This was done using the Bryant-Hartley-Jessen technique described in Cochran (1977). Table 2.4 shows the resulting allocation.

Table 2.4 Allocation of 19 Noncertainty PSUs to Region by Soil Lead Cells

Region	(0-2) Homes with Soil Lead at Least 200 ppm	(3-6) Homes with Soil Lead at Least 200 ppm	Total
Northeast	1	2	3
North Central	2	2	4
South	4	3	7
West	1	4	5
Total	8	11	19

The resulting 40 PSU subsample is listed in Appendix B, Table B-5. The 40 PSUs contained 481 of the originally completed 831 housing units. All 21 housing units in the 75 PSUs with soil lead above 5,000 ppm are included in the 40 PSUs. The percent of housing units with maximum soil lead between 200 ppm and 5,000 ppm was increased from 28 percent in the original 75 PSUs, to 34 percent for the 40 PSU sample. Thus, the goal of regional representation while increasing the percentage of sampled homes with high soil lead was achieved. The housing unit weights compensate for the oversampling of homes with high soil lead (see section 2.5 below), so that the sample is still representative of housing stock in the United States when estimates are produced using the weights.

Tables 2.5 through 2.7 show that the distribution of the 481 housing units in the 40 subsampled PSUs is nearly identical to that of the original sample of 831 housing units from the 75 PSUs with respect to region, construction year category, and soil lead indicators. The housing unit base weights, which have been adjusted for the subsampling of the 40 PSUs, were used in constructing these tables. Table 2.5 gives the distribution of the sample of 481 housing units with respect to region and year of construction category. In comparing this with the distribution of the original sample of 831 housing units in Volume I, Table 2.1, it can be seen that the percent of housing units in each region by year of construction category in Table 2.5 below is contained within the full sample confidence interval. Table 2.6 gives the soil lead distribution of the 481 housing units in the 40 PSUs, which is comparable with Volume I, Table 6.1. Table 2.7 compares the distribution of soil lead by region for the two housing unit samples.

Table 2.5 481 HUs in Play Areas Sample

Region	Construction Year	Percent of HUs	Lower 95% CI	Upper 95% CI	HUs in Sample
Northeast	Before 1940	6.92	4.68	9.16	45
	1940-1959	4.40	0.81	7.99	27
	1960-1977	2.88	2.01	3.76	20
	1978-1998	5.96	3.95	7.98	24
	All years	20.16	17.94	22.38	116
Midwest	Before 1940	6.18	3.48	8.88	37
	1940-1959	5.80	2.34	9.27	30
	1960-1977	5.89	1.43	10.36	33
	1978-1998	5.20	2.85	7.56	25
	All years	23.08	20.30	25.86	125
South	Before 1940	2.79	0.95	4.64	17
	1940-1959	5.80	2.50	9.09	35
	1960-1977	13.61	10.81	16.40	56
	1978-1998	14.88	10.36	19.40	48
	All years	37.07	33.67	40.48	156
West	Before 1940	1.75	-0.08	3.57	11
	1940-1959	4.84	2.34	7.35	28
	1960-1977	6.60	4.11	9.10	33
	1978-1998	6.50	3.15	9.85	12
	All years	19.69	18.25	21.13	84

Table 2.6 Soil Lead Distribution for 831 HUs

Soil Lead	Percent of HUs	Lower 95% CI	Upper 95% CI	HUs in Sample
LT 20 ppm	20.0%	15.5%	24.6%	147
LT 50 ppm	41.0%	36.5%	45.5%	305
LT 200 ppm	68.9%	65.6%	72.2%	535
LT 400 ppm	78.4%	75.1%	81.7%	613
LT 2,000 ppm	94.1%	91.9%	96.2%	745
LT 5,000 ppm	97.1%	95.7%	98.5%	768
GE 5,000 ppm	2.9%	1.5%	4.3%	21
Missing				42

Table 2.7a Soil Lead Distribution by Region for 831 HUs

Region	Percent of HUs Soil <= 200 ppm	Lower 95% CI	Upper 95% CI	HUs in Sample Soil <=200 ppm
Northeast	43.1	35.0	51.1	61
Midwest	64.5	58.3	70.7	115
South	79.7	74.6	84.9	204
West	79.4	72.2	86.7	155
All US	68.9	65.6	72.2	535

Table 2.7b Soil Lead Distribution by Region for 481 HUs in Play Areas Sample

Region	Percent of HUs Soil <= 200 ppm	Lower 95% CI	Upper 95% CI	HUs in Sample Soil <=200 ppm
Northeast	47.0	41.8	52.3	46
Midwest	66.0	62.8	69.3	65
South	80.2	76.7	83.7	79
West	80.2	76.4	84.0	43
All US	70.2	67.8	72.7	233

2.5 Weighting and Variance Estimation for Play Areas

Final housing unit weights described in Section 2.3.1 constitute the base weights for the play area subsample. These weights were adjusted for the subsampling of only 40 PSUs from the original 75, and for nonresponse to the play area sampling. The PSU subsampling adjustment controlled for region and the two soil lead strata discussed in the previous section. This was done to assure the correct representation of each region in national estimates and to take into account the oversampling of PSUs with higher soil lead values. The housing unit weights were then poststratified to 1997 American Housing Survey control totals by region, building age category, and soil lead strata.[5] This adjustment also compensated for nonresponse to the play area sampling. The poststratification of the weights to American Housing Survey totals reduced sampling error and nonresponse bias in the estimates.

Variance estimation followed a similar procedure to that described in Section 2.3.3. A set of 48 jackknife replicate weights was created for each housing unit in the 40 PSUs. However, it was necessary to collapse the variance strata used for the 75-PSU data because there were fewer PSUs for the play areas sample. Reducing the number of PSUs from 75 to 40 resulted in reducing the number of variance strata from 47 to 21 and the degrees of freedom for variance estimates from 52 to 27, decreasing the precision of analytic comparisons.

[5] Raking was the form of poststratification actually performed. The housing unit weights were raked to 1997 AHS control totals using region x building age category (pre-1940, 1940-1959, 1960-1977, 1978 and later) as the first raking dimension and region x soil lead stratum (less than or equal to 200 ppm, greater than 200 ppm) as the second raking dimension.

3. RESPONDENT IDENTIFICATION, SCREENING, AND RECRUITMENT

In order to select a probability sample of housing units (HUs), a housing unit frame was first compiled by listing all households in each sampled segment. Once the HU frame was finalized, the study sample of HUs was generated by randomly selecting two (or in some cases, three) residential addresses from the frame for each sampled segment. Interviewers then visited each sampled address, determined if the address met the eligibility criteria, and attempted to recruit the housing unit into the study.

Before the survey was implemented, the plan for the survey was submitted to the applicable authorities required by Federal law for their review and approval. All required approvals were received before the survey was implemented. Specifically, the proposed information collection was submitted to the Office of Management and Budget (OMB) for review, as required by the Paperwork Reduction Act of 1995 (44 U.S.C. Chapter 35). The OMB review process requires the publication of a *Notice of Proposed Information Collection: Comment Request* in the Federal Register 60 days before the submission of an Information Collection Request to OMB. The *Notice* was published in the Federal Register on October 3, 1997. The Information Collection Request (ICR) was prepared in accordance with OMB's requirements, which are focused on controlling paperwork burdens on the public. The ICR discussed the need for the information collection, the statutory authorization for the information collection, the unavailability of existing data, the efforts made to minimize respondent burden and protect respondent privacy, and presented a detailed description of the information collection procedures and protocols. Approval of the ICR was received from OMB on April 30, 1998.

In addition, the survey plan was reviewed and approved by the NIEHS and Westat Institutional Review Boards (IRB's), in compliance with the Public Health Service Act (45 CFR 46, Protection of Human Subjects). Title 45 CFR 46 is designed to protect the rights of human subjects in biomedical or behavioral research. Consequently, the IRB review process also requires the submission of a detailed description of the study needs, objectives, and data collection procedures. However, this description focuses on the potential benefits and risks to the human subjects of the study procedures, the procedures for obtaining the informed consent of the human subject, and the measures taken to protect the human subject from the risks. Approval was received from the Westat IRB on May 20, 1998, and from the NIEHS IRB on June 16, 1998.

3.1 Compilation of the Housing Unit Frames

The HU frame of all units in the sampled segments was created by a process called *listing*. *Listing* involves the identification and recording of the addresses of all households (or if there are no addresses, their descriptions and locations) in the sampled segment. In this way, all eligible places where people live, or might live, within the boundaries of each segment were available for inclusion in the study. Listing personnel were trained in standard listing protocols, as used on many government surveys. Listing tasks included:

1. Cruise the designated segment.

   This initial activity was to (1) verify segment boundaries, (2) update the electronically generated Segment or Block Group Map (from Census Bureau's Topographically Integrated Geographic Encoding and Referencing [TIGER] files; example shown in Appendix C, page C-4) with roads that had changed or were not shown, and (3) make an approximate count of the number of HUs in the segment. Listers compared the approximate count of HUs with the expected range of HUs. If the approximate count was within the expected range for a specified segment, the lister proceeded to validate the address listings. When the approximate count was outside the expected range, the lister attempted to explain the discrepancy, for instance, misinterpretation of segment boundaries or failing to note HUs on a hidden cul-de-sac. In some cases, the discrepancy was due to inaccuracies in available information. For example, because the expected range of dwelling units for a selected block group was based upon 1990 Census data, recent construction (or demolition) of HUs could yield an approximate count above (or below) the expected count. Listing did not begin until such discrepancies were resolved with the Field Office. If the number of HUs was very large, the segment was split into chunks, one chunk was randomly selected by the Field Office, and only that chunk was listed.

2. List all household addresses.

   For this study, listing of addresses began in the upper northwest corner of a block group or segment and proceeded in a clockwise fashion (to the right on the map.) This rule was applied for consistency, which facilitated verification and was useful to other field personnel during the recruiting and data collection phases of the fieldwork.

   While moving through the segment in the prescribed manner, the lister recorded the address information and all HUs on the Main Listing Sheet (see Appendix C, page C-5) and marked the route followed by drawing arrows on the Segment Map. The arrows acted as a control that all streets in the segment were covered in a logical order. To address problems frequently encountered in rural segments (e.g., unnumbered HUs and mobile homes), listers were required to indicate the exact location of all HUs on the Segment Map, using the line numbers from the Main Listing Sheet.

3. Record relevant survey information.

During the listing activity, visual inspections of each address were made to preliminarily determine if an address was an eligible residential dwelling unit. The lister also recorded any other information relevant to the survey, e.g., a hospital or prison were noted on the map but not listed. The result of this activity was a complete and current list of residential addresses from which the random sample of HUs was drawn.

3.2 Respondent Contact, Screening, and Recruitment

After the lists of housing units were compiled and reviewed, and the sample of addresses selected for each segment, an Interviewer was given the list of the sampled HUs to visit, contact a resident adult, screen, and recruit. As discussed in Chapter 2, the number of HUs on the list were determined from the desired number of completes and the anticipated attrition rate (percentage of HUs that do not yield a completed data collection visit, for any reason—ineligible, unable to contact, refusal, etc.). For example, if it was desired to complete 10 housing units and the aggregate attrition rate was assumed to be 50 percent, the Interviewer was given a list of 20 HUs to recruit.

Each household address in the sample was sent an initial contact letter written on combined HUD and NIEHS letterhead and signed by senior agency representatives. The letter introduced and explained the need for the study, indicated the importance and advantages of participation, briefly outlined the data collection procedures, and advised the householder that an Interviewer would be visiting them in the near future. The letter is displayed in Appendix C,page C-6.

For each of the 75 primary sampling units (PSUs), a field Interviewer was assigned to visit, contact, screen, and recruit *all* sampled HUs. S/he made no less than four attempts to contact an adult householder, spaced over various days of the week and times of day. Specific initial and supplemental training was provided on how to screen and recruit households. Interviewers were provided with official identification badges, and copies of the introductory letter previously sent to the HU. An *At A Glance Notebook*, filled with newspaper and magazine articles pertaining to lead, allergies, and asthma in the U.S., was also provided to assist with recruiting. These measures helped to ensure that the sample, which was a probability sample when drawn, continued to be a probability sample through the fieldwork. The Interviewers attempted to recruit all assigned HUs, because recruiting only a target number of HUs would produce a non-probability quota sample, biased towards respondents who are easier to recruit.

Interviewers' recruiting visits to the sampled homes were generally "cold calls," that is, they were made without prior scheduling with the residents. Consequently, many of the attempts found no one home. When this happened, the Interviewer left a "Sorry we missed you" card in the door. (Appendix C, Page C-7). This card told the residents that a representative of the HUD/NIEHS-sponsored survey had attempted to contact them and would try again in the near future. The card referred to the advance letter that had been recently mailed to them. Starting about halfway through the field period, the Interviewer also called the Field Office to report the non-contact. The Field Office then sent out a "no-contact" letter to the respondent via an overnight express delivery service. This letter (Appendix C, Page C-8) told the respondent s/he had been visited by a representative of the survey, reiterated the purpose of the survey, and again asked for the respondent's participation.

Approximately one week was allotted to produce an adequate sample of recruited respondents to begin data collection. At the beginning of the second week at a PSU, the Technician arrived at the site and the team conducted field data collection activities during the second and third weeks, as described in Chapters 4 and 5. The Interviewer also continued to recruit the remaining respondents in the PSU during the second and third weeks.

3.2.1 Respondent Screening

Respondent screening was the process of determining if households were eligible for the study. The Interviewers began the first successful contact with each selected household by administering a short screening questionnaire (see CB, pages C-9 through C-17) to any adult resident of the household. Ineligible homes included institutional housing, such as prisons or hospitals, housing where children were not permitted to live, or vacation housing. The Interviewer ascertained if the housing unit was vacant by visual inspection or by proxy response from a neighboring resident. If the housing unit was not eligible, the Interviewer thanked the householder for his/her time and terminated the interview. If the housing unit was eligible, the Interviewer was immediately proceeded to recruit the household for the study.

For the subsample of homes that were recontacted to collect play area soil, a second short screening questionnaire was administered (see Appendix C, pages C-72 through C-78) to determine whether play areas were present, soil in play areas had been previously sampled, and whether the home needed to be revisited.

3.2.2 Respondent Recruitment

The Interviewer continued to administer the Recruiting Questionnaire (see Appendix C, pages C-9 through C-17) in eligible HUs. The questionnaire invited the respondent to participate in this very important national study, recruited the respondent, and scheduled an appointment for the data collection visit. The data collection visit was scheduled for a date and time convenient to the respondent in the following two to three weeks.

In the early stages of the field work, respondents were offered a monetary incentive of $50. However, response rates were lower than anticipated, so the incentive was increased to $100, and eventually to $200. The incentive was expected to positively influence the respondent’s willingness to participate in the study and once it was increased, it did seem to have the desired effect. Respondents whose homes were revisited for play area soil sample collection were offered an incentive of $20.

At the time of recruitment into the study, a reminder card (see Appendix C, page C-18) identifying the study and documenting the date and time of the appointment was left with the respondent. The respondent was reminded not to vacuum, dust, or mop floors a minimum of three days before the appointment since the team was collecting dust samples. This card provided a toll-free number to call for further questions about the study, and a telephone number where the Interviewer could be reached in case the appointment needed to be rescheduled. In addition, the Interviewer called to confirm with the respondent a day before the scheduled appointment. For respondents without telephones, the Interviewer confirmed the data collection appointment in person.

In cases when a respondent was reluctant to participate, the Interviewer used standard refusal avoidance techniques by answering any questions the respondent had, providing additional details about the data collection procedures, and emphasizing confidentiality and the importance of representing the respondent’s household in the study. When the respondent still refused, the Field Office was notified and a refusal conversion letter, further explaining the importance of the study, was sent via overnight carrier (see Appendix C, page C-19). A few days after the refusal conversion letter was sent, another visit was made to the household to attempt to convert the respondent.

Interviewers used the Control Log and In-Person Contact Record (see Appendix C, page C-20) to record all contact attempts and their outcomes, either in-person or by telephone.

3.3 Room Inventory

Once the respondent was recruited, the Interviewer completed the Room Inventory and Selection form by asking the respondent to list all rooms and the major entrance in the home (see Appendix C, page C-21). Further, the respondent was asked whether each room was an addition since the original construction of the home. If a room was an addition, the respondent was asked whether the addition was constructed before, or during or after 1978. The Field Office used this inventory list to select the rooms in which environmental sampling would be conducted during the subsequent data collection visit.

3.4 Issues Related to the Lead Disclosure Rule

HUD and EPA jointly issued a rule in 1996 requiring that sellers and lessors of most residential housing built before 1978 disclose any knowledge they have of the presence of lead-based paint and/or lead-based paint hazards in the housing (HUD's rule is at 24 CFR 35.80-98; EPA's identical rule is at 40 CFR 745.100-119). The rule requires sellers and lessors to provide purchasers and lessees with any available records or evaluation reports pertaining to the presence of lead-based paint and/or lead-based paint hazards. The rule does not cover the results of evaluations performed by others that are not provided to the owners or lessors. Participants needed to be informed of the responsibilities they would incur under the disclosure rule if they requested information on the lead-based paint or lead-based paint hazards found.

In view of these issues, the following notification plan was developed. If a respondent took the initiative to request the data for his/her home, a letter was sent informing him/her of the Disclosure Rule, asking him/her to sign and return the letter to receive the lead data for his/her home. Allergen data was provided if a respondent requested it, but there were no "normal" values set for household allergen levels and no legal issues attached to this data.

Lead hazards primarily affect small children, especially those under six years of age (CDC, 1991). In homes without children under six, there may be hazards, but no exposure for these susceptible persons. Therefore, homes with significant lead hazards (as defined in the HUD *Guidelines*, Chapter 5) and with resident children under age six or pregnant women, were automatically sent a report on any lead hazards found in the home (see Appendix C, page C-71, Letter to Inform About Possible Lead Hazard).

4. FIELD DATA COLLECTION

At each home, the field staff asked an adult householder questions about the home, made observations, and collected environmental samples. The protocols and forms prepared for these tasks were modified from those in the HUD *Guidelines*, the 1990 National Survey of LBP in Housing, Program Monitoring and Evaluation of the LBP Hazard Control/Reduction Grant Program, and other recent studies of lead hazards in housing, as well as the NIEHS/NIAID Inner-City Asthma Study.

The questionnaire data elicited information needed to 1) perform data analysis for lead hazards and allergen levels by subpopulation, and 2) assess the potential hazard(s) that may result from high lead or allergen levels found in the home. Thus, information was collected about age and renovation history of the home; the occupants' age, race and ethnic group, occupation, hobbies, and smoking patterns; household cleaning schedules; type of heating, air conditioning, dehumidification and other ventilation; type of flooring; the presence of pets and pests; the use of insecticides; the occupants' income and government support of the housing costs; and the use of allergen avoidance practices. Dust environmental samples and paint measurements were collected in a sample of rooms in each home to determine whether lead was present in these media. Additional dust samples were collected to determine the presence of allergens thought to be related to allergy and asthma. Soil samples for lead were also taken from the yard and play areas. Relevant information was recorded about each environmental sample, including location of the sample, total surface area represented by the sample, presence of damaged paint, carpeting, and vinyl mini-blinds, building condition and cleanliness, evidence of moisture, cockroaches and rodents, pets, and smoking, and temperature/humidity in the sampled rooms. Paint samples were tested at the home using a non-destructive direct reading x-ray fluorescence (XRF) instrument. Soil and dust samples were sent to approved laboratories for lead and allergen analysis.

Before the data collection procedures described in this chapter were implemented, the plan for the survey, including these data collection protocols, was submitted to the applicable authorities required by Federal law for their review and approval. All required approvals were received before the survey was implemented. Specifically, the proposed information collection was submitted to the Office of Management and Budget (OMB) for review, as required by the Paperwork Reduction Act of 1995 (44 U.S.C. Chapter 35). In addition, the survey plan was reviewed and approved by the NIEHS and Westat Institutional Review Boards, in compliance with the Public Health Service Act (45 CFR 46, Protection of Human Subjects). The review processes are described in Chapter 3.

This chapter first describes the qualifications, responsibilities, and scheduling of field staff members. We then present protocols and forms for each of the following tasks involved in the field collection of data and environmental samples:

- Administration of the Resident Questionnaire,
- Selection of the rooms in which the environmental samples were collected,
- Selection of sampling locations and protocols for dust sample collection for lead and allergens,
- Selection of sampling locations and protocols for interior and exterior paint lead determination, and
- Selection of sampling locations and protocols for soil collection.

4.1 Field Staff Qualifications and Organization

4.1.1 Field Team Assembly

Two-person teams were assembled for the field data collection. Each team consisted of a Technician and an Interviewer. The Technician was responsible for all X-ray fluorescence (XRF) analyzer measurements and lead dust sample collection and related measurements, and assisting the Interviewer with soil sample collection. The Interviewer was responsible for introducing the team to the occupants, obtaining informed consent, explaining the tasks involved, administering the study questionnaire, and collecting the allergen dust samples and the lead soil samples. On average, the data collection took approximately 2 to 3 hours to complete in each home.

4.1.2 Field Team Qualifications

Since the study findings have national implications, the field team members had the following credentials and qualifications:

- Technicians had conducted at least 20 lead-based paint (LBP) inspections without supervision, had successfully completed an EPA- or State-approved LBP inspector training course, were certified as a LBP inspector in at least one State (for further information, see 40 CFR 745, subparts L and Q, and the associated Federal Register (FR) preamble, at 61 FR 45777-45830), and were approved by HUD for this survey.

- In addition, in study States with certification programs, the agency responsible for LBP contractor certification was contacted, explained the study purpose, activities, and team qualifications, and requested reciprocity or exclusion from the State certification. For those States without reciprocity and which did not approve exclusion, Technicians were certified in those States, e.g., by passing the State examination. In one case, a state certified technician was hired to accompany the study team, with that particular state approval.

- Interviewers were experienced Westat field personnel competent in recruitment, interview techniques and communication with study subjects (i.e., the occupants).

- Some of the Interviewers and Technicians were bilingual to accommodate Spanish-speaking respondents. When a respondent had difficulties communicating in spoken English or Spanish, attempts were made to speak with another adult in the household or a neighbor, nearby friend or relative to assist with recruitment, explanation of the study, and the questionnaire. Attempts were made to employ ethnically diverse staff as appropriate.

- References were obtained and work history verified for all potential field personnel.

All field staff received study-specific training as a group, which included practice house visits with supervisory review. The training team included senior project staff, the XRF manufacturer technical representative, and lead and allergen testing subject matter experts. The use of practice sessions in training and practice house visits allowed team members to become familiar with team dynamics and interaction and to conduct all tasks required in an efficient manner. In addition, Technicians were recruited from a limited number of companies to reduce the number of company-specific 'standard procedures' to be modified for the study purposes. The study procedures were written so that subjective judgment by team members was minimized.

4.1.3 Field Staff Scheduling

The fieldwork occurred from July 1998 to February 1999, from July to August 1999, and from June to July 2000. The Field Director, located in the Field Office in Rockville, MD, scheduled, coordinated and supported all field team activities with the assistance of two Field Supervisors. Where possible, field staff were recruited from areas of the country with the higher densities of PSUs and from different broad geographical areas. Attempts were made to pair team members by geographical area.

The combination of geographical area and time to complete study tasks at each home had some role in the scheduling of home visits, e.g., how many homes could be visited per day and per week. One average, the Technician was at each PSU for approximately two weeks, and the Interviewer for approximately three weeks, as displayed in Table 4.1.

After a home was recruited, the room inventory was faxed to the Field Office. The Field Office used the information on the room inventory to select the rooms for environmental sampling and data collection. In most homes four rooms were selected, in a few homes five rooms were selected. The room selection protocols are described later in this chapter. Once the rooms were selected, the Field Office generated a HU Cover Sheet that identified the home, showed which rooms had been selected, and which environmental samples were to be collected (See Appendix C, page C-22.) The HU Cover Sheet was sent to the field team, along with all materials needed to collect the data and samples from home documented in the HU Cover. Both the Field Office staff and the Field Staff used a Survey Materials Checklist (Appendix C, page C-23) to ensure that all materials were in place for each data collection visit to a participating home.

Table 4.1 Team Activity at each PSU

Team member	Week 1	Week 2	Week 3
Interviewer	Recruiting	Data collection, recruiting	Data collection, recruiting
Technician		Data collection	Data collection

4.2 Resident Questionnaire

After introduction of the team members, the first activity at each home was for the respondent to read and sign the Informed Consent (see Appendix C, pages C-24 through C-25) before continuing with the data collection visit. When the resident spoke mainly Spanish, a Spanish speaking Interviewer used the Spanish language translation of the consent form. When the resident was disabled (e.g., auditory or visual disability) or has difficulty communicating in English or Spanish, the Interviewer asked for permission to get a neighbor, nearby friend or relative to assist prior to the appointment, to assure that the resident understood and agreed to signing the form. Team members then answered any questions the respondent had regarding the study and the activities conducted in their home.

Once consent was obtained, the Interviewer began to administer the Resident Questionnaire to collect the following information (see CB, pages C-26 through C-41):

- Building-related questions: housing unit age, how long the respondent has lived in the home, number of stories, type of heating and air conditioning, type of flooring, presence of dehumidification system, cleaning schedules, presence of pets, presence of cockroaches and rodents, insecticide application, and current allergen avoidance practices.

- Resident-related questions: number of people in the household, age, gender, race, presence of asthma and/or allergy of each resident, household income, and smoking patterns.

- Lead-related occupations or hobbies.

- Allergen-related occupation or hobbies (e.g., veterinarian, exterminator, farm worker)

During the interview with the respondent, the Technician began setting up the materials necessary to conduct the lead wipe sampling and calibrated the XRF. After the questionnaire was completed, the Interviewer informed the respondent of which rooms had been selected from the room inventory form for the purpose of environmental data collection (dust samples) and the XRF paint analysis.

4.3 General Interior Environmental Sampling Protocol

The sampling strategy began with a stratified random selection of rooms, followed by testing of specific surfaces in each selected room, as illustrated in Figure 4.1.

Table 4.2 summarizes the rooms, components, and environmental sample types included in the interior of homes. Because the purpose of the study was to assess dust lead hazards and allergen levels in the nation's homes irrespective of the current occupants, room selection did not depend on behavioral characteristics of the occupants. This room selection strategy provided statistically valid inferences for specific rooms as well as for average dust levels within homes. Room equivalents (as defined in the *Guidelines*) that were not traditional rooms, such as hallways, stairways, and unfinished attics, were not sampled.

Figure 4.1 Multi-Stage Area Probability Sampling Strategy

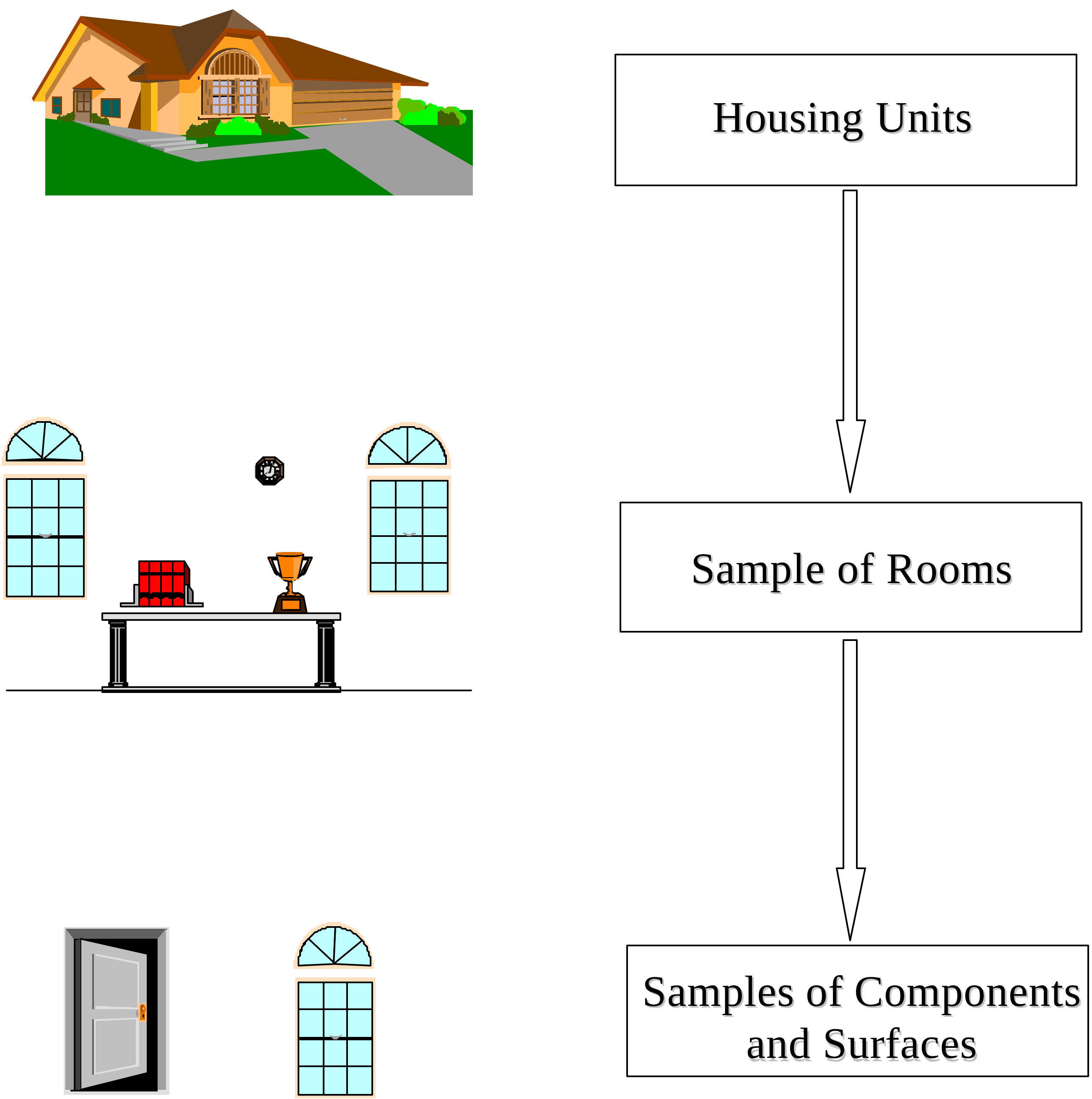


Table 4.2 Sampling Matrix of Rooms, Components, and Sample Types within a Home

Rooms	Sample Type	Sofa/ Bedding	Walls	Ceiling	Windows	Doors	Other Trim	Floors
Kitchen	Lead Dust				X			X
	Allergen Dust							X
	Paint		X	X	X	X	X	X
Common living area	Lead Dust				X			X
	Allergen Dust	X						X
	Paint		X	X	X	X	X	X
Bedroom(s)	Lead Dust				X			X
	Allergen Dust	X						X
	Paint		X	X	X	X	X	X
Other random room(s)	Lead Dust				X			X
	Allergen Dust							
	Paint		X	X	X	X	X	X
Basement (if present)	Allergen Dust							X
Major entrance	Lead Dust							X
Interior common area	Lead Dust							X
(multi-family only)								

The rooms in which environmental samples were collected were:

- Kitchen – In the rare case that multiple kitchens were present, one was randomly selected.

- Common living area (living room, den or family room) - If multiple common living areas were present, one was randomly selected.

- One bedroom - If one or more children age 17 and younger resided in the home, one bedroom was randomly selected from among the bedrooms in which the children sleep. If no such children resided in the home, one bedroom was selected randomly from all the regularly occupied bedrooms (i.e., not a guest bedroom) in the home. Bedrooms were rooms in which people sleep, i.e., there was a bed present in the room. Rooms that were designed as bedrooms, but were being used for another purpose, e.g., as a guest room, office or storage room, were not classified as bedrooms.

- Other random room - This fourth room was randomly selected from among the remaining rooms in the house. This included bathrooms, dens, home offices, utility rooms, etc. It also included bedrooms occupied only by adults, if the home had one or more bedrooms occupied by children. This ensured every room in the home had a chance of being included in the study.

- Second other room - In homes with seven or more rooms in the “other” stratum, a second “other” room was randomly selected. Large homes may have many rooms in this category, perhaps six or more.[6] If only one of these rooms was selected, it would have a within-home sampling weight of seven or more. In contrast, the kitchen's weight was one in nearly all homes, while the living room and bedroom weights typically ranged from one to three. Since variable weights reduce the precision of estimators, it was desirable to structure the sampling to minimize their variability. The procedure set the maximum "other" room weight at six. Data from these second "other" rooms was also used to estimate between-room error, as discussed in Chapter 6 and in Volume I.

Additionally, floor lead dust samples were collected were taken in the following areas:

- Major entrance to the housing unit - immediately inside the home.
- Common area - immediately outside the housing unit (for multi-family housing with interior common areas only).

Finally, an allergen floor dust sample was collected from the basement (where the housing unit had a basement and a basement room was not selected for allergen sampling as part of the random room selection process).

4.4 Interior Dust Sample Collection

The basic dust sampling strategy is presented in Table 4.3, followed by a discussion of the rationale for the strategy.

4.4.1 Surfaces Sampled for Dust

The HUD Lead Safe Housing Rule and the HUD *Guidelines* specify maximum acceptable dust lead levels for three surfaces - floors, interior window sills, and window troughs. Thus, sampling for lead dust was limited to these surfaces. As shown in Table 4.3, only floors were sampled in the major entrance and interior common area (if present).

[6] Only 6.5 percent of US homes have nine or more rooms, and potentially have seven or more "other" rooms. (American Housing Survey, 1993)

Table 4.3 General Dust Sampling Strategy within Each Selected Housing Unit

Rooms/Areas	Surface Tested in Each Room/Area *	No. of Samples per Room **	Sample Location
Kitchen	Floor (L) Floor (A) Window sill and trough (L)	1 1 2	Center of largest open area Perimeter of room Sill and trough of random window
Common living area	Floor (L) Floor (A) Window sill and trough (L) Sofa (A)	1 1 2 1	Center of largest open area Area, 6'x3', in front of sampled sofa Sill and trough of random window One entire sofa seat
Random bedroom	Floor (L) Floor (A) Window sill and trough (L) Bedding (A)	1 1 2 1	Center of largest open area Area, 6'x3', along side of sampled bed Sill and trough of random window Entire bed surface up to an area of 6'x3'
Random other room	Floor (L) Window sill and trough (L)	1 2	Center of largest open area Sill and trough of random window
Basement (if not otherwise selected)	Floor (A)	1	Center of largest open area
Major entrance	Floor (L)	1	Six inches from door
Interior common area (if present)	Floor (L)	1	Six inches from door

* L = lead , A = allergen ** Wipe samples for lead, vacuum samples for allergens

For allergens, floor, sofa and bedding dust were of interest. The National Institutes of Health does not currently define acceptable levels of allergens in dust; however, some data exist as to levels that are associated with diseases such as asthma (Sporik et al., 1990, Rosenstreich et al., 1997).

4.4.2 Dust Sampling Locations

Dust samples for lead within each housing unit were collected in the following locations:

- A randomly selected window from each of the four[7] selected rooms (if a window was present in the room). Sill and trough dust were collected as distinct samples. If the

[7] Since four rooms were selected in most homes and a fifth room was selected in only a few homes, the text, for simplicity of exposition, refers to four rooms.

selected window did not open, other windows were randomly selected until an openable window was found. If no window was openable, the sill on the first window selected was sampled, and no trough dust was sampled.

- The center of the largest open floor area in each of the four selected rooms. This location was readily determinable in each selected room, and was presumed to be accessed by all mobile family members.

- The floor in the major entrance, inside the housing unit approximately six inches away from the center of the doorway. This sample represented dust brought on feet or by wind.

- The floor in the interior common area (if present) of multi-family buildings, collected approximately six inches away from the center of the doorway.

Dust sampling for allergens within each housing unit was as follows:

- The floor in the kitchen, common living area, the same bedroom selected for lead dust sampling, and the basement (if present and regularly occupied). In the kitchen, the dust sample was collected along the base of the cabinets and then along the entire floor as time permitted. In the bedroom and common living area, dust samples were collected directly adjacent to the sampled bed or sofa, respectively. In the basement, the dust sample was collected per the room type, or in the center of the largest open area.

- A bedding sample from the bed in the selected bedroom most often slept in by a child. If no child resided in the housing unit, the most used bed in the selected bedroom was sampled.

- The sofa (or chair) most often used by a child. If no child resided in the housing unit, the most used sofa (or chair) in the selected common living area was sampled. Only upholstered sofas (or chairs) were sampled. If a cushion(s) was present on a wooden or metal sofa (or chair), the cushion(s) were sampled.

4.4.3 Dust Sample Collection Protocols

Single surface dust samples were collected from all locations. Single surface sampling allowed statistical estimation of variance between rooms within a home and between room types across all homes.

Because applicable standards exist only for lead dust sampling by the wipe method and because wipe samples correlate well with blood leads (HUD, 1995b), interior dust wipe samples were collected in accordance with ASTM E 1728-*95 Practice for the field determination of settled dust samples using wipe sampling methods for lead determination by atomic absorption spectrometry techniques* (ASTM, 1995b). One-square-foot templates were used for floor samples. Unless the window was large, i.e. wider than about four feet or deeper than six inches, the entire area was wiped for window sill and trough samples.

The dust sampling method used for allergens was the Mighty Mite vacuum (fitted with a thimble) – the same method employed in the Inner City Asthma Study (ICAS), (ICAS, 1998). Two square yards were vacuumed for floor and bedding dust samples. The entire bedding down to the mattress or impermeable cover was vacuumed for bedding samples, and the seat cushions, seat back, and arms were vacuumed on selected sofas (or chairs). Vacuuming was conducted for 5 minutes for each allergen dust sample.

All dust sampling information was recorded on the appropriate Dust Sampling Logs (see Appendix C, pages C-46 through C-57). Sample location data was recorded, including the surface type for floor and window samples (i.e., whether painted or unfinished wood or metal, linoleum, ceramic or vinyl tile, concrete, carpet, etc.), any deteriorated surface area, the total surface area, the type of material for the sofa (or chair) and bedding (e.g., whether plastic-covered or leather, or cotton, polyester, or wool), the temperature and humidity in each room, and the presence of vinyl mini-blinds, air conditioning devices, evidence of smoking, food debris, moisture, cockroaches, rodents, and pets.

4.5 Paint Testing

Paint was evaluated in a non-destructive manner by XRF to determine if lead-based paint was present in the sampled rooms. This evaluation was conducted in accordance with the HUD *Guidelines*, Chapter 7 (1997), and the applicable Performance Characteristics Sheet. This information will assist HUD in meeting future goals, e.g., to estimate remediation costs. In addition, it may be used to determine the potential or most likely source of lead in the dust. If lead-based paint is present and lead levels in the dust are high, we may infer that the dust contains leaded paint. However, other sources of lead may also contribute to dust lead. For example, if elevated lead levels are found in soil outside the home, the soil could also be a major or contributing source of lead in dust.

The Technician tested specific components in each of the four rooms selected for dust sampling and the exterior of the housing unit as shown in Table 4.4. This approach limited the number of rooms and components evaluated so that all work was completed in about a two- to three-hour period, while maximizing the likelihood of finding lead-based paint in the home. The following surfaces were tested in each selected room if they were present and painted: all four walls, the ceiling, baseboard, the floor, a randomly selected door, and a randomly selected window. In addition, all painted components with damaged or deteriorated paint or friction surfaces were tested.

Table 4.4 XRF Testing Strategy within Each Selected Room or Exterior Side

Interior XRF Testing/Room	Exterior XRF Testing/One Random Side
Wall – all 4 major walls	Siding - all 4 walls
Ceiling	Trim - 2 miscellaneous
Door testing combination (if present)	Window testing combination
Window testing combination (if present)	Door of major entrance to building
Baseboard	Porch and railing: even if not on selected side
Floor	
Surfaces with damaged paint or friction areas	

The siding of all four exterior walls was tested. For other exterior components (trim, windows, doors, etc.), two exterior walls of the housing unit were selected—the wall with the main entrance and one randomly selected wall. The directional orientation of the randomly selected wall was recorded, and its orientation with respect to the front of the building. If the housing unit was in a multi-unit building, the selection was made from the wall(s) that bordered the housing unit sampled. Once the two walls were selected, the following painted components were tested: siding, miscellaneous trim, one random window and the exterior door of the major entrance. The most used exterior door and porch were sampled.

One XRF reading was made per painted component approximately in the center of a randomly selected quadrant of the total surface area. If there was visual evidence that all paint layers were not present in the center, a location in the selected quadrant where all layers were present was tested.

To avoid destructive paint sampling, all teams used the same model XRF analyzer that had no inconclusive range, and did not require substrate correction, according to its Performance Characteristic

Sheet (PCS) developed in accordance with the HUD *Guidelines*. The analyzer model also had acceptable precision, nominal reading time, and compact physical size. The manufacturer provided specific use instructions and training. Calibration and interpretation of results were in accordance with the HUD *Guidelines*, Chapter 7, on Lead-Based Paint Inspection, and the PCS for this model. Paint chips were not collected for laboratory confirmation, because this would have involved destructive testing of the residential surfaces.

XRF results were recorded on the XRF Data Sheet and Calibration Check Test Results Form (see Appendix C, pages C-58 through C-66). Dimensions of painted components, percentage of deteriorated paint, and type of deterioration were recorded.

4.6 Soil Sample Collection

Soil samples were collected for two reasons: soil is a separate pathway for lead exposure because children contact soil directly, and tracking of soil may contribute to lead in house dust. Soil analysis also provides additional data on the correlation between house dust lead levels and soil lead levels, and can be used to assess the previously-reported correlation between elevated soil lead levels and non-intact exterior lead-based paint (EPA, 1995a).

Soil samples were collected from the three general yard sites listed below. At each site, samples were collected from bare soil, i.e., not covered with grass, concrete, asphalt, or other permanent covering, if possible. If no soil was bare, soil samples were collected from covered ground, if possible. Thus, soil samples may have been collected from soil covered by grass or mulch, but not concrete or asphalt. Soil samples were collected in three sites as follows:

- *Main entry (single sample)* - This sample represented soil which may be blown or easily tracked into the home. In addition, deteriorated lead paint or lead dust from inside the home may be swept out onto this soil area. Children may also play near the front entry.

- *Foundation/drip line (composite of up to 3 subsamples)* - These samples represented soil which may have been contaminated with exterior lead paint or lead from flashing, window troughs, etc., and were taken within 3 feet of the building foundation uniformly along a randomly selected wall.

- *Mid-yard area (composite of up to 3 subsamples)* - This soil represented lead in the residential yard to which a child may have had direct exposure. Soil was preferentially sampled from any bare area approximately midway between the drip line and the nearest property boundary or between the drip line and another building on the housing unit property, and uniformly along the mid-yard line. If no mid-yard soil was bare, soil samples were collected from covered mid-yard area, if possible.

In addition to the general yard sites, bare soil was sampled in play areas, if present, in a subsample of homes (as described in Chapter 2). Play area locations sampled were as follows:

- Up to four units of fixed play equipment *(composite of 2 to 5 subsamples)*. Fixed play equipment included swing sets, climbing gyms, sandboxes, permanent/immovable pools, and sport/game areas (basketball, net games, horseshoes, ball field, etc.). Pieces of attached, contiguous equipment, such as an attached slide, swings, and teeter-totter, were treated as one fixed unit of play equipment.

- If no fixed play equipment/area was present, one sample was collected from the major entrance, mid-yard, or dripline of one side of the building (as described above) where the respondent reported that children do/would play in the yard.

Soil sampling was conducted in accordance with core sampling procedures described in the HUD *Guidelines,* which are based on ASTM E 1727-95 *Standard practice for the field collection of soil samples for lead determination by atomic spectrometry techniques* and EPA's *Residential Sampling for Lead: Protocols for Leaded Dust and Soil Sampling* (ASTM, 1995a; EPA, 1995c). Only the top one-half inch of each soil core, i.e., that portion most accessible, was included in the sample. Mulch or leaf covering was gently removed before taking the core. Bare soil was defined as "an area of dirt/ground with no covering and at least 4 inches in diameter (approximately 12 square inches)….coverings include grass, mulch, moss, ivy, etc."

All soil sampling information was recorded on the Soil Sampling Logs (see Appendix C, page C-67 and page C-79). The total area of the yard and the area covered with bare soil and building condition information were also recorded on these forms.

4.7 Data Collection Closeout

At the end of the data collection, the team thanked the respondent and gave them the incentive check. The respondent signed a Participant Receipt (see Appendix C, page C-68), acknowledging receipt of the incentive payment. The field team then edited their work as soon as possible after data collection was completed – while still at the HU, if possible. The Interviewer also conducted a detailed edit of all data collection forms and samples before sending them to the Field Office.

4.8 Field Sample Handling and Shipping

Environmental samples were labeled with unique identification numbers that incorporated the room number, sample number and the survey number assigned to the PSU and housing unit. Lead and allergen dust and soil samples were shipped via an overnight carrier to the Field Office with all data forms, as soon as possible after the data collection visit and after all necessary in-field edit checks were completed. Interviewers kept the allergen samples cool and placed them in refrigerators, including over weekends, when they were not immediately shipped to the Field Office. Allergen samples were placed into a freezer at –20°C immediately upon receipt at the Field Office. After data collection materials were logged, the environmental samples were sent to the approved study laboratories for analysis (see Chapter 5) on a regular basis.

5. LABORATORY PROTOCOLS

The laboratory qualifications and procedures for survey sample preparation and analysis are described below for lead in dust, lead in soil, and allergens in dust. Quality assurance samples are discussed in Chapter 6.

5.1 Lead Dust Wipe Analyses

The laboratory that analyzed lead dust wipe samples was recognized under EPA's National Lead Laboratory Accreditation Program (NLLAP),[8] by being accredited by the American Industrial Hygiene Association (AIHA) Environmental Lead Laboratory Accreditation Program (ELLAP) as a fixed site laboratory, i.e., the operation performed testing from a permanent location. Use of an accredited laboratory ensured that minimum standards were met for the following aspects of laboratory operation: organization and function, facilities, equipment, personnel, analytical methods, quality assurance, safety and health, proficiency testing, site visits, maintenance of accreditation, and reaccredidation. In addition, the laboratory was rated by AIHA's Environmental Lead Proficiency Analytical Testing (ELPAT) Program as "proficient" for lead wipe sample analysis. Copies of the AIHA accreditation audit report(s), all ELPAT proficiency reports, and written procedures for sample preparation, analysis, quality control (QC), and reporting from candidate laboratories were submitted for review and approval.

Dust wipe sample preparation consisted of digestion of both the wipe and collected dust by NIOSH 7300, a hot plate digestion utilizing 15 milliliters (ml) of 1:1 nitric acid and perchloric acid for oxidation of sample components and solubilization of lead, reconstituted to 30 ml with 3.5% nitric acid. Sample digestates were brought to a final volume of 30 ml.

Because the laboratory analyzing the dust samples used flame atomic absorption spectrometry (FAAS) for analyzing their ELPAT dust proficiency samples, FAAS was used for the study analyses of the digested dust samples. The analytical procedure complied with the particular FAAS instrument manufacturer's instructions, an accepted method for analysis, and the ELLAP Quality Manual and Policies.

[8] See www.epa.gov/lead for information about the NLLAP, www.hud.gov/lead for information about recognized laboratories, and www.aiha.org for information on ELLAP and ELPAT participants.

5.2 Soil Analyses

The laboratory that analyzed the soil samples for lead was also accredited by the American Industrial Hygiene Association (AIHA) Environmental Lead Laboratory Accreditation Program (ELLAP) as a fixed site. In addition, the laboratory was rated by AIHA's Environmental Lead Proficiency Analytical Testing (ELPAT) Program as "proficient" for soil lead sample analysis. Copies of the AIHA accreditation audit report(s), all ELPAT proficiency reports, and written procedures for sample preparation, analysis, quality control (QC), and reporting from candidate laboratories were submitted for review and approval by HUD.

The preparation of soil samples involved the following sequential steps: drying, homogenization (by passing through a 2 mm sieve, followed by a 500 um sieve), subsampling, and digestion. Digestion was conducted in accordance with EPA SW 846, Method 3050, a hot plate digestion utilizing nitric acid and hydrogen peroxide acid for oxidation of sample components and solubilization of lead. One-half gram of soil sample was digested and brought to final volume of 50 ml.

Because the laboratory analyzing the soil samples used inductively-coupled plasma atomic emission spectrophotometry (ICP-AES) for analyzing their ELPAT soil proficiency samples, ICP-AES was used for the study analyses of the digested soil samples. The analytical procedure complied with the particular ICP-AES instrument manufacturer's instructions, an accepted method for analysis of digested samples, and the ELLAP Quality Manual and Policies.

5.3 Allergen Vacuum Dust Analyses

Since there were no accreditation programs and few laboratories qualified to conduct the required allergen analyses, NIEHS identified and approved the laboratory that conducted the allergen analyses.

Dust samples were shipped to the laboratory in styrofoam coolers on dry ice via overnight delivery. Within two working days of sample receipt, the dust was sieved through a 425 µm pore size grating. Approximately 100 mg (exact weight measured and recorded) of dust was placed in each of multiple test tubes labeled with the sample ID, date, and amount of dust. These aliquots of fine dust were stored at -70°C. When ready for analysis, dust aliquots were extracted in borate buffered saline (pH 8.5), 2 ml per 100 mg dust extracted. Extracts were clarified by centrifugation and the supernatant decanted.

All analytical methods had high sensitivity and low inter- and intra-assay variability (less than 10%). The cockroach antigen *Bla g* I was measured by a 2-site, monoclonal antibody enzyme-linked immunosorbent (ELISA) (Pollart et al., 1991). The dust mite allergens *Der f* I and *Der p* I were measured using antigen-capture ELISA assays employing monoclonal capture and detector antibodies (Chapman et al., 1987).

Assays for other allergens (*Fel d* I, *Can f* I, *Mus m* I, and *Rat n* I) will be performed according to previously published methods (Wood et al., 1988; Schou et al., 1991; Twiggs et al., 1982; Swanson et al., 1985). Alternaria allergen measurements will be performed according to methods of Burge and co-workers (in press). All samples were stored by the laboratory in such a manner that additional allergen assays can be done as new tests are developed.

6. QUALITY ASSURANCE

The collection of high quality data was essential to this study. Quality assurance was integrated into all components of the study, with special emphasis on field data collection and laboratory procedures. The principle source of quality assurance was the utilization of well-planned, detailed protocols for all aspects of data collection: listing, in-person interviews, field observation, measuring and recording physical data, collecting environmental samples, and equipment and sample handling. Thorough study-specific training of experienced field staff was critical to assurance of a quality product. Finally, ongoing communication between and among the various individuals responsible for each stage of the study was rigorously maintained to assure quality information.

6.1 Overall Study Design

A prudent and defensible study design must consider the objectives, available options, and logistical issues throughout the planning phase. The study design was developed through a series of steps aimed at obtaining quality data to meet HUD's and NIEHS's goals. The first step was to hold a series of meetings during which subject matter experts, HUD and NIEHS representatives, and Westat project staff discussed the objectives and various alternatives for meeting those objectives. Following those meetings, an options report was developed which delineated possible methods for selecting the sample, recruiting households, and conducting field data collection and laboratory analysis. This report was reviewed by HUD, NIEHS, and EPA staff and revised to reflect their concerns. The study design was then developed based on the objectives, desired statistical precision estimates and logistical issues including funding level.

6.2 Personnel Responsibilities

The project personnel had appropriate education and experience for the conduct of this study. Importantly, each individual had clear responsibilities as outlined below.

Project Director - Oversight of all project work. Principally responsible for design and implementation of the study. Reported progress and issues to HUD.

Deputy Project Director/Field Director - Supported the Project Director in all study activities. Acted in cases of Project Director's absence. Oversaw all field data collection activities and flow of samples and data from the field to Westat and to the laboratories.

Field Supervisors - Managed field teams and planned and coordinated their activities. Available to field staff on a 24-hour basis during the field period. Monitored the field data on a scheduled basis for completeness and consistency and immediately resolve any issues that arise.

Listing Personnel - Listed all residential units in selected segments.

Field Interviewers - Determined eligibility and recruited households into the study. Administered resident questionnaire, collected dust and soil samples, and worked with the Technician during data collection. Ensured all data was collected and properly recorded.

Field Technicians - Determined all environmental sample locations, took XRF readings, and collected soil samples. Ensured all samples were collected and properly logged.

QA Officer - Responsible for field aspects of quality assurance. Developed and implemented field and laboratory protocols. Offered advice in modification of protocols and acted as liaison to contract laboratories.

Contract Laboratories - Analyzed samples submitted in a timely manner in accordance with agreed upon procedures. Reported any problems immediately to the Field Director. Resolved all problems identified by QA Officer.

6.3 Development of Field Data Collection Forms

The field data collection and interview protocols and forms were developed from previous studies of similar scope to meet the current study objectives. Subject matter experts reviewed the draft protocol, which were also available for review by any interested party during the 60-day public comment period required for OMB approval.

In addition, Westat conducted pilot studies of the draft field protocols and forms for screening and recruiting and for field data collection.

- *Screening and recruitment:* A number of homes in the Washington, DC metropolitan area were recruited following the proposed single-stage screening and recruiting procedure. This pilot tested whether the questionnaire properly screened for eligible homes and flowed smoothly, whether the introductory letter and Interviewer introductory statements answered typical questions and concerns posed by respondents, and whether the incentives and recruitment strategy were effective.

- *Field data collection:* Senior staff and subject matter experts conducted field data collection activities at five homes in the DC area to test the draft protocols and forms. In particular, the proposed distribution of labor among the team members, the order in which study activities were conducted, and the estimated actual time to complete each activity were evaluated.

Following the pilot studies, recruitment efforts and the written field protocols, forms, and questionnaires were modified, as necessary, based on our findings. Once finalized as to content, Westat coding and data entry staff reviewed the protocols and forms to ensure efficient and accurate transfer of the data into the database.

6.4 Quality of Field Data Collection

6.4.1 Manual Edit by Field Staff

Each field team performed a manual edit of all data and samples collected. If possible, this edit was performed while still in the respondent's home. Otherwise, it was performed later the same day. The edit entailed an item-by-item proofreading of all hard copy forms to make sure all required information had been collected and properly recorded, all required samples were collected, and all information was legible and consistent. Samples were checked to ensure proper labeling and packaging. All materials and samples were identified by the unique housing unit or HU number. The field team used an edit checklist to document the manual edit process. Data collection materials for each HU were returned to the Field Office by overnight carrier as soon as the detailed review was completed.

6.4.2 Review by Field Office

Once the data collection materials arrived at the Field Office, the Field Supervisor checked all field data using a data collection packet review checklist. Any errors were reconciled as soon as possible with the field team prior to submission of the samples to the laboratory.

6.4.3 Telephone Verification of Data Collection

The Field Director and Supervisors contacted a random sample of the completed households by telephone to verify the team's activities and conduct and to validate selected information from the data forms. A telephone verification form was used to document this process.

In addition to the random verification process, a toll-free phone number was given to each respondent should they have questions or comments. A number of respondents and potential respondents utilized this phone number. All questions and concerns were answered or addressed by the Field Director.

6.4.4 Random Field Audits

The QA Officer or designee, and HUD and NIEHS representatives conducted random field audits of the field teams to verify the accuracy and completeness of data collected. Audits were conducted by accompanying and observing the field team during data collection activities. Observations and recommendations were recorded on a field team audit form. The findings were reviewed with the team immediately following the data collection visit. To provide feedback and correct any deviations noted from study protocols. An attempt was made to audit each team member at least once. If problems were noted, a second audit was conducted.

6.5 Replicate Sampling for Estimation of Measurement Error

Measurement error is the error in determining the true lead or allergen content of a sample. The measurement error variance can be determined using independent measurements on components (such as paint lead measurements or dust allergen measurements at two randomly selected locations). Estimates of the magnitude of the measurement error, including spatial variability, are required and cannot be obtained from other data. When assessing whether a home has lead-contaminated dust or lead-based paint or allergens present in dust based on measurements on several surfaces in randomly selected rooms, bias results from a combination of (1) the distribution of the true lead loadings, (2) the effects of measurement error, and (3) the incomplete sampling of rooms. A correction for bias requires assumptions about the distribution of components in unsampled rooms and the distribution of true lead loadings, a model for the measurement error, and an estimate of the measurement error variance.

To collect data on the components of measurement error variance, between-room and within-room replicate dust samples and paint lead measurements were collected according to the following plan:

- Between-room variability within room strata was assessed by sampling additional (or replicate) rooms in a random subsample of housing units. Replicate room testing was conducted only in the bedroom and other room types.

- Paint lead measurements and lead dust samples were collected in these replicate rooms exactly as in the primary rooms. It is possible that a replicate room and a second "other" room (for large homes with more than six other rooms) were selected in the same housing unit. If both procedures selected a room from the other room stratum, one room was selected and its data served both purposes. If the two procedures selected a bedroom and a second other room, only the second other room was sampled. That is, no home had six rooms sampled. The application of these procedures resulted in 115 homes with a replicate room sampled.

- Replicate (within-room) samples were required for the estimation of the within-room measurement error. One within-room replicate dust sample for lead was collected from a randomly selected room and surface in each housing unit. One replicate XRF reading was taken per room, with the component selected randomly. Replicate soil samples were collected in one-third of the housing units, with the location randomly selected from the three primary sampling sites (main entry, foundation/dripline, or midyard).

The specific procedures, equations, and justification for measurement error correction are presented in Appendix D.

The quality control environmental samples summarized in Table 6.1 include the samples collected to ascertain measurement error.

Table 6.1 Summary of Environmental Testing Quality Control Samples

Purpose	XRF	Lead Dust Wipes	Allergen Vacuum Dust	Soil
Materials Screen: To ensure sampling supplies do not have lead contamination or allergen contamination	NA	2 per lot of supplies	NA	NA
Field Blank: To ensure contamination does not occur during sample handling and preparation	A zero check is part of each XRF calibration – 2 per HU (pre/post)	1 blank wipe per HU	NA	NA
Reference Sample: To check the accuracy of the analytical results	XRF Calibration of SRM film – 2 per HU (pre/post)	Spiked wipes: 1 per 50 samples to lab	NA	1 per 50 samples to lab
Sample Replicate: To determine instrument precision	XRF Calibration – three SRM measurements made – 2/HU (pre/post)	*Random duplicate analyses of sample, blank, and spiked sample – 5% samples	*Random duplicate analyses of sample and spiked sample	*Random duplicate analyses of sample, blank, and spiked sample – 5% samples
Component/Surface/Soil (within-room) Replicate: To measure component/ surface lead/allergen variation within a room, or soil variation within a yard	1 random component per room	1 surface replicate per HU - random surface in random room	NA	1 soil replicate at every 3rd HU – random site
Room Replicate: To measure component lead or allergen variation between rooms within a room strata	One entire room in 115 HUs	One entire room in 115 HUs	NA	NA

* Lab-generated QC analyses HU = housing unit NA = Not applicable

6.6 XRF Quality Control Measurements

6.6.1 Instrument Calibration

Calibration of the XRF analyzer was performed before and after the XRF testing in every housing unit. The calibration was conducted in accordance with the appropriate performance characteristic sheet (PCS) for the manufacturer and model. Three readings of the NIST Standard Reference Material (SRM) 2579, Level III paint film, nominal lead loading of 1.02 mg/cm^2, were taken using the same nominal time used in the housing units (20 seconds). The SRM film was positioned at least one foot away from any potential lead source. The average of the three readings was compared to the PCS calibration check tolerance limits. No analyzer was used if the calibration check average was greater than the tolerance limits. In addition, the manufacturer required taking a single reading of the front and back of the 1.02 mg/cm^2 NIST standard. Each of these values had to fall within the tolerance range as well.

The calibration procedure also provided a measure of the variation in XRF response at a lead concentration of 1.02 mg/cm^2.

6.6.2 Replicate Component (Within-Room) XRF Testing

Replicate component testing was conducted to assess the variation in XRF measurement error for given component within a given room (variation in paint lead content within a room plus variation in XRF measurement). One replicate component XRF reading was made in every room on a randomly selected component.

The Technician visually divided the surface of each painted component to be tested into fourths (quadrants). The primary quadrant to be tested was selected at random. The Technician then tested in approximately the center of the painted area of the quadrant. For the replicate component testing, the Technician took the XRF reading in the quadrant diagonal from the primary reading. Thus, if the replicate component was a window and the primary reading was taken in the lower left quadrant, the replicate reading was taken in the upper right quadrant.

6.7 Lead Dust Wipe Sample Collection Quality Control

Since the laboratory was not provided with the surface area wiped, laboratory wipe sample analyses were reported as total lead per wipe sample.

6.7.1 Lead Dust Wipe Materials Screens

A wipe materials screen was prepared and analyzed by laboratory personnel. The screen was prepared just like a regular sample, except that no surface is wiped. The purpose of a materials screen was to verify that the various sampling supplies used in the field did not have lead contamination. At least two screens were prepared and analyzed for every lot of materials used in the study. The results of analysis were reviewed before the supplies were used in the field.

6.7.2 Field Blank Wipes

The Technician prepared a field blank wipe just like a regular sample except that no surface was wiped. This sample indicated whether any contamination of the samples had occurred during handling and transportation; e.g., if the Technician did not properly clean his/her hands between sample collections. One field blank was prepared for each housing unit at a random sample bcation where another wipe sample was collected.

6.7.3 Reference Sample Dust Wipes

Reference wipe samples for the study were prepared by applying an accurately weighed portion of NIST powdered lead-based paint (SRM 1579a) to a blank wipe of the study sample materials. The wipes were then placed into clean centrifuge tubes from the same lot used in the study. An identification number was affixed to each reference wipe and submitted to the Field Office with results of analysis. Approximately 350 reference wipes were made in the following five different concentration ranges (approximately 70 per range):

- 0-25 µg/wipe
- 25-75 µg/wipe
- 75-150 µg/wipe
- 150-300 µg/wipe
- 300-600 µg/wipe

The Field Office re-labeled each reference wipe sample with labels designed to look like a normal HU wipe sample label. The Field Office then submitted 2 of each reference wipe to the wipe laboratory for analysis. After acceptable results for this trial run, the Field Office then randomly inserted one reference wipe sample with each group of 50 samples (approximately every 3-4 HUs) before sending samples to the laboratory.

A reference analysis was considered acceptable if the recovery ranged between 80% and 120% of the true value (the range used in the AIHA's ELPAT, and accepted by the EPA's NLLAP), and if the recovery results were not consistently near the extremes of the acceptable range. If a reference sample was out of the acceptable range, two things happened:

1. The laboratory was called and asked to examine the batch data, and stop all further sample analyses.

2. If the data review did not resolve the problem, the laboratory was asked to analyze the batch digestates a second time.

These procedures resolved all discrepancies that arose from the reference wipe analyses. The laboratory was instructed to maintain all sample digestates indefinitely after submission of results to allow for possible re-analysis.

6.7.4 Replicate (Within-Room) Dust Wipe Samples

A replicate (within-room) wipe is a wipe sample conducted in the same room for the purpose of assessing the measurement error in dust levels within a room (variation in dust concentration from location to location plus error in the actual sampling procedure). One replicate dust wipe was collected on one surface in each housing unit. The Field Office randomly selected both the room and surface where the replicate was collected.

Replicate floor wipes were collected in the second largest open area in the room. Replicate sill or trough wipes were collected on another window, selected at random.

6.8 Allergen Vacuum Dust Quality Control

Due to the type of allergen analyses conducted, no material screens were analyzed nor were any field blanks collected. Also, due to the specificity of sample surface vacuumed (i.e., the entire surface was vacuumed), no surface replicates were collected. Vacuum sample analyses were reported by the laboratory as total sample mass and allergen per sample.

6.9 Soil Quality Control Samples

The University of Cincinnati Hematology and Environmental Laboratory provided three reference soil samples for the study. These soils had been sieved to a 250 μm particle size and homogenized. A consensus lead value was obtained for each sample by a number of laboratories and analytical methods. Two additional reference soil samples were obtained from NIST. These were SRMs 2709 and 2711. Approximately two grams of each homogenized soil reference material was placed in a clean centrifuge tube from the same lot used in the study. Approximately 140 reference soils were made in the following concentration ranges (approximately 20-30 per range):

- 18.9 ppm (SRM 2709)
- 640 ppm
- 1,162 ppm (SRM 2711)
- 3,132 ppm
- 6,090 ppm

The Field Office labeled each reference soil sample with labels designed to look like a normal HU soil sample label. The Field Office then submitted 2 of each reference soil to the laboratory for analysis. After acceptable results for this trial run, the Field Office randomly inserted one reference soil sample with each group of 50 samples (approximately every 10 HUs) before sending samples to the laboratory.

A reference analysis was considered acceptable if the recovery ranged between 80% and 120% of the true value, and if the recovery results were not consistently near the extremes of the acceptable range. If a reference sample was out of the acceptable range, two things happened:

1. The laboratory was called and asked to examine the batch data, and stop all further sample analyses.

2. If the data review did not resolve the problem, the laboratory was asked to analyze the batch digestates a second time.

These procedures resolved all discrepancies that arose from the reference soil analyses, except analysis of the 18.9 ppm NIST SRM 2709. Lead was not detectable in this low lead level San Joaquin soil reference sample. The laboratory director reported that the high aluminum content interfered with the ICP-AAS analysis of low lead levels in these samples. To resolve this issue, the laboratory conducted a method detection limit study on four representative and distinct study soils (40 CFR Part 136, Appendix B), and concluded that the method detection limit for the soil samples was 20 ppm. (The method detection limit is defined by this procedure as "the minimum concentration of a substance that that can be measured and reported with 99% confidence that the analytic concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte.") The laboratory was instructed to maintain all sample digestates indefinitely after submission of results to allow for possible re-analysis.

6.10 Laboratory Quality Control

The laboratories provided copies of their quality assurance procedures during the selection and qualification process. Once approved, the laboratories adhered to these procedures and provided the results of the approved QC analyses, as requested. In general, the laboratories performed instrumental and duplicate quality control analyses as described below.

6.10.1 Instrumental Quality Control Samples for Lead Analyses

A variety of instrumental QC samples were prepared and incorporated into each lead analysis run to ensure that the original calibration solutions were accurate, the instrument was properly zeroed, instrumental drift was not excessive, and carryover between samples did not occur. The protocols used for these analyses are described in ASTM E 1613-94 and the ELLAP Quality Manual and Policies.

The laboratories conducted QC checks, which included duplicate injections of the same sample (lab split), method blanks, and spiked samples to measure instrument precision. Precision checks were included at a minimum frequency of five percent of the samples.

6.10.2 Quality Control for Allergen Analyses

Each allergen assay was assigned a unique code that included the date on which the assay was performed, and the type of assay (i.e., the allergen being measured). Paper data sheets were used to record the sample numbers as well as the dilutions used. In addition, this information became part of each permanent computer file. Standard curves were included on each assay plate. Each standard dilution was run in duplicate, with unknown samples run at three dilutions. Positive controls were the standards; negative controls were buffers with no allergen.

Data was generated based on the microtiter plate reader, and read into a mainframe computer database, which was backed up on tape weekly (or equivalent data storage procedure). The computer file included: assay number, type of allergen, standard dilutions, unknown sample numbers, unknown dilution factors, absorbance readings for each well of the plate, calculated values for each sample, measures of variability for each sample, an indication of the validity of the standard curve, and of each sample measurement.

6.11 Sample Management

All samples were labeled with pre-printed, bar-coded labels using a standard numbering scheme. Samples to be collected were logged out with each data collection package, and logged back in when the completed data collection package was returned to Field Office. In addition to the computer tracking, a transmittal sheet (chain-of-custody) accompanied each group of samples or data packets whenever they were shipped.

6.12 Data Management, Preparation and Analyses

6.12.1 Protocols for Data Entry

All data requiring key entry was re-typed 100 percent. Any discrepancies were immediately resolved. The resultant data and test results were then submitted to computerized range and logic checks. All discrepancies and out-of-range values were investigated and resolved.

6.12.2 Sample Weighting and Variance Calculation

To fully account for the complex survey design, it was necessary to apply sampling weights to each completed case. A given unit's sampling weight is roughly the number of housing units nationwide represented by the study unit. The initial weights were further adjusted to balance differences in nonresponse and noncoverage, as discussed in Chapter 2.

6.12.3 Survey Database

The survey data on questionnaires and log sheets was coded, key, and compiled into a data base consisting of several inter-related files. The laboratories submitted their data electronically. The lab data was merged with the corresponding log sheet data. Data files were organized by the type of data that have been collected. Each questionnaire or log sheet has its own subdirectory that contains data specific that particular questionnaire/log. For each questionnaire/log, the data are broken down into separate files, one for each record in our original data file. All files are linked by a common variable -- the unique household unit identification number. Each record type is documented in a codebook for that particular data file. The directory structure is as follows:

ALLERGEN -	5 files containing allergen log and laboratory assay data
LEAD -	7 files containing lead dust wipe log and lab data
RECRUIT -	10 files containing household recruiting questionnaire data
RESIDENT-	8 files containing residential questionnaire data
SOIL -	1 file containing soil log and lab data
XRFEXT -	5 files containing external XRF data sheet
XRFQUEX1 -	12 files containing XRF sampling logs for Kitchen and Living Room
XRFQUEX2 -	12 files containing XRF sampling logs for Bedroom 1 and 2
XRFQUEX3 -	12 files containing XRF sampling logs for Other room 1 and 2

6.12.4 Analysis Data File

An analysis data file was created from the survey data files. The analysis data file has one record per HU, and contains the housing unit ID, the HU weights, the replicate HU weights, and a number of derived variables, set forth below. This file is the result of the merging of the questionnaire and log files referenced above, along with the files that contain the respective laboratory data. This section now presents the definitions of the derived room level and HU-level categorical variables that underlie the statistical analyses presented in Volume 1.

HU Construction Year. This was taken from the resident questionnaire, Q1. If Q1 was missing, then construction year was imputed as the midpoint of the interval ranges from Q2. For the interval 1939 or earlier, the construction year was imputed as 1922, because that is the median construction year for pre-1940 housing, according to the 1995 AHS. If Q2 is missing, then the number of years anyone in household has lived in HU, and the number of years respondent has lived in HU were computed from Q3. Then the construction year was estimated as the older of 5 years before the respondent or anyone else in the household moved in, and the modal age for the Census tract (from the 1990 Census). This assumed the house was at least 5 years old when the respondent's household moved in. It is likely that the HU was at least this old and may have been older. The 5-year interval was based on the assumption that the current residents are not the original residents; otherwise they would know how old the building is. Similarly, it is likely that subsequent residents for a building that was no more than 5 years old when they moved in would know the age of the building fairly well. The median time a household occupies a home is 5 years. Use of Census data to override this imputation of the HU age corrects for some underestimation of HU age. If Q3 was missing, then the construction year was imputed from 1990 Census data.

Housing Unit type. HU type was derived from the resident questionnaire, questions Q5 and Q6. For the purposes of this survey, if a building has 1 to 4 units, it was single family; if it has 5 or more, it was multi-family. Many HUD programs and regulations, e.g., the Lead-Based Paint Disclosure Rule (61 FR 9064), use this cutpoint between single and multi-family housing.

Race and Ethnicity. Race and ethnicity of the household are the race and ethnicity of the youngest member of the household, and are taken from the Resident questionnaire, Q25.

Government support. This variable comes from Q33 through Q36 in the resident questionnaire by following the skip patterns for owner or renter (Q33) through to receipt of government support in Q35 or Q36, or living in public housing (Q34).

A household has government support, if Q34 = 2 or if Q35 = 1 or if Q36 = 1
A household has no government support if Q33 = 1 and Q36 = 2, or if Q34 = 1 and Q35 = 2

Poverty. The definition of poverty follows the 1996 Census Bureau Poverty Thresholds by size of household and number of children. The variable uses Q24, Q37, and Q38 from the resident questionnaire. A household was in poverty:

if Q24 = 01 or 02	and Q38 = 01 or 02
if Q24 = 03	and Q38 = 01 or 02 or 03
if Q24 = 04 or 05	and Q38 = 01 or 02 or 03 or 04
if Q24 = 06 or 07 or 08	and {Q37 = 1 or Q38 = 01 or 02 or 03 or 04 or 05}
if Q24 = 09	and {Q37 = 1 or Q38 = 01 or 02 or 03 or 04 or 05 or 06}

The following variables are described for the kitchen. Parallel variables were also created for the common living area, bedrooms, other rooms, and the main entrance (floor dust only) following identical specifications. This analysis was also performed for the exterior, but with slightly different specifications.

LBP in Kitchen, Room level. There was LBP in the kitchen if any of the XRF readings in the kitchen was 1.0 mg/ft^2 or larger.

Deteriorated LBP in Kitchen (*Guidelines*), Room Level. The threshold amount of deteriorated LBP for a hazard for large surfaces -- walls, floor, ceiling, and doors -- was more than 2 square feet. The area was determined from the total amount of painted surface multiplied by the percent deteriorated. For the small surface components, hazard was defined as more than 10 percent deterioration. There was deteriorated LBP in the kitchen if any of the components in the kitchen has deteriorated LBP.

Deteriorated LBP in Kitchen (Lead Safe Housing Rule), Room Level. Any amount of deteriorated LBP was a hazard under 1999 rule.

Kitchen lead contaminated dust (*Guidelines*), Room Level. There was lead contaminated dust in the kitchen if the floor dust lead loading was 100 µg/ft^2 or greater, or if the window sill dust lead loading was 500 µg/ft^2 or greater, or if the window trough dust lead loading was 800 µg/ft^2 or greater.

Kitchen lead contaminated dust (Lead Safe Housing Rule), Room Level. There was lead contaminated dust in the kitchen if the floor dust lead loading was 40µg/ft^2 or greater, or if the window sill dust lead loading was 250 µg/ft^2 or greater.

Lead soil hazard (*Guidelines*). A soil lead hazard was defined as bare soil with greater than 2,000 ppm lead. If at least one sample was taken from bare soil, and reached the threshold, there was a soil lead hazard.

Lead soil hazard (Lead Safe Housing Rule). A soil lead hazard was defined as more than 9 square feet of bare soil with greater than or equal to 2,000 ppm lead. If at least one sample was taken from greater than 9 square feet of bare soil, and reached the threshold, there was a soil lead hazard.

LBP Hazard in Kitchen (*Guidelines*), Room level. A LBP hazard existed if there was deteriorated LBP present, or lead-contaminated dust present, or lead-contaminated soil present.

LBP Hazard in Kitchen (Lead Safe Housing Rule), Room level. A LBP hazard exists if there was deteriorated LBP present, or lead-contaminated dust present, or lead-contaminated soil present.

Interior LBP, HU Level. A HU had interior LBP if any of the sampled rooms had LBP.

Any LBP, HU Level. A HU had LBP somewhere if it had either interior or exterior LBP.

Interior Deteriorated LBP, HU Level. A HU had interior deteriorated LBP if any of the sampled rooms have deteriorated LBP.

Interior LBP Hazard. A HU had LBP hazard in the interior if any room had an LBP hazard.

Interior Dust Lead Above Thresholds. A HU had interior dust lead above thresholds if any of the samples exceed their respective thresholds.

Lead Related Hobby. A household member had a lead related hobby if there was a positive response to any part of Q32 in the resident questionnaire, except parts 04 and 06. Since these related to removing or sanding paint from the house, they were counted as lead-related only if the house was built before 1978.

Amount of LBP by Painted Component. This complex derived variable was built as follows. First determine which components in each room are painted, determine the amount of paint on each component, and determine if the component has LBP. Since the painted areas of the various architectural components were not computed in the field, it was necessary to calculate the areas from the dimensional data recorded in the field. Tables 6.2 and 6.3 give the algorithms for calculating the painted area of each interior and exterior painted component.

Table 6.2 Algorithms for Calculation of Painted Areas of Interior Components

Architectural Component	Calculation of Painted Area
Walls	Ceiling height times length of wall, minus total area of doorways, windows and other openings. Doorways were assumed to be 21 sq. ft., windows were assumed to be 12 sq. ft., and other openings were assumed to be 16 sq. ft. If this calculation resulted in a negative value, the result was forced to zero.
Window sills	Width was measured, length was assumed to be 36 inches.
Window sash	Assume standard size windows 3 foot by 4 foot without mullions (3 square feet)
Window casing	Assume standard size windows 3 foot by 4 foot with apron (5 square feet)
Window jamb	Assume standard size windows 3 foot by 4 foot (3 square feet)
Door	Assume standard size doors 30 inches by 78 inches (17 square feet)
Door jamb	Assume 4-inch trim on a standard size door (5 square feet)
Floor	Length of room times width of room. If opposite walls have different lengths, use the larger length.
Baseboard	Amount was sum of 4 wall lengths less doors widths (assume 3 feet per door), times representative baseboard width of 4 inches.
Ceiling	Same as floor area
Crown molding	Amount was the sum of all 4 wall lengths times representative width (7 inches)
Chair rail	Amount was sum of 4 wall lengths less door lengths and window widths (assume 3 feet per door and window), times representative chair rail width of 3 inches
Chimney/fireplace	Assume area of 16 square feet.
Beam/column/joist	Assume each beam was 12 feet tall/long and has a cross section 6 inches square, of 24 square feet. Total area was product of number of beams times 24 square feet per beam.
Shelves	Assume shelf depth was 1 foot. Multiply by total shelf length.
Built-in cabinets	Assume each cabinet was 3 foot by 4 foot. Multiply by number of cabinets.
Stair rail	Amount was length of rail times representative diameter (8 square inches)
Stair tread	Amount was the representative size 10 inches by 3 feet times number of treads
Stair riser	Amount was representative size 7.5inches by 3 feet times number of risers
Radiator/heater	Assume a radiator, not vent of representative size 18 square feet
Window trough	Amount = trough width x length x number of windows in room. Trough width was the lesser of the two trough dust wipe dimensions, length was assumed to be a standard = 3 ft = 36 inches
Vent cover	Assume 1 square foot

Table 6.3 Algorithms for Calculation of Painted Areas of Exterior Components

Architectural Component	Calculation of Painted Area
Siding	Amount = Building height x wall length. The building height was assumed to be a representative wall height (10 feet) times the number of floors.
Main Entry Door	Assume a standard size entry door (21 square feet)
Door jamb	Assume a standard size door (21 square feet) and representative 6-inch trim times the number of doors in house (assume 2 doors).
Porch/stairwell Floor	Amount was length of porch times standard width of 8 feet.
Porch/stairwell Ceiling	Amount was same as porch floor
Porch/stairwell Railing	Amount was length of railing times standard 10 inch width.
Window sill	Amount was sill width x length x number of windows on wall. Sill width and length are assumed to be standard of 4 inches by 3 feet. Assume 2 windows per floor times number of floors.
Window sash	Assume a standard size window (3 feet by 4 feet) without mullions (3 square feet) x 2 windows per floor times number of floors on the wall.
Window casing/apron	Assume a standard size window (3 feet by 4 feet) with apron (5 square feet) x 2 windows in building per floor times number of floors.
Cornerboard	Amount was the length of the wall plus 20 ft (two sides times 10 ft representative floor height) times number of floors x assumed width of 1 foot
Foundation Wall:	Amount was length of wall times height of foundation wall (assumed to be 2 feet).
Skirt/dripboard	Amount was length of wall times width of skirt (1 foot)
Soffit/fascia	Amount was length of wall times the width of the soffitt/fascia (20 inches)
Chimney/fireplace	Assume 1 on wall equal to representative area of width (assume 6 feet) by building height (10 feet times number of floors) plus 5 feet extension above roofline
Shutters	Amount equals standard height (4 feet) times standard width (8 in) times 2 (number of shutters per window) times number of windows (2 times number of floors
Column/post	Amount equals standard 20 inches around post times 10 ft
Downspout	Amount was assumed to be height of building (10 x number of floors) times 1 foot around downspout
Garage door	Assume 1-1/2 car garage average = 8 x 12 = 96 square feet
Gutter	Amount was length of wall times 1 foot around the gutter

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APPENDIX A

Sample Design Details

APPENDIX A: SAMPLE DESIGN DETAILS

The following sections are excerpted from the *National Survey of Lead Hazards and Allergens in Housing Protocol and Sample Design Report: Revision 4* (April 8, 1998). They are included here as documentation of the analyses that went into planning the sample design.

First-Stage: Sampling PSUs

The stratification used in the sampling of the Westat PSUs was beneficial for the National Survey of Lead Hazards and Allergens in Housing, because it improved the representativeness of the PSU sample with respect to low-income households and urban, suburban, and rural housing units through the use of MSA status, population size classes, and Per Capita Income as stratification variables. The large, certainty MSAs are urban areas, while the noncertainty MSAs are suburban areas and smaller cities, and the noncertainty, non-MSAs are rural areas and small towns. However, two important housing characteristics, housing age and percent of housing that is single-family, were not used in the Westat PSU frame stratification. Therefore, it was necessary to compare the distribution of housing units by these two variables in the Westat PSUs against the U.S. distribution to check the representativeness of the Westat PSU sample for the HUD/NIEHS housing survey. The source of the U.S. level data is the 1993 American Housing Survey (AHS). The 62 PSU sample was chosen for this. The number of housing units with each characteristic -- number of units in the building and decade of construction -- in each of the PSUs was obtained from a file of 1990 Census data at the county level, then multiplied by the PSU weight to obtain the U.S. distribution. This comparison showed that the estimated U.S. housing distribution with respect to construction year and number of units in the building were very close, even within region (see Tables A-1 and A-2). Thus, although a new sample of PSUs could have been drawn from Westat's PSU frame using housing age as a stratification variable, it was concluded that this expenditure of project resources would not result in any significant improvement.

Second-Stage: Sampling Segments

To further reduce travel costs and the cost of listing housing units within the sampled PSUs, the second stage of selection was segments. A segment consisted of one or more contiguous blocks, depending on the number of housing units in the block. Segments were therefore generally smaller than Block Groups, as defined by the Census Bureau. To control listing costs, very large blocks were split into chunks and one chunk was subsampled with probability proportional to size. A fixed number of segments

Table A-1. National Distribution of Housing Units in the U.S. and the 62 Westat PSUs

Characteristic	1993 AHS	62 Westat PSUs
Year Built		
pre-1940	21%	21%
1940-49	8%	9%
1950-59	13%	13%
1960-69	15%	16%
1970-79	22%	23%
1980-89	16%	19%**
**contains housing units built in Jan-Mar 1990		
Number of Units in Building		
1	68%	65%
2 - 4	10%	10%
5 - 19	9%	10%
20 - 49	3%	4%
50+	4%	4%
Mobile Home/Trailer/Other	6%	7%

Table A-2. Regional Distribution of Housing Units in the U.S. and the 62 Westat PSUs

	1990 Census	62 Westat PSUs
Region		
Northeast	20%	21%
Midwest	24%	24%
South	35%	34%
West	21%	20%
Decade and Region		
pre-1940		
Northeast	33%	32%
Midwest	25%	27%
South	9%	9%
West	11%	12%
1940-49		
Northeast	10%	11%
Midwest	9%	10%
South	7%	7%
West	8%	8%
1950-59		
Northeast	15%	16%
Midwest	16%	16%
South	13%	13%
West	15%	15%

Table A-2. Regional Distribution of Housing Units in the U.S. and the 62 Westat PSUs (continued)

	1990 Census	**62 Westat PSUs**
1960-69		
Northeast	14%	15%
Midwest	16%	16%
South	17%	17%
West	17%	18%
1970-79		
Northeast	14%	14%
Midwest	20%	19%
South	26%	25%
West	25%	25%
1980 - March 1990		
Northeast	13%	13%
Midwest	14%	11%
South	28%	28%
West	24%	23%
Number of Units in Structure and Region		
1 unit		
Northeast	57%	56%
Midwest	69%	70%
South	66%	67%
West	63%	63%
2 - 4 units		
Northeast	17%	18%
Midwest	10%	10%
South	7%	7%
West	8%	9%
5 - 19 units		
Northeast	9%	10%
Midwest	9%	9%
South	10%	10%
West	11%	11%
20 - 49 units		
Northeast	5%	5%
Midwest	3%	3%
South	3%	3%
West	5%	5%

Table A-2. Regional Distribution of Housing Units in the U.S. and the 62 Westat PSUs (continued)

	1990 Census	62 Westat PSUs
50+ units		
Northeast	7%	8%
Midwest	3%	3%
South	3%	3%
West	4%	4%
Mobile Home/Trailer/Other		
Northeast	4%	3%
Midwest	6%	6%
South	11%	10%
West	9%	9%

in each PSU were sampled with probability proportional to the number of housing units in each segment, as reported in the 1990 Census. The number of segments sampled in each PSU was fixed, but what that fixed sample size was depended on two factors. The first was how homogeneous the housing units were with respect to lead and allergen levels within segments. The second was the ratio of the cost of obtaining a sampled household (including listing housing units within a segment and traveling to the sampled housing unit) to the cost of collection and processing data within the household. The larger the tendency of housing units within the same segment to have similar lead and/or allergen levels, the less information gained from sampling additional housing units in the segment, and the smaller the within-segment sample size should be.

In general, it is best from a statistical standpoint to keep clustering to a minimum because it usually increases the standard errors of the survey estimates. This argued for sampling as many PSUs and as few housing units within each PSU as the data collection budget would permit. It also argued for spreading the within-PSU sample over as many segments as possible. However, some clustering was necessary to control travel and other data collection costs, such as listing housing units. To keep the workload relatively equal across the PSUs and to limit the clustering of housing units, ten segments per PSU were sampled, and a sample size of one cooperating, eligible housing unit within each segment was targeted. These sample sizes were based on the assumption that the maximum number of housing units the budget can support is 1,000. Our analysis showed the optimal sample size of cooperating housing units per segment was 1 (the smallest possible). With 100 PSUs, this implied 10 cooperating housing units per PSU; 1 cooperating housing unit per segment implied 10 segments per PSU. The initial sample size of housing units was increased to 2 or 3 per segment to offset anticipated losses due to household nonresponse, refusal and ineligibility. We expected, on average, ten cooperating housing units per PSU.

However, it was the case that in some segments, either both or none of the sampled housing units will cooperate.

Power of Tests

Power measures the ability of a survey to detect specified differences between two or more subgroups. By 'detect' we mean show statistical significance. Power calculations are generally performed in the course of designing a study to determine the sample sizes required to detect interesting or "important" differences between important subgroups. There are no universal standards for how much power is "good enough". In some contexts a power as low as 50% is considered good; in others a power of 95% or higher may be required. The power of a survey depends on a number of factors, including:

- The subgroup sample sizes.
- The effects of the survey design (e.g., strata and clusters) on the target variables.
- The intraclass correlation (in a clustered design). Intraclass correlation measures the tendency of neighboring housing units and households to be similar with respect to some characteristics.
- The size of the difference to be detected, e.g., 10%, 15%, or 20% differences in prevalence rates for selected allergens or lead hazards.
- The standard deviations of the estimates of the parameters being compared.
- The functional form of the distributions of the target variables, e.g., normal, lognormal, etc.

Table A-3 shows the planned survey's power to detect specified differences between two subgroups for a characteristic measured by a percentage. The table assumes the percentages being compared are 60% and 45%, a 15 percentage point difference in say, allergen prevalence, between low-income families with children and middle/upper income families with children. For example, in the first row below the double line, we see that a sample of 620 would only have a 2 in 5 (40%) chance of detecting a 15 percentage point difference in the allergy prevalence rates. With samples of 810 this power increases to approximately 1 in 2, and for 1,000 it is 3 in 5.

Table A-3. Power for Detecting Differences between Two Percentages, for Selected Housing Unit subgroups and Sample Sizes

Housing Unit Subgroups (See Notes)	Percent of U.S. Housing	Expected Sample Size, N = 1,000	Expected Sample Size, N = 810	Expected Sample Size, N = 620	Percentages Compared 60% vs. 45% N = 1,000 Zero Corr.	N = 1,000 High Corr.	N = 810 Zero Corr.	N = 810 High Corr.	N = 620 Zero Corr.	N = 620 High Corr.
Low Income vs. Middle-Upper Income	23% 77%	230 770	186 624	143 477	0.98	0.84	0.95	0.76	0.88	0.64
Single-Family vs. Multi-Family (2+ HUs)	68% 32%	680 320	551 259	422 198	0.99	0.87	0.98	0.79	0.94	0.67
Urban vs. Rural	31% 22%	310 220	251 178	192 136	0.93	0.79	0.87	0.70	0.77	0.59
Urban vs. Suburban	31% 47%	310 470	251 381	192 291	0.98	0.85	0.96	0.77	0.90	0.65
Rural vs. Suburban	22% 47%	220 470	178 381	136 291	0.96	0.82	0.91	0.73	0.83	0.62
White Householder vs. Black and Other Race Householder	85% 15%	850 150	689 122	527 93	0.93	0.79	0.87	0.70	0.76	0.59
West vs. South	21% 35%	210 350	170 284	130 217	0.93	0.41	0.87	0.34	0.78	0.28
West vs. Northeast	21% 20%	210 200	170 162	130 124	0.86	0.33	0.78	0.28	0.67	0.23
With One or More Asthmatics Resident vs. With No Asthmatics Resident	24% 76%	240 760	194 616	149 471	0.98	0.84	0.96	0.76	0.89	0.65
With Children vs. Without Children	35% 65%	350 650	284 527	217 403	1.00	0.87	0.98	0.79	0.95	0.68
Low Income, with Children vs. Middle/Upper Income, with Children	7% 28%	71 279	58 226	44 173	0.62	0.57	0.53	0.49	0.43	0.39
Low Income Urban vs. Low Income Rural	7% 5%	71 51	58 41	44 31	0.37	0.37	0.31	0.31	0.25	0.25
Low Income White vs. Low Income Black and Other Races	17% 6%	173 57	140 46	108 35	0.50	0.48	0.43	0.41	0.34	0.33
White, with Children vs. Black and Other Races, with Children	30% 6%	300 60	243 49	186 37	0.57	0.53	0.48	0.44	0.39	0.36
With Asthmatic Children vs. With Children, none Asthmatic	7% 28%	67 284	54 230	41 176	0.60	0.55	0.51	0.47	0.41	0.38

Notes:

1. "Zero Corr." refers to an assumed intraclass correlation of 0.00. "High Corr." refers to an assumed intraclass correlation of 0.33.
2. "Low income" means household income under $15,000 per year.
3. Other races include Asian and Pacific Islander, Native American, Eskimo, and Aleut. Hispanics may be of any race.
4. "Children" means children under 18 years old.
5. An estimated 20% of homes with children have incomes under $15,000. Source: U.S. Bureau of the Census, Current Population Surveys
6. Data on income v. urbanization not available. Assumed the low income rate is the same for rural and urban homes.
7. 20% of White homes are low income; 38% of Black and other race homes have low incomes. Source: Current Population Surveys.
8. Assumed 10% of persons are asthmatic, 2.65 persons per household (Current population survey).
9. Assumed 10% of children are asthmatic, and 2 children per household with children (Current Population Survey).
10. Table assumes subgroups are spread uniformly throughout the PSU's, except for regional comparisons.
11. Northeast, South, and West regions are as defined by the Census Bureau.

For major subgroups (those above the double line), a sample of 620 provides good probability of detecting most 15 percentage point differences (except for the regional comparisons when there is high intraclass correlation). A high intraclass correlation for the lead and allergen survey would be in the order of 0.33, while a low intraclass correlation is equal to zero. We would expect the highest intraclass correlations for neighborhood variables such as lead in residential soil. Lower, but still large, intraclass correlations would be expected for variables such as cockroach contamination in multifamily buildings, lead in residential dust, or lead in paint. The lowest intraclass correlations might be those that are behaviorally related, such as cat allergens. To achieve good power levels when there is high intraclass correlation, or to be able to detect smaller point differences, it is necessary to use a larger sample.

For more detailed sub-subgroups (below the double line), the 620 home sample would not provide very high power. These analyses are the ones that benefit the most from the larger samples. The 1,000 home sample would provide a good chance of detecting differences of 15 percentage points or greater. The larger sample increases the probability of detecting such differences by about 50% over the 620 home sample. Therefore, we proposed a sample size of 1,000 housing units, which we believe is necessary to obtain adequate power for the types of analysis of interest to NIEHS and HUD.

Precision of Estimates

Sample estimates will differ from the true values for the U.S. housing stock population because they are based on a randomly chosen subset of the housing unit population, rather than a complete census of all housing units. This type of error is known as sampling error and is measured by the standard error (square root of the variance). The standard error is a function of the sample size and the sample design. The cumulative effect on the variance of such features of the sample design as stratification, clustering, and unequal weights of an estimate is measured by the *design effect* (Kish, 1965). The design effect is calculated as the ratio of the variance actually obtained for the given sample to the variance of a sample of the same size that would be obtained under simple random sampling. The *effective sample size* is defined as the actual sample size divided by the design effect. It is the size of the simple random sample that gives the same precision as the actual, larger sample size selected with the complex sample design. For example, if the variance for a simple random sample of 100 housing units is .0025, but the variance for a multi-stage clustered design of the same sample size is .05; the design effect for the more complex design is 2.0. This means that for the multi-stage clustered design, it would take an actual sample size of 200 housing units to achieve the same precision as the simple random sample of size 100. Thus the complex design of 200 housing units has an effective sample size of 100 housing units. A design effect that is greater than one implies a reduction in precision due to some aspect of the sample design, such as clustering or unequal weights. The design effect is defined as unity for a simple random sample. A multistage design almost always provides less precise estimates than simple random sampling.

Design effects and effective sample sizes are used to compare tradeoffs between the increase in sample size gained through clustering, and the penalty of loss of precision in the estimate from clustering. To obtain a rough estimate of the precision that might be expected for the 1998 HUD/NIEHS National Survey of Lead Hazards and Allergens in Housing, design effects due to the clustering of housing units within PSUs and block groups were calculated for a few key lead-related statistics, using data from the 1990 National Survey of Lead-based Paint in Housing. Corresponding design effects could not be calculated for allergen-related variables, because the needed data were not available.

The actual design effects for the 1998 HUD/NIEHS survey were expected to be lower than those presented below for several reasons. The actual overall design effects for the 1998 HUD/NIEHS survey included the beneficial effects of the stratification of PSUs and the sorting of segments prior to sampling. Since stratification reduces the standard errors of statistics that are correlated with the stratification variables, the actual design effects were expected to be lower than those presented below, which account only for the harmful effects of clustering. Also, the amount of clustering in the 1998 HUD/NIEHS survey was reduced, since we sampled ten segments per PSU and targeted only one cooperating, eligible housing unit per block group instead of 2. This reduction in clustering of housing units within PSUs reduced the design effect somewhat.

Another source of noncomparability in the sample designs for the 1990 and 1998 surveys was the stratification. The stratification of counties in the 1990 National Survey of Lead-based Paint in Housing was quite different than that used to select the Westat PSUs, and blocks were not sorted by a measure of housing age or percent of housing that is multi-family within counties prior to selection. In addition, the final sample sizes of blocks and housing units within blocks were not fixed in the 1990 survey. In the 1990 study, the sample design provided for uniform sample sizes within blocks and counties. This was not maintained in the final sample, for a number of reasons: data collection began before the screening was completed and response rates were lower than expected in some of the early counties. Therefore it was necessary to increase the sample sizes in some of the later counties to achieve the required national stratum sample sizes. This consideration suggested that it was very important to conduct the 1998 survey in a manner that maintained the uniformity of the design as much as possible. Therefore the final housing unit weights from the 1990 survey may be more variable than for the 1998 HUD/NIEHS survey, where these sample sizes will be fixed. (In fact, the design effect due to the unequal housing unit weights alone in the 1990 survey was 1.5.)

We expected the variability in housing unit weights to be much less than in the 1990 survey for estimates of single-family and multi-family housing separately, since the sample was designed to be approximately self-weighting within housing type. For estimates of all housing types, the variability in housing unit weights was not expected to be great because we expected that the oversampling factor K will probably be less than 3. Thus the 1990 survey data was used only to approximate overall design effects due to clustering, and not the overall design effect.

The estimated design effects due to clustering are given in Table A-4. As would be expected, these design effects were higher for soils than for in-house dust, since the former is dominated by lead sources common to all houses in a segment. Because the design effects shown in Table 2-5 for the lead-related variables were unusually large, we expected that the design effects for allergen variables would be smaller than those in Table A-4.

Table A-4. Design Effects for Dust, Paint and Soil Due to Clustering within PSUs from the 1990 National Survey of LBP in Housing

Statistic	Dust	Paint	Soil
Prevalence of Housing Units with Lead Levels Exceeding HUD Limits Anywhere in the Unit	3.4		4.5
Prevalence of Housing Units with LBP Anywhere in the Unit		1.5	
Mean Lead Levels			
Floor Dust (averaged over entranceway, dry room and wet room)	2.1		
Window Trough Dust (averaged over dry room and wet room)	1.6		
Window Sill Dust (averaged over dry room and wet room)	2.4		
Dry Room Lead-based Paint		2.5	
Wet Room Lead-based Paint		2.9	
Exterior Lead-based Paint		2.4	
Exterior Soil (averaged over entrance, drip line and remote locations)			4.9

These design effects indicated that clustering would cause the effective sample size to be considerably less than the actual sample size. Variances for estimates of dust and paint lead levels would be two to three times as large as the variances that would be obtained from a simple random sample of housing units, while variances for estimated soil levels will be more than four times as large. Ninety-five percent confidence interval half-widths for the most important subpopulations of interest based on the design effects in Table A-4 are given in Table A-5. Standard errors computed under the assumption of simple random sampling and the confidence interval half-widths based on them were increased by a factor equal to the square root of the design effect due to clustering. This can be seen in the formula for the 95% confidence interval half-width which accounts for the design effect:

$$\text{95\% CI half-width} = 1.96*(\text{standard error})*\sqrt{\text{design effect}} \quad ,$$

where the standard error in the formula above assumes simple random sampling. This formula is for illustrative purposes only. For the 1998 survey, a set of replicate weights were created based on either the jackknife or balanced repeated replication methodologies. The replicate weights reflected the sample design and weighting procedures and hence provided correct estimates of the standard error.

The expected sample sizes in Table A-5 are a result of multiplying the total sample size of 1,000 housing units by the proportion each subpopulation represents in the housing population. They are the sample sizes that would be expected if a simple random sample of housing units were drawn. Table A-5 estimates the precision that was expected in terms of 95 percent confidence interval half-widths for estimated proportions for various subpopulations of housing units from the 1998 HUD/NIEHS survey, given a plausible range of design effects and a sample of 1,000 cooperating housing units. The design effect would be less for subpopulations, such as housing type, because there will be fewer sampled housing units of each subpopulation per PSU; hence the effects of clustering were reduced. For example, if the subpopulation of interest is housing built before 1940, we expected 210 such housing units in a sample of 1,000, or on average 2 per PSU. Estimates based on the full national sample would have an average of 10 sampled housing units per PSU. Again, if there was no oversampling of special housing types, these variance and confidence interval estimates were expected to be over-estimates for the 1998 HUD/NIEHS survey, because only clustering was factored into the computation, and not stratification, and the degree of clustering was larger in 1990 than it will be in 1998.

Table A-5. U.S. Housing Characteristics and 95% Confidence Interval Half-Widths under Various Design Effect Assumptions

	No. In US (000)	Pct.	Expected Sample size	95% Confidence Interval Half-Width for P = 50%					
				National Design Effect					
				1.0	1.5	2.0	2.5	3.0	4.0
Total Housing Units[1]	94,724	100%	1000	3%	4%	4%	5%	5%	6%
Built After 1980:	19,716	21%	210	7%	7%	7%	7%	8%	8%
Built 1960-1980:	35,223	37%	370	5%	6%	6%	6%	6%	7%
Built 1940-1959:	19,899	21%	210	7%	7%	7%	7%	8%	8%
Built pre-1940:	19,886	21%	210	7%	7%	7%	7%	8%	8%
Housing Units in Buildings with:									
1 unit:	64,293	68%	680	4%	4%	5%	5%	6%	6%
2-4 units:	9,279	10%	100	10%	10%	10%	10%	10%	10%
5-19 units:	8,914	9%	90	10%	10%	10%	10%	10%	10%
20-49 units:	3,154	3%	30	18%	18%	18%	18%	18%	18%
50+ units:	3,429	4%	40	16%	16%	16%	16%	16%	16%
Mobile Homes/Trailers	5,655	6%	60	13%	13%	13%	13%	13%	13%
Owner Occupied:	61,252	65%	650	4%	4%	5%	5%	6%	7%
Renter Occupied:	33,472	35%	350	5%	6%	6%	6%	7%	7%
Total number of Households[2]	98,990	100%	1000	3%	4%	4%	5%	5%	6%
Households with Income Levels:									
Below $10,000	13,463	14%	140	8%	8%	9%	9%	9%	9%
Below $15,000	22,471	23%	230	7%	7%	7%	7%	7%	8%
Households with:									
Children Under Age 6	16,624	17%	170	8%	8%	8%	8%	8%	8%
Children Under Age 18	34,296	35%	350	5%	6%	6%	6%	7%	7%
Urban: MSA	29,838	31%	310	6%	6%	6%	7%	7%	7%
Suburban: MSA	44,060	47%	470	5%	5%	5%	6%	6%	7%
Rural: non-MSA	20,826	22%	220	7%	7%	7%	7%	7%	8%
White, non-Hispanic:	74,280	78%	780	4%	4%	5%	5%	6%	6%
White, Hispanic:	5,749	6%	60	13%	13%	13%	13%	13%	13%
Black:	11,128	12%	120	9%	9%	9%	9%	9%	9%
Other:	3,567	4%	40	16%	16%	16%	16%	16%	16%

[1] Source: 1993 American Housing Survey, available at www.census.gov

[2] Source: March 1995 Current Population Survey, available at www.census.gov

Calculation of Intraclass Correlation Coefficients

The magnitude of the design effect due to clustering depends on two factors, the sample size per cluster, b, and the internal homogeneity of the clusters, measured by the *intraclass* (within-cluster) *correlation*, r. The value of the intraclass correlation depends on the nature of the clusters and the distribution of the variable under study. While r can theoretically range from -1/(b-1) to 1, it will generally be positive for clustered samples. The intraclass correlation is zero for a simple random sample. In general, the larger the size of the clusters, the lower the value of the intraclass correlation coefficient. For a simple two-stage design in which a equal-size PSUs are selected at the first stage and b housing units are selected from each PSU, the relationship between the design effect, the number of housing units per cluster, and the intraclass correlation is (Kish, 1965):

$$\text{Design effect} = 1 + r * (b - 1),$$

Data from the 1990 National Survey of Lead-Based Paint in Housing were used to estimate the value of r for different statistics, which were then used to estimate the design effects due to clustering of housing units within PSU for the 1998 National Survey of Lead Hazards and Allergens in Homes. The design effects due to clustering were computed using this formula with b equal to the average number of housing units per PSU. In the 1990 survey there were, on average, 9 cooperating, eligible housing units per PSU for most statistics. The intraclass correlation coefficient in this context is a measure of similarity of the housing units within a PSU with respect to the statistic being estimated, such as the mean lead level in soil, the prevalence of housing units with lead dust in excess of HUD limits, or the prevalence of housing units with specific allergen levels that exceed certain sensitization or disease thresholds.

There were actually three stages of sampling in the 1990 survey, with clustering at the first two stages, but there were too few blocks within PSUs and housing units within blocks to reliably estimate between-block and within-block components of variance. Therefore the clustering by blocks within the PSUs was ignored in estimating r, and only between-PSU and within-PSU variance components were calculated. Since housing units are more likely to be similar within a block than within the PSU, the intraclass coefficients obtained this way overstate the effects of clustering within PSUs. However, this overstatement was likely to be slight, since the number of housing units in each block was on average only 2.5.

The intraclass correlation coefficient were estimated from the between-PSU and within-PSU components of variance for a given statistic using the following formula (Kish, 1965, eqn. 5.6.18):

$$r = \frac{s_a^2 - s_b^2 / b}{s^2},$$

where b is the average number of sampled housing units within the PSU upon which the estimate is based, s_a^2 is the between PSU component of variance, s_b^2 is the within PSU component of variance, a is the number of PSUs, and s^2 is the overall variance for the estimate. Intraclass correlation coefficients calculated from the 1990 survey data are given in Table A-6.

The variance component calculations in this report were based on the natural logarithms of the lead measurements from the 1990 survey rather than the original data. This is appropriate because the mean and variance of the log-transformed measurements are independent, whereas the variance of the original data (which follow a lognormal distribution), depends on its mean. In other words, standard errors for mean lead levels based on the original data would change depending on the value of the mean, whereas standard errors using the log-transformed data would be independent of the value of the mean lead level.

Table A-6. Intraclass Correlation Coefficients Due to Clustering Within PSU from 1990 National Lead-based Paint in Housing Survey

Statistic	**Dust**	**Paint**	**Soil**
Prevalence of Housing Units with Lead Levels Exceeding HUD Limits Anywhere in the Unit	.26		.41
Prevalence of Housing Units with LBP Anywhere in the Unit		.06	
Mean Lead Levels			
Floors (averaged over entranceway, dry room and wet room)	.12		
Window Troughs (averaged over dry room and wet room)	.11		
Window Sills (averaged over dry room and wet room)	.18		
Dry Room		.19	
Wet Room		.24	
Exterior		.17	
Exterior (averaged over entrance, drip line and remote locations)			.46

A few caveats apply to these intraclass correlation coefficients and the design effects based upon them. The first is that they are likely to be unstable because they are based on a sample of only 30 counties. The variance components that go into the calculation of intraclass correlation coefficients are themselves estimates and can have high sampling variability associated with them. The second, as already noted, is that they were based on PSUs which are defined as single counties. The Westat PSUs are sometimes larger because they can consist of groups of counties. The third is that the number of blocks sampled per PSU and the number of housing units sampled per block in the 1990 survey varied, whereas in the 1998 design we plan to sample a fixed number of segments per PSU and a fixed number of housing units per segment. The fourth is that the clustering of housing units within blocks had to be ignored in the calculation of within-PSU variance from the 1990 survey data, because there were insufficient blocks groups per PSU and housing units per block to calculate between-block and within-block components of variance.

The implication of these caveats is that the calculated design effects due to clustering were not taken too literally, but rather used as an indication of a high degree of homogeneity of housing units within PSUs and blocks (especially the latter). They suggested a sample design that minimized the degree of clustering to the extent possible, given data collection costs. This included at a minimum increasing the number of segments sampled per PSU and decreasing the number of housing units per segment, and increasing the number of PSUs as well.

APPENDIX B

75 PSU SAMPLE

Table B-1. Noncertainty Strata for 1990 Westat Master PSU Sample

Stratum	Census Region	Metropolitan Status	1990 PSU Population Size Class	1990 Stratum Population	Stratum Description
1	Northeast	NonMSA	——	5,629,176	All PSUs
2	Northeast	MSA	1,000,000+	4,122,596	$23,053 or more per-capita income
3	Northeast	MSA	1,000,000+	4,182,793	Less than $23,053 per-capita income
4	Northeast	MSA	<1,000,000	4,209,044	$19,275 or more per-capita income
5	Northeast	MSA	<1,000,000	4,111,905	$17,280-19,052 per-capita income
6	Northeast	MSA	<1,000,000	4,625,123	$15,993-17,192 per-capita income
7	Northeast	MSA	<1,000,000	4,131,836	$12,280-15,927 per-capita income
8	Midwest	NonSMSA	——	4,254,850	$14,123 or more per-capita income
9	Midwest	NonSMSA	——	4,269,559	$13,291-14,121 per-capita income
10	Midwest	NonSMSA	——	4,217,707	$12,188-13,272 per-capita income
11	Midwest	NonSMSA	——	4,238,013	$7,096-12,174 per-capita income
12	Midwest	SMSA	900,000+	4,829,551	$17,156 or more per-capita income
13	Midwest	SMSA	900,000+	4,747,670	Less than $17,156 per-capita income
14	Midwest	SMSA	<900,000	4,357,761	$16,475 or more per-capita income
15	Midwest	SMSA	<900,000	4,607,506	$15,713-16,466 per-capita income
16	Midwest	SMSA	<900,000	4,681,564	$14,418-15,647 per-capita income
17	Midwest	SMSA	<900,000	4,103,955	$10,185-14,389 per-capita income
18	South	NonSMSA	——	4,790,519	33 percent or more black persons
19	South	NonSMSA	——	4,775,912	20-32.8 percent black persons
20	South	NonSMSA	——	5,079,408	$12,696 or more per-capita income
21	South	NonSMSA	——	5,112,596	$11,190-12,612 per-capita income
22	South	NonSMSA	——	5,099,417	$6,115-11,167 per-capita income
23	South	SMSA	——	4,705,283	31.6 percent or more black persons
24	South	SMSA	——	4,748,589	20 < percent black persons < 31.6, and $14,744 or more per-capita income
25	South	SMSA	——	4,343,512	20 < percent black persons < 31.6, and less than $14,744 per-capita income
26	South	SMSA	——	4,734,441	14.5 percent or more Hispanic persons
27	South	SMSA	900,000+	4,508,985	$16,399 or more per-capita income
28	South	SMSA	900,000+	4,918,551	Less than $16,399 per-capita income
29	South	SMSA	<900,000	4,803,770	$15,432 or more per-capita income
30	South	SMSA	<900,000	4,734,062	$14,059-15,068 per-capita income
31	South	SMSA	<900,000	4,903,747	$11,262-14,017 per-capita income
32	West	NonSMSA	——	4,099,320	$12,885 or more per-capita income
33	West	NonSMSA	——	4,028,831	Less than $12,885 per-capita income
34	West	SMSA	——	4,058,651	26.3 percent or more Hispanic persons
35	West	SMSA	——	4,289,847	13.2-24.3 percent Hispanic persons
36	West	SMSA	1,300,000+	5,077,043	$17,057-19,667 per-capita income
37	West	SMSA	500,000-1,299,999	4,475,962	$13,087-17,540 per-capita income
38	West	SMSA	<500,000	4,587,206	$9,993-21,840 per-capita income

Table B-2. 75 PSU Sample

Stratum	PSU	MSA	State	Counties	Population	PSU Weight	Weighted Population
Certainty MSA PSUs							
A101	001	Boston-Lawrence-Salem-Lowell-Brockton	MA	Essex-MIDDLESEX-Norfolk-Plymouth-Suffolk	3,783,817	1	3,783,817
A102	001	Nassau-Suffolk	NY	Nassau-SUFFOLK	2,609,212	1	2,609,212
A106	001	Philadelphia	PA	Bucks-Chester-Delaware-Montgomery-PHILADELPHIA	4,856,881	1	4,856,881
			NJ	Burlington-Camden-Gloucester			
A113	001	New York	NY	Kings-Richmond	2,679,641	1	2,679,641
A114	001	New York	NY	NEW YORK-Queens	3,439,134	1	3,439,134
A115	001	New York	NY	BRONX-Putnam-Rockland-Westchester	2,428,071	1	2,428,071
A203	001	Detroit	MI	Lapeer-Livingston-MACOMB-Monroe-Oakland-St. Clair-Wayne	4,382,299	1	4,382,299
A204	001	Minneapolis-St. Paul	MN	Anoka-Carver-Chisago-Dakota-Hennepin-Isanti-Ramsey-Scott-Washington-Wright	2,464,124	1	2,464,124
			WI	St. Croix			
A205	001	St. Louis	MO	Franklin-Jefferson-St. Charles-St. Louis-St. Louis City	2,444,099	1	2,444,099
			IL	Clinton-Jersey-Madison-Monroe-St. Clair			
A211	001	Chicago	IL	CHICAGO CITY	2,783,726	1	2,783,726
A212	001	Chicago	IL	COOK-Du Page-McHenry	3,286,248	1	3,286,248
A301	001	Atlanta	GA	Barrow-Butts-Cherokee-Clayton-Cobb-Coweta-De Kalb-Douglas-Fayette-Forsyth-FULTON-Gwinnett-Henry-Newton-Paulding-Rockdale-Spalding-Walton	2,833,511	1	2,833,511
A302	001	Baltimore	MD	Anne Arundel-BALTIMORE-Carroll-Harford-Howard-Queen Annes-Baltimore City	2,382,172	1	2,382,172
A303	001	Dallas	TX	Collin-Dallas-Denton-Ellis-Kaufman-Rockwall	2,553,362	1	2,553,362
A304	001	Houston	TX	Fort Bend-HARRIS-Liberty-Montgomery-Waller	3,301,937	1	3,301,937
A305	001	Miami & Ft. Lauderdale	FL	BROWARD-Dade	3,192,582	1	3,192,582
A306	001	Washington	MD	Calvert-Charles-Frederick-Montgomery-Prince Georges	3,923,574	1	3,923,574
			DC	D.C.			
			VA	Arlington-FAIRFAX-Loudoun-Prince William-Stafford-Alexandria City-Fairfax City-Falls Church City-Manassas-Manassas Park			

Stratum	PSU	MSA	State	Counties	Population	PSU Weight	Weighted Population
A401	001	Anaheim-Santa Ana	CA	Orange	2,410,556	1	2,410,556
A404	001	Riverside-San Bernardino	CA	Riverside-San Bernardino	2,588,793	1	2,588,793
A405	001	Phoenix	AZ	MARICOPA	2,122,101	1	2,122,101
A406	001	San Diego	CA	SAN DIEGO	2,498,016	1	2,498,016
A407	001	Oakland & San Francisco	CA	ALAMEDA-Contra Costa-Marin-San Francisco-San Mateo	3,686,592	1	3,686,592
A412	001	Los Angeles-Long Beach	CA	Los Angeles City	3,485,398	1	3,485,398
A413	001	Los Angeles-Long Beach	CA	Los Angeles	5,377,766	1	5,377,766
Non-Certainty MSA PSUs							
B101	001	Bergen-Passaic	NJ	Bergen-PASSAIC	1,278,440	3.225	4,122,969
B102	002	Pittsburgh	PA	Allegheny-Fayette-Washington-Westmoreland	2,056,705	1.017	2,091,669
B102	003	Rochester	NY	Livingston-Monroe-Ontario-Orleans-Wayne	1,002,410	2.086	2,091,027
B103	005	Atlantic City	NJ	Atlantic-Cape May	319,416	6.589	2,104,632
B103	006	Monmouth-Ocean	NJ	Monmouth-Ocean	986,327	2.134	2,104,822
B104	006	Springfield	MA	Hampden-Hampshire	602,878	6.820	4,111,628
B105	001	Providence-Pawtucket-Woonsocket	RI	Bristol-Kent-PROVIDENCE-Washington	916,270	5.048	4,625,331
B106	009	Harrisburg-Lebanon-Carisle	PA	Cumberland-Dauphin-Lebanon-Perry	587,986	7.027	4,131,778
B201	001	Cleveland	OH	Cuyahoga-Geauga-Lake-Medina	1,831,122	2.637	4,828,669
B202	003	Indianapolis	IN	Boone-Hamilton-Hancock-Hendricks-Johnson-Marion-Morgan-Shelby	1,249,822	3.799	4,748,074
B203	001	Aurora-Elgin	IL	Kane-Kendall	356,884	6.105	2,178,777
B203	008	Iowa City	IA	Johnson	96,119	22.669	2,178,922
B204	003	Akron	OH	Portage-Summit	657,575	3.503	2,303,485
B204	010	Peoria	IL	Peoria-Tazewell-Woodford	339,172	6.792	2,303,656
B205	005	Gary-Hammond	IN	Lake-Porter	604,526	7.744	4,681,449
B206	025	Youngstown-Warren	OH	Mahoning-Trumbull	492,619	8.331	4,104,009
B301	004	Fayetteville	NC	Cumberland	274,566	8.569	2,352,756
B301	013	Shreveport	LA	Bossier-Caddo	334,341	7.037	2,352,758
B302	001	Birmingham	AL	Blount-Jefferson-St Clair-Shelby-Walker	907,810	5.231	4,748,754
B303	016	Tallahassee	FL	Gadsden-Leon	233,598	18.594	4,343,521
B304	002	Austin	TX	Hays-Travis-Williamson	781,572	3.029	2,367,382
B304	013	San Antonio	TX	Bexar-Comal-Guadalupe	1,302,099	1.818	2,367,216
B305	003	Greensboro-Winston-Salem-High Point	NC	Davidson-Davie-Forsyth-Guilford-Randolph-Stokes-Yadkin	942,091	4.786	4,508,848

Stratum	PSU	MSA	State	Counties	Population	PSU Weight	Weighted Population
B306	002	Nashville	TN	Cheatham-Davidson-Dickson-Robertson-Rutherford-Sumner-Williamson-Wilson	985,026	2.497	2,459,610
B306	004	Tampa	FL	Hernando-Hillsborough-Pasco-Pinellas	2,067,959	1.189	2,458,803
B307	003	Charlottesville	VA	Albemarle-Fluvanna-Greene-Charlottesville City	131,107	18.320	2,401,880
B307	014	Wilmington	DE	New Castle	513,293	4.679	2,401,698
B308	015	Cincinnati	KY	Boone-Campbell-Kenton	283,486	16.699	4,733,933
B309	016	Johnson City-Kingsport-Bristol	TN	Carter-Hawkins-Sullivan-Unicoi-Washington	436,047	11.246	4,903,785
			VA	Scott -Washington-Bristol City			
B401	006	Merced	CA	Merced	178,403	22.750	4,058,668
B402	004	San Jose	CA	Santa Clara	1,497,577	1.432	2,144,530
B402	008	Tucson	AZ	Pima	666,880	3.216	2,144,686
B403	002	Sacramento	CA	El Dorado-Placer-Sacramento-Yolo	1,481,102	1.714	2,538,609
B403	003	Seattle	WA	KING-Snohomish	1,972,961	1.287	2,539,201
B404	002	Las Vegas	NV	Clark	741,459	3.018	2,237,723
B404	003	Portland	OR	Clackamas-Multnomah-Washington-Yamhill	1,239,842	1.805	2,237,915
B405	010	Boulder-Longmont	CO	Boulder	225,339	20.357	4,587,226
Non-MSA PSUs							
C101	001		RI	Newport	87,194	64.559	5,629,157
C201	015		NE	Hall-Hamilton	57,787	36.815	2,127,428
C201	079		KS	Cheyenne-Decatur-Graham-Rawlins-Rooks-Sheridan	23,293	91.333	2,127,420
C202	053		IN	Fountain-Montgomery-Putnam	82,559	51.715	4,269,539
C203	027		KS	Atchison-Jackson-Jefferson	44,362	95.075	4,217,717
C204	079		IA	Monona	16,970	249.736	4,238,020
			NE	Thurston			
C301	005		MS	Lauderdale-Newton	95,846	24.991	2,395,287
C301	015		GA	Greene-Lincoln-Oglethorpe-Wilkes	39,595	60.494	2,395,260
C302	002		TX	Anderson	48,024	99.448	4,775,891
C303	011		TX	Howard	32,343	157.048	5,079,403
C304	038		AR	Pope	45,883	111.427	5,112,605
C305	094		AR	Franklin-Madison	26,515	192.322	5,099,418
C401	009		MT	Missoula	78,687	52.097	4,099,357
C402	022		ID	Elmore-Twin Falls	74,785	53.872	4,028,818
75 PSU Totals:					**106,842,284**		**248,709,329**

Table B-3 PSUs Where the Number of Sampled Segments Did Not Equal 10

PSU Number	PSU Name	Number of Sampled Segments
231	Philadelphia, PA	13
951	Los Angeles County, CA	13
321	Detroit, MI	12
121	Boston, MA	11
211	New York – Queens, NY	11
531	Washington, DC	11
111	Springfield, MA	9
212	Bergen-Passaic, NJ	9
242	Newark, NJ*	9
331	Aurora-Elgin, KO	9
812	Elmore-Twin Falls, ID	9
842	Cibola-Valencia, NM*	9
942	San Jose, CA	9
932	Fresno, CA*	8
952	Merced, CA	8

* These three PSUs were not among the 75 PSUs where data were collected.

Table B-4 List of Segments that Required Chunking Before Listing

PSU ID	Segment ID	PSU Name	State
131	102	Providence-Pawtucket-Woonsocket	RI
141	109	Newport	RI
211	101	Queens	NY
211	102	Queens	NY
211	103	Queens	NY
211	106	Queens	NY
211	108	Queens	NY
211	205	Queens	NY
211	207	Queens	NY
213	108	Pittsburgh	PA
213	202	Pittsburgh	PA
221	103	Bronx	NY
221	201	Bronx	NY
221	304	Bronx	NY
222	103	Rochester	NY
222	108	Rochester	NY
223	102	Harrisburg	PA
223	105	Harrisburg	PA
223	203	Harrisburg	PA
231	106	Philadelphia	PA
241	101	Brooklyn	NY
241	106	Brooklyn	NY
241	108	Brooklyn	NY
241	405	Brooklyn	NY
251	105	Nassau-Suffolk	NY
252	101	Monmouth-Ocean	NJ
311	108	Indianapolis	IN
312	103	Peoria	IL
312	110	Peoria	IL
313	109	Youngstown	OH
322	208	Cleveland	OH
331	105	Aurora-Elgin	IL
332	108	Akron	OH
333	107	Gary-Hammond	IN
341	105	Chicago (suburbs)	IL
341	108	Chicago (suburbs)	IL
341	204	Chicago (suburbs)	IL
351	102	Chicago	IL
422	101	Iowa City	IA
422	103	Iowa City	IA
422	107	Iowa City	IA
422	110	Iowa City	IA
431	101	Minneapolis-St. Paul	MN

Table B-4 List of Segments that Required Chunking Before Listing (continued)

PSU ID	Segment ID	PSU Name	State
431	105	Minneapolis-St. Paul	MN
511	103	Miami & Ft. Lauderdale	FL
511	109	Miami & Ft. Lauderdale	FL
512	105	Tampa	FL
512	108	Tampa	FL
512	110	Tampa	FL
521	102	Atlanta	GA
521	108	Atlanta	GA
521	109	Atlanta	GA
521	204	Atlanta	GA
522	103	Fayetteville	NC
523	105	Tallahassee	FL
524	104	Charlottesville	VA
524	106	Charlottesville	VA
531	104	Washington	DC
531	110	Washington	DC
531	111	Washington	VA
531	206	Washington	DC
541	101	Baltimore	MD
541	102	Baltimore	MD
542	105	Greensboro-Winston-Salem-High Point	NC
542	106	Greensboro-Winston-Salem-High Point	NC
611	101	Cincinnati (suburbs)	KY
611	107	Cincinnati (suburbs)	KY
611	110	Cincinnati (suburbs)	KY
631	105	Nashville	TN
642	103	Johnson City-Kingsport-Bristol	TN
642	104	Johnson City-Kingsport-Bristol	TN
711	103	Dallas	TX
711	106	Dallas	TX
711	409	Dallas	TX
721	110	Shreveport	LA
722	102	Pope	AR
731	107	Houston	TX
731	108	Houston	TX
731	109	Houston	TX
731	110	Houston	TX
731	204	Houston	TX
732	101	San Antonio	TX
732	106	San Antonio	TX
732	108	San Antonio	TX

732	109	San Antonio	TX
741	101	Austin	TX

Table B-4 List of Segments that Required Chunking Before Listing (continued)

PSU ID	Segment ID	PSU Name	State
741	104	Austin	TX
751	107	Howard	TX
811	107	Las Vegas	NV
811	401	Las Vegas	NV
831	105	Phoenix	AZ
831	110	Phoenix	AZ
832	104	Tucson	AZ
832	105	Tucson	AZ
832	106	Tucson	AZ
832	108	Tucson	AZ
851	106	Boulder-Longmont	CO
911	101	San Diego	CA
911	103	San Diego	CA
911	105	San Diego	CA
911	110	San Diego	CA
912	110	Sacramento	CA
921	106	Riverside-San Bernardino	CA
921	110	Riverside-San Bernardino	CA
922	103	Los Angeles City	CA
922	109	Los Angeles City	CA
922	306	Los Angeles City	CA
923	107	Seattle	WA
931	101	Anaheim-Santa Ana	CA
931	102	Anaheim-Santa Ana	CA
931	106	Anaheim-Santa Ana	CA
941	105	Oakland-San Francisco	CA
942	109	San Jose	CA

Table B-5 40-PSU Subsample for Play Area Data Collection

PSU No.	PSU Largest City	PSU Counties	PSU State
121	Boston	Essex, Middlesex, Norfolk, Plymouth, Suffolk	MA
131	Providence	Kent, Providence, Washington	RI
141	Newport	Newport	RI
213	Pittsburgh	Allegheny, Westmoreland	PA
221	New York	Bronx, Rockland, Westchester	NY
222	Rochester	Livingston, Monroe, Orleans, Wayne	NY
223	Harrisburg, Lebanon	Cumberland, Dauphin, Lebanon	PA
231	Philadelphia	Camden, Gloucester, Chester, Delaware, Montgomery, Philadelphia	NJ, PA
232	Atlantic City	Atlantic, Cape May	NJ
252	Toms River, Lakewood	Monmouth, Ocean	NJ
313	Youngstown	Mahoning, Trumbull	OH
321	Detroit	Oakland, Wayne	MI
322	Cleveland	Cuyahoga, Lake, Medina	OH
331	Aurora, (west of Chicago*)	Kane	IL
332	Akron	Portage, Summit	OH
351	Chicago	Chicago City	IL
421	St. Louis	Jefferson, St Louis, Madison	MO, IL
422	Iowa City	Johnson	IA
432	Onawa, (south of Souix City*)	Monona, Thurston	IA, NE
451	Oberlin, (Colby*)	Decatur, Rawlins, Rooks, Sheridan	KS
522	Fayetteville	Cumberland	NC
523	Tallahassee	Gadsden, Leon	FL
531	Washington	DC, Calvert, Montgomery, PG, Fairfax, Alexandria	DC, MD, VA
533	Wilmington	New Castle	DE
541	Baltimore	Anne Arundel, Baltimore, Harford, Balt. City	MD
611	Covington (south of Cincinnati*)	Boone, Campbell, Kenton	KY
631	Nashville	Davidson, Dickson, Sumner, Williamson	TN
642	Kingsport, Bristol, Johnson City	Carter, Hawkins, Sullivan, Washington, Scott, Washington, Bristol City	TN, VA
651	Birmingham	Blount, Jefferson, St. Clair, Shelby	AL
711	Dallas	Collin, Dallas	TX
722	Russellville	Pope	AR
731	Houston	Harris, Montgomery	TX
732	San Antonio	Bexar, Guadalupe	TX
812	Twin Falls	Elmore, Twin Falls	ID
912	Sacramento	El Dorado, Sacramento	CA
922	Los Angeles	Los Angeles City	CA
931	Anaheim	Orange	CA
941	San Francisco, Oakland	Alameda, Contra Costa, San Francisco, San Mateo	CA
951	Los Angeles	Los Angeles	CA
952	Merced	Merced	CA

APPENDIX C

Questionnaires and Study Forms

Appendix C

Table of Contents

Page

Appendix C
Questionnaires and Study Forms

These files have been compressed in a separate file to facilitate downloading. The file "appendix_c.ZIP" is available at:

http://www.hud.gov/offices/lead/techstudies/appendix_c.ZIP

APPENDIX D

Measurement Error Correction Procedures

Appendix D: Measurement Error Correction Procedures

This appendix presents details of the measurement error adjustment procedure to correct for classification error. It should be noted that there are a number of ways to adjust for the effects of measurement error and handle measurements below detectable limits (censored data). While the procedure described below proved useful, particularly for the dust and soil measurements, we acknowledge that there are other approaches that could have been explored with additional resources.

The procedure used here is presented in the context of classifying surfaces and homes as having or not having lead values (i.e., paint lead loading, dust lead loading, or soil lead concentrations) above a specified limit. The results of the measurement error adjustment include 1) adjusted lead values and 2) adjusted maximum within-home lead values. The adjusted lead values are used to estimate the number of surfaces with lead values over a specified limit. The maximum within-home lead values are used to estimate the proportion of homes with maximum lead values over a limit. The measurement error adjustment was performed separately for soil, floor dust, window (sill and trough) dust, and interior paint.

As used here, measurement error refers to the effects of both spatial variation across the surface from which the sample was taken, variation in sample collection (for dust and soil samples), and variation in the measurement process (laboratory measurement of lead in dust and soil or XRF reading for paint). Thus, the term measurement error refers to error in more than just the measurement process.

The basis for the measurement error adjustment procedure assumes that the transformed measurements and measurement errors have a normal distribution. The presentation below first discusses measurement error adjustment assuming that the transformed measurements fit this assumption. The transformation used is then discussed. Subsequent sections discuss modifications to the procedure to account for characteristics of the data not included in the simple normal model, including outliers and non-constant variances after transformation.

D.1 Classification Error Adjustment Procedure, Normal Distribution Assumptions

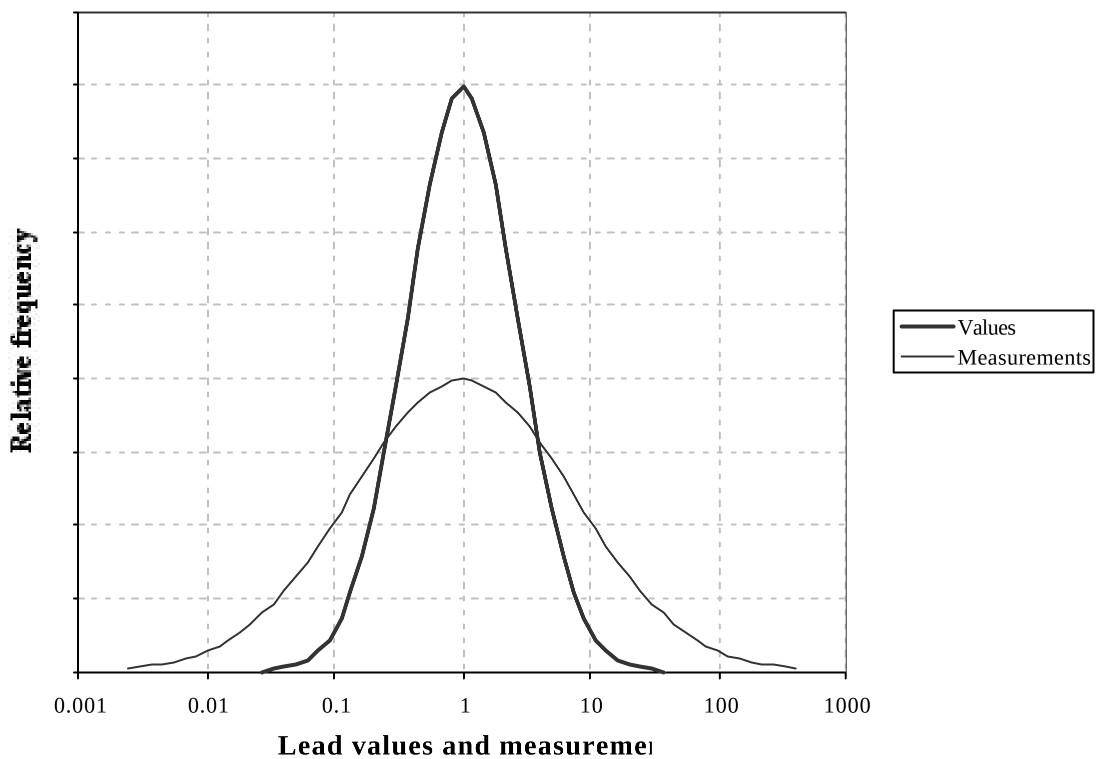
Overview

If
- A set of lead values have a normal distribution around a mean,
- The lead values are measured with error, and
- The measurement error has a normal distribution,

Then
- The measurements will also have a normal distribution,
- The standard deviation of the measurements will be greater than the standard deviation of the lead values being measured.

Figure D.1 illustrates the assumed relationship between the distribution of the measurements and the lead values being measured. Note that the data shown in Figure D.1 are fictitious and are for illustration only. Log transformed lead loadings and lead concentrations often have a roughly normal distribution. Therefore, to be more realistic, Figure D.1 uses a log scale for the lead values and measurements. The lead measurements are more spread out than the lead values. In this fictitious illustration, only 2% of the surfaces have lead values are greater than 10, however, 16% of the surfaces have measurements greater than 10. The number of surfaces with lead measurements greater than a limit may provide a biased estimate of the number of surfaces with lead values greater than the limit. The bias depends on the limit being used and the distributions of the values and measurements.

Figure D.1 Illustration of the effect of measurement error using fictitious data



If the standard deviation of the lead values is s_t and the standard deviation of the measurement error is s_m then the standard deviation of the lead measurements is $\sqrt{s_t^2 + s_m^2}$. If s_t and s_m are known, the measurements can be adjusted so that the adjusted measurements have the same distribution as the lead values. This can be accomplished by decreasing the distance from each measurement to the mean (the middle of a normal distribution) by the factor $\sqrt{\frac{s_t^2}{s_t^2 + s_m^2}}$.

Although this approach for adjusting for the effects of measurement error is relatively straight forward, implementation with real data is more complicated for the following reasons:

- The mean and standard deviations are not known and must be estimated from the data.
- The data must be transformed to make the distributions normal, however, the correct transformation is not known.
- The standard deviations of the lead values and measurement error may be different for different types of surfaces,
- The data may have unusual values (or outliers) that affect estimates of the mean and standard deviation,
- Measurements were not collected from all surfaces of interest, and
- The measurements were collected using a complex probability sample rather than random sample.

Section D.2 presents the basic measurement error adjustment approach in mathematical form. Subsequent sections present modifications to the approach to account for the characteristics of the data mentioned above. Finally Section D.7 presents the entire procedure. Section D.8 describes how the procedure was implemented for the different types of data.

D.2 The Basic Adjustment in Mathematical Terms

The term "lead value" refers to values for 1) paint lead loading across the entire surface of a component, 2) dust loading across a floor, 3) dust lead loading on window troughs and sills across all windows in a room, and 4) soil lead concentration across a portion of a yard (such as the drip line area). The term "lead value" can also be thought of as the "true value" in the sense that it is a precise value for the lead loading (or concentration) across the surface. The lead measurement, usually from only one small portion of the surface, provides an imprecise measurement of the lead value. The measurement error is the difference between the lead value and the lead measurement and is a combination of equipment measurement error and spatial variability across the surface. The measurement error analysis assumes that the transformed lead values and measurements have a normal distribution. The transformation used is discussed in a later section. More explicitly, assume:

$$
\begin{aligned}
P_{ij} &= f\left(Z_{ij}\right) \\
P_{ij} &= \boldsymbol{m}_j + \boldsymbol{d}_{ij} + \boldsymbol{h}_{ij} = Q_{ij} + \boldsymbol{h}_{ij}
\end{aligned} \qquad (1)
$$

Where:

Z_{ij} is the measurement on surface *i* in house *j*,

$P_{ij} = f\left(Z_{ij}\right)$ is the transformed measurement on surface *i* in house *j* using the monotonic transformation f,

Q_{ij} is the transformed lead value (or true value) on surface *i* in house *j*,

$\boldsymbol{m}_j$ is the mean of the transformed lead values across all surfaces within a house *j*,

$\boldsymbol{d}_{ij}$ is the difference between the lead value on surface *i* and the mean value across all surfaces in home *j*, assumed to be independent and normally distributed with variance $\boldsymbol{s}_t^2$, and

h_{ij} is the measurement error for surface i in home j, assumed to be independent and normally distributed with variance s_m^2.

The variance of P_{ij} around m_j is:

$$s_e^2 = s_t^2 + s_m^2$$

If m_j and the ratio s_t^2 / s_e^2 are known, the adjusted transformed measurements are:

$$\hat{Q}_{ij} = (P_{ij} - m_j)\frac{s_t}{s_e} + m_j = (P_{ij} - m_j)\sqrt{1 - \frac{s_m^2}{s_e^2}} + m_j = (P_{ij} - m_j)G + m_j \qquad (2)$$

Within house j, the distribution of $\hat{Q}_{ij}$ and Q_{ij} are the same; both are normally distributed with mean m_j and variance s_t^2. Thus, the proportion of surfaces with $\hat{Q}_{ij}$ greater than a limit will be an unbiased estimate of the proportion of surfaces with Q_{ij} above the limit.

We can calculate an untransformed adjusted measurement as:

$$\hat{Z}_{ij} = f^{-1}(\hat{Q}_{ij}).$$

A surface is assumed to have lead value greater than or equal to a limit L if $\hat{Z}_{ij}$ is greater than or equal to L.

D.2.1 Using a More Complicated Model

For most data, the model that describes the true values will be more complicated than just assuming a mean for each home. Equation (1) can be modified as follows:

$$P_{ij} = p_{ij} + d_{ij} + h_{ij} = Q_{ij} + h_{ij} = p_{ij} + e_{ij} \qquad (3)$$

Where p_{ij} is the predicted true value for surface i of house j from a (possibly complicated) model. Equation (1) suggests that the model has a separate mean for each home. This is not required. In the following discussion, the measurements are referred to by the subscripts i and j. However, the model may not use the surface or house as a factor. The adjusted transformed lead measurements become:

$$\hat{Q}_{ij} = (P_{ij} - p_{ij})\frac{s_t}{s_e} + p_{ij} = (P_{ij} - p_{ij})G + p_{ij} \qquad (4)$$

D.2.2 Estimating Parameters for a Model Using Regression

Since the model which best describes the lead values for paint lead loading, soil lead concentration, and dust lead loading are not known, the models must be estimated. Linear regression was used to fit equation (3) to the data. The transformed measurements are assumed to follow the model:

$$P_{ij} = X_{ij} b + e_{ij} \tag{5}$$

Where b is a vector of parameters, X_{ij} is a matrix of predictor variables and e_{ij} is random error, independent of other terms in the model, $Var(e_{ij}) = \sigma_e^2$, and $E(X_{ij} b) = \pi_{ij}$.

The adjusted transformed lead measurements are calculated as:

$$\hat{Q}_{ij} = \left(P_{ij} - \hat{P}_{ij}\right) G_{ij} + \hat{P}_{ij}$$

Where $\hat{P}_{ij} = X_{ij} b$

The objective is to find G_{ij} such that the distribution of $\hat{Q}_{ij}$ and Q_{ij} have the same variance (and the same probability of exceeding the relevant standard), that is:

$$\begin{aligned} Var\left(\hat{Q}_{ij}\right) &= Var\left(\left(P_{ij} - \hat{P}_{ij}\right) G_{ij} + \hat{P}_{ij}\right) \\ &= G_{ij}^2 Var\left(P_{ij} - \hat{P}_{ij}\right) + Var\left(\hat{P}_{ij}\right) \\ &= Var\left(Q_{ij}\right) = \sigma_t^2 = \sigma_e^2 - \sigma_m^2 \end{aligned}$$

So $G_{ij}^2 Var\left(P_{ij} - \hat{P}_{ij}\right) + Var\left(\hat{P}_{ij}\right) = \sigma_e^2 - \sigma_m^2$. (6)

The variances in this equation are estimated from the data as described in more detail in Section D.5. The estimates of $Var\left(P_{ij} - \hat{P}_{ij}\right)$, $Var\left(\hat{P}_{ij}\right)$, σ_e^2, and σ_m^2 and are $\hat{O}_{ij}$, $\hat{A}_{ij}$, $\hat{E}_{ij}$, and $\hat{M}_{ij}$, respectively.

Solving equation (6) for G_{ij} gives:

$$G_{ij} = \sqrt{\frac{\hat{E}_{ij} - \hat{M}_{ij} - \hat{A}_{ij}}{\hat{O}_{ij}}} \tag{7}$$

For a simple model with only a mean, equal sampling weights, and known variances, equation (7) simplifies to:

$$G = \sqrt{\frac{1 - \frac{s_m^2}{s_e^2} - \frac{1}{n}}{1 - \frac{1}{n}}}$$

Note that G is undefined if the numerator is negative. This happens if the error variance is large compared to the true variance around the mean, in particular, if $s_m^2 > (n-1)s_t^2$. In this case, the variance of the predicted mean around the true mean is greater than the variance of the transformed lead values around the true mean. If G is estimated using sample estimates of the variances, G may also be undefined due to sampling error in the estimation of G. If G is set to zero when it is undefined, the predicted transformed adjusted measurements will have a greater variance than the transformed lead values, resulting in slightly biased estimates of the number of surfaces above a limit. Using this modification, the equation (7) for G_{ij} becomes:

$$G_{ij} = \begin{cases} \sqrt{\frac{\hat{E}_{ij} - \hat{M}_{ij} - \hat{A}_{ij}}{\hat{O}_{ij}}} if\, \hat{E}_{ij} - \hat{M}_{ij} - \hat{A}_{ij} > 0 \\ 0 \quad otherwise \end{cases} \qquad (8)$$

D.3 Transformations

The true lead loadings and concentrations cannot be negative and the measurements were highly skewed to the right, suggesting the use of a log transformation. However, some XRF readings and lab measurements are negative. To accommodate negative measurements, a modified log transformation was used as described below. In general, measurements below the detection limit, including negative measurements, are not reported by the lab. For this study the lab agreed to provide their best estimate of the soil and dust lead values, even if they were below the detection limit. XRF readings can also be negative. Although negative and below detection readings may correspond to small lead values with relatively large measurement errors, these measurements still contain some information, e.g., surfaces with lower measurements tend to have lower true values. Therefore, all the measurements were used for the measurement error correction. For the presentation of the results, values below the detection limit (or below zero for the XRF) are presented as only below the detection limit.

The measurement error model assumes that the regression residuals have a normal distribution, the variance of the residuals is roughly constant, the model describes the data, the measurement error is independent of the measurements, and that, in the transformed scale, the measurement error is additive. For the dust soil, and paint measurements, these assumptions can be reasonably met by using the log-transformed measurements. However, since the log of zero and negative measurements are not defined, we have used an alternate transformation closely related to the log transformation.

If the measurement error has a normal distribution with constant standard deviation s, and the lead values, Z, have a lognormal distribution with coefficient of variance c then the standard deviation of the lead values is $\sqrt{s^2 + c^2 Z^2}$. If the standard deviation is small, the transformation that makes the standard deviation of the transformed data constant is:

$$P = \ln\left(Z + \sqrt{Z^2 + \frac{s^2}{c^2}} \right)$$

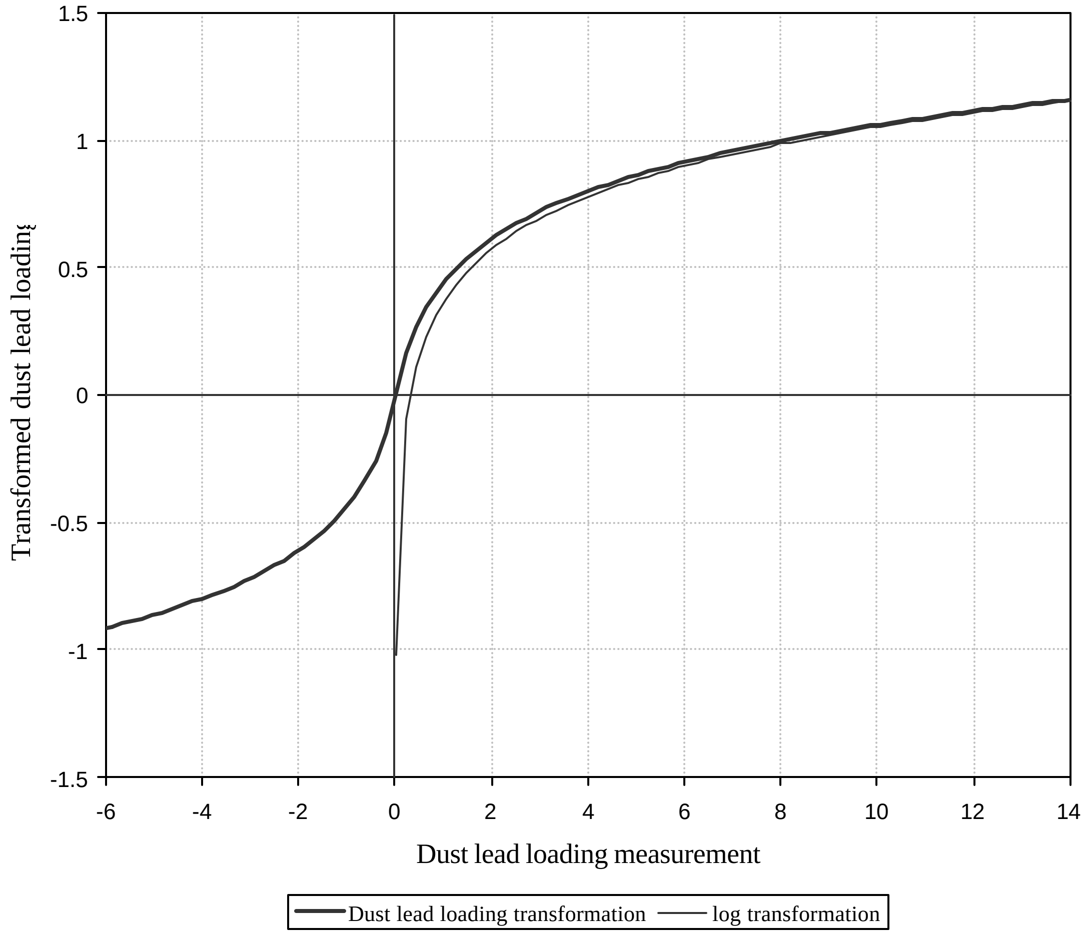
This transformation has the disadvantage that reversing the transformation is difficult. Also, the transformation does not handle negative measurements. If s is much smaller than c, $P \approx \ln(Z) + \ln(2)$. If s is much larger than c, $P \approx \ln\left(Z + \frac{s}{c} \right)$. This suggests that a transformation of the form $P = \ln(Z + C)$, with C roughly equal to s/c will approximately equalize the standard deviation of the transformed measurements. In practice, transformations that equalize the standard deviation (or variance) often make the distribution of the data roughly symmetrically distributed.

The following transformation is scaled and translated so that measurements in the vicinity of zero get the least transformation and negative values are also transformed. This transformation was used for the measurement error analysis for the dust, soil, and paint lead measurements.

$$f(Z) = sign(Z)\left(\ln\left(|Z| + C\right) - \ln(C)\right)C \qquad (9)$$

The constant C is adjusted so that the residuals are approximately normal and the variances are roughly constant and independent of the measurement level. The initial value for C is the ratio of the standard deviation of the measurements that are close to zero (generally in new homes) to the coefficient of variation of measurements that are large (generally in older homes). C was set independently for the XRF, soil, and dust measurements. Figure D.2 illustrates the transformation used for floor dust samples (where C = 0.3). Note that the transformation is symmetric around zero. Figure D.2 also shows the equivalent log transformation.

Figure D.2 Transformation Used for the Dust Lead Loading Measurements



Many of the negative soil measurements were reported as zero by the lab. For consistency, all negative soil measurements were set to zero for the measurement error analysis. Homes with all zero values were assumed to have soil lead concentrations well below the detection limit and were excluded in the measurement error analysis. For the soil analysis C was set to zero. However to avoid problems with small measurements, all non-zero measurements below 5 were set to 5.

For the window dust samples, C was set to 0.1. For the interior XRF measurements, C was set to 1.0.

D.4 Accounting for Unsampled Rooms

The adjusted lead measurements can be used to classify surfaces as having or not having lead values over a specified limit. There is also a need to classify homes as having or not having lead values greater than a specified limit values on any surface. The maximum lead value within a home determines whether the home is classified as having or not having lead values over a limit. The maximum depends on the number of surfaces in the home with observations and the number without observations.

If there are n surfaces in a home and the lead values on the surfaces have a normal distribution with cumulative distribution function Φ, mean m, and standard deviation s, then the distribution of the maximum lead value can be calculated. The expected maximum is close to the median value. The median is:

$$\Phi^{-1}\left(.5^{\frac{1}{n}}\right) \bullet s + m$$

The .5 in the equation above corresponds to the percentile for the median. For other percentiles, substitute the percentile (expressed as a fraction). The mean and standard deviation can be estimated from the measurement error analysis above.

If there are n surfaces in the home of which n_m surfaces are measured, and the distribution of lead values on the measured and unmeasured surfaces is the same, then the expected maximum lead value across all surfaces is greater than the expected maximum for the measured surfaces by:

$$F = \left(\Phi^{-1}\left(.5^{\frac{1}{n}}\right) - \Phi^{-1}\left(.5^{\frac{1}{n_m}}\right) \right) s \tag{10}$$

Once the relevant count of the surfaces with and without measurements is established, the estimated maximum lead value in a home can be estimated by:

$$M_j = \max_{Home\, j}\left(\hat{Q}_{ij}\right) + \left(\Phi^{-1}\left(.5^{\frac{1}{n}}\right) - \Phi^{-1}\left(.5^{\frac{1}{n_m}}\right) \right) \sqrt{\hat{E}_{ij}} \tag{11}$$

For the sampled homes, we know the number of rooms in different strata that were sampled and the number that were not sampled. However, we do not know how many surfaces are in the unsampled room. If we assume that each unsampled room has the same number of surfaces as the sampled room in the same strata, then the approximate number of surfaces in the home is:

$$n \approx \frac{n_m\left(n_s + n_u\right)}{n_s}. \tag{12}$$

Where n_s is the number of sampled rooms, n_u is the number of unsampled rooms in a strata.

This procedure is approximate in that the adjustment F in equation (10) depends on 1) the unknown number of surfaces in the unsampled rooms, 2) the percentile which is selected, 3) the number of measurements (in part because the mean is not known and is estimated from the data), and the assumption that the distribution of lead values is the same in the sampled and unsampled rooms.

The survey sampling design included sampling in a small number of extra rooms in order to assess the between room variation. Estimates of the between room variation would be useful if we were simulating lead values and measurements to assess the effects of measurement error, as was done for the 1990 Survey of Lead-Based Paint in Housing. The approach outlined above was adopted because it is likely to provide similar results to simulation with less overall work. Using models that have factors for house and not room or strata implies that the variance estimates include between room variation. As a result, the data from the extra replicate rooms was not used for the measurement error analysis.

D.5 Estimating Variances

Although the objective was to identify a transformation such that the transformed values have constant variance for all subsets of the data, this objective could not be guaranteed. Even if it could be found, the transformation that equalized residual variance for the data might not equalize residual variance for the replicate measurements. Therefore, the following procedure was adopted to adjust for differences in variance among different subsets of the data.

Two additional weight factors were used to reduce the influence of outliers and to adjust for possible differences in the error variance among different subsets of the data. The weight for reducing or down-weighting the effect of outliers (D_{ij}) is discussed in the next section. The weight for adjusting for variation in the error variance (V_{ij}) is discussed in this section. However, D_{ij} also appears in the equations presented in this section.

If the model for the lead measurements includes only a mean, the variance of the measurements around the mean would be estimated as:

$$s_e^2 = \frac{\sum e_{ij}^2}{n-1}$$

This overall variance can be partitioned into the variance of the residuals plus the variance of the estimated mean as follows:

$$\frac{\sum e_{ij}^2}{n-1} = \frac{\sum e_{ij}^2}{n} + \frac{\sum e_{ij}^2}{n(n-1)}$$

Where $\frac{\sum e_{ij}^2}{n}$ is the variance of the residuals and $\frac{\sum e_{ij}^2}{n(n-1)}$ is the variance of the mean.

Substituting $h = 1/n$, this equation can be rewritten as a function of three means:

$$\frac{\sum \frac{e_{ij}^2}{1-h}}{n} = \frac{\sum e_{ij}^2}{n} + \frac{\sum \frac{e_{ij}^2 h}{1-h}}{n}$$

For this simple model, $h = 1/n = X'(X'X)^{-1}X$ is the leverage (calculated by regression programs). The formulas above can be easily generalized to more complicated models. For a model with separate means for two different groups of measurements, a pooled estimate of variance would be used to estimate the overall error. The pooled estimate corresponds to a weighted average, with the weights proportional to the degrees of freedom. If H_{ij} is the leverage for P_{ij}, then for a model with several means, $1 - H_{ij}$ is proportional to the degrees of freedom needed for pooling variances.

This approach to estimating variances is easily extended to the use of sampling weights (S_{ij}). The model (equation (5)) can be fit using sampling weights, where:

$$P_{ij} = X_{ij}b + e_{ij}, \hat{P}_{ij} = X_{ij}b, \text{ and } H_{ij} = S_{ij}X_{ij}'(X'SX)^{-1}X_{ij} \tag{13}$$

Outliers are down weighted as described in the next section. The down-weighting factor, D_{ij}, is a number between one (for values that are not down-weighted) and zero. Because the down weighting will reduce the variance estimates slightly, even if there are no outliers, an adjustment factor (F_N) was included to compensate. F_N is the ratio of the variance of the normal distribution assumed by the model to the variance of the down weighted normal distribution. For calculating variances, the terms in equation (6) were multiplied by $F_N D_{ij}$. The weights for the model for the lead measurements were multiplied by D_{ij}.

Define the following variables:

$$\begin{aligned} E_{ij} &= \frac{e_{ij}^2}{1 - H_{ij}} F_N D_{ij}, \\ O_{ij} &= e_{ij}^2 F_N D_{ij}, and \quad . \\ A_{ij} &= \frac{e_{ij}^2 H_{ij}}{1 - H_{ij}} F_N D_{ij} \end{aligned} \tag{14}$$

Weighted averages of O_{ij}, A_{ij}, and E_{ij} provide estimates of $Var(P_{ij} - \hat{P}_{ij}), Var(\hat{P}_{ij})$, and σ_e^2, respectively. More generally, separate variance estimates can be produced for different subsets of the data defined by a class variable X_E.

The objective is to define the transformation such that the variances are as constant as possible across all subsets of the data. Calculating variances for different subsets of the data was used to adjust for possible differences not accounted for in the transformation. In order to assess whether the differences associated with a class variable were significant, the transformed residuals were modeled. The log-transformed variances have roughly constant variance. Therefore, define:

$$T_{ij} = \ln\left(\frac{e_{ij}^2}{1 - H_{ij}} D_{ij} + \frac{I^2}{100}\right) \tag{15}$$

Where I is the interquartile range of the residuals, as defined in Section D.6. Note that T_{ij} is roughly equal to the log of e_{ij}, with a constant added to minimize the occurrence of particularly small values. The significance of X_E for predicting differences in the error variance is assessed by regressing T_{ij} onto X_E. For assessing significance, the error degrees of freedom was reduced by the number of parameters in the model from which the residuals were obtained (equation (5)).

The variance estimates are obtained by regressing O_{ij}, A_{ij}, and E_{ij} onto X_E, saving the predicted values.

The weight factor for adjusting for non-homogenous variances is proportional to: $V_{ij} = \frac{\overline{\hat{E}}}{\hat{E}_{ij}}$.

A similar procedure was used to model the measurement error from the replicate measurements. When modeling the replicate measurements, the model for the data includes factors that define the replicate pairs, and the measurement error variance $\hat{E}_{ij}$ is called $\hat{M}_{ij}$ in the equations below.

D.6 Outliers

There are some measurements in the data file that are very unusual when compared to other measurement made under similar conditions. These values are generally called outliers. Outliers may be correct values for unusual surfaces or may have unusually high measurement errors due to unusual circumstances (such as problems reading handwriting, instrument bias, or incorrect sample handling). Outliers that are due to unusual measurement error conditions will adversely affect variance estimates that are needed to correct for measurement error. If these outliers could be identified, they should probably be removed from the data. Outliers that are reasonable values for unusual circumstances should be kept in the data; however, the model may not provide a good prediction for the unusual conditions.

The outlier approach used for the measurement error analysis had the following characteristics:

1. Weights for outliers were reduced to minimize their affect on the model and variance estimates
2. The adjustment for measurement error was reduced for outliers such that extreme outliers are not adjusted for measurement error.

The procedure for down-weighting outliers follows similar approaches in the statistical literature (for example, see Tukey's Bi-weight in Mosteller, F. and Tukey, J.W., 1977, *Data Analysis and Regression*, Addison Wesley). The particular function used was chosen to down-weight only observations that were in the tails of the normal distribution.

On the assumption that the data, excluding outliers, fit the measurement error model the non-outliers can be adjusted for measurement error. Without knowing why a measurement is an outlier, it is difficult to decide how to adjust an outlier measurement for measurement error. If the outlier is unusual due to measurement error, then a large adjustment may be justified. If the outlier is unusual because the surface being measured is unusual, then a small adjustment is reasonable.

For this work, it was decided to not adjust extreme outliers. Analysts of the data must decide whether particular unusual values are to be used in their analysis.

Users of the data have the option of excluding outliers from analyses. The summary statistics in the report use all measurements, including outliers.

The residuals were scaled to have approximately equal variance:

$$R_{ij} = e_{ij}\sqrt{\frac{V_{ij}}{1-H_{ij}}} \qquad (16)$$

The scaled residuals were normalized by dividing by their interquartile range.

$$N_{ij} = \frac{R_{ij}}{IQR(R)} = \frac{R_{ij}}{I} \qquad (17)$$

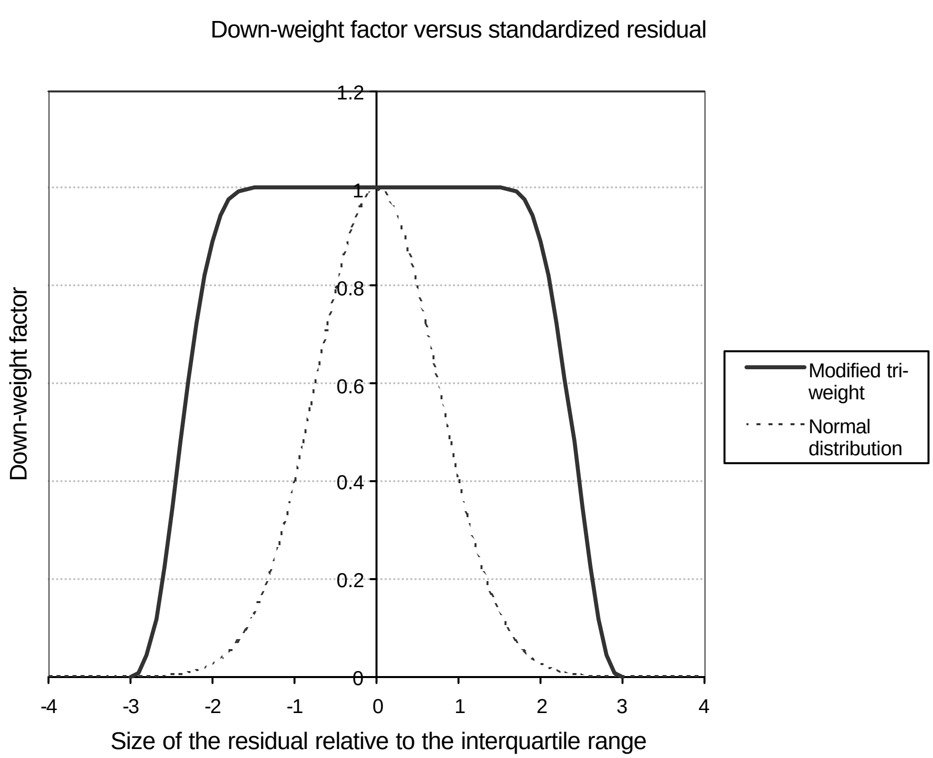
The normalized residuals were used to calculate weights (D_{ij}) for down-weighting the outliers, as shown in Table D.1.

Table D.1 Formulas for Calculating the Weight to Down Weight Outliers

N_{ij}	$D_{ij} = g_k(N_{ij}) = g_k\left(\frac{R_{1ij}}{I}\right)$
> k + 1.5	0
k to k+1.5	$\left(1-\left(\frac{N_{ij}-k}{1.5}\right)^3\right)^3$
-k to k	1
-(k+1.5) to –k	$\left(1-\left(\frac{-N_{ij}-k}{1.5}\right)^3\right)^3$
<-(k+1.5)	0

Figure D.3 shows the form of the down-weighting factor on the same scale as the assumed normal distribution of the residuals (k = 1.5). If the residuals have a normal distribution, the weights are unaffected for most observations (the middle 95.7% of the distribution). For observations in the tails of the distribution, the weights are reduced. Only for observations at the extremes of the distribution are the weights reduced to zero.

Figure D.3 Downweights



The percentage of the data judged to be outliers is the sum of the down-weights divided by the number of non-missing measurements.

D.7 Iterative fitting

Because the down-weights and variance weights were not known when the model was first fit to the data, an iterative procedure was used. In each iteration, the weighted regression model for the lead measurements was fit, the down-weight factor for outliers was calculated, and the variance weight factor was then calculated. In the first iteration, the model for the lead measurements was fit with only the sampling weights. In the second through fourth iterations the model was fit with the sampling weights, down-weights from the previous iteration, and variance weights from the previous iteration. In the fifth and last iteration, the regression model was fit with the final down-weights and variance weights from the previous iteration. The down-weights and regression weights were not recalculated in the last iteration.

Because the down-weighting of outliers and the variance estimates are interrelated, the change in the down-weighing factor from one iteration to the next was less than shown in equations in table D.1. The down-weight in iteration k+1 was equal to

$$D_{ij(k+1)} = F_d D_{ij} + (1 - F_d) D_{ij(k)}$$

Where F_d is a number between 0 and 1. If $F_d = 0$, no change is made in the down-weighting factor; if $F_d = 1$, the down-weight factor is defined in Table D.1. For the measurement error corrections, this factor was set to 0.5 for the first iteration and 0.9 for iterations 2, 3, and 4 and zero for iteration 5.

D.8 Summary of the Fitting Procedure

The procedure for calculating the adjusted lead measurements has the following steps:

1. Identify a model for the lead measurements and variances,
2. Fit the model to the survey data using a SAS macro,
3. Fit the model to the replicate survey data using a SAS macro, and
4. Calculate the adjusted lead measurements.

1. WesVar and SAS were used to identify significant predictors of the lead measurements. SAS provides quicker answers however the SAS significance tests are at best approximate. WesVar was generally used to assess statistical significance. The dependent variables identified in this step include: X for predicting lead measurements, X_E for modeling variance of the lead measurements, and X_M for modeling the measurement error.

2. Fit the lead measurement model to the survey data using a SAS macro

   Transform the lead measurements: $P_{ij} = f_c(Z_{ij})$

   Initialize variance weight and outlier down-weight: $D_{ij} = 1$ and $V_{ij} = 1$

A) Model the lead measurements:

Calculate the regression weights: $W_{ij} = S_{ij} V_{ij} D_{ij}$

Fit the weighted regression model to the lead measurements, saving the leverage

$P_{ij} = Xb + e_{ij}, \hat{P}_{ij} = Xb,$ and $H_{ij} = W_{ij} X'(X'WX)^{-1} X$

B) Calculate the outlier down-weight

Calculate residuals scaled to have constant variance: $R_1 = e_{ij} \sqrt{\frac{V_{ij}}{1 - H_{ij}}}$

Calculate interquartile range (I) for R_1

Update the outlier weight: $D_{ij} = F_d g_k \left(\frac{R_{1ij}}{I} \right) + (1 - F_d) D_{ij}$

Calculate residual functions

$$E_{ij} = \frac{e_{ij}^2}{1 - H_{ij}} D_{ij},$$

$$O_{ij} = e_{ij}^2 D_{ij}, \textit{ and}$$

$$A_{ij} = \frac{e_{ij}^2 H_{ij}}{1 - H_{ij}} D_{ij},$$

Regress the residual functions onto X_E, saving the predicted values.

$$E_{ij} = X_E b_E + e_{Eij}, \hat{E}_{ij} = X_E b_E$$

$$O_{ij} = X_E b_O + e_{Oij}, \hat{O}_{ij} = X_E b_O$$

$$A_{ij} = X_E b_A + e_{Aij}, \hat{A}_{ij} = X_E b_A$$

Calculate variance weights: $V_{ij} = \frac{\bar{\hat{E}}}{\hat{E}_{ij}}$

Return to step A) until 5 iterations have been completed. For iteration 1, F_d = .5, k = 2. For iterations 2 through 4, F_d = .9, k = 1.5. For iterations 5, F_d = 0.

3. Fit the lead measurement model to the replicate data using the SAS macro

The procedure is the same as above except X_M is used in place of X_E and the only variable saved for later calculations is $\hat{E}_{ij}$ which is renamed to $\hat{M}_{ij}$.

4. Calculate the adjusted lead measurements,

$$G_{ij} = \sqrt{\frac{\hat{E}_{ij} - \hat{M}_{ij} - \hat{A}_{ij}}{\hat{O}_{ij}}}$$

$$\hat{Q}_{ij} = \left(P_{ij} - \hat{P}_{ij}\right)G_{ij} + \hat{P}_{ij}$$

The measurement error adjusted measurements in the original units are: $\hat{Z}_{ij} = f^{-1}\left(\hat{Q}_{ij}\right)$

The estimated maximum lead value in a home is:

$$M_j = \max_{Home\ j}\left(\hat{Q}_{ij}\right) + \left(\Phi^{-1}\left(.5^{\frac{1}{n}}\right) - \Phi^{-1}\left(.5^{\frac{1}{n_m}}\right)\right)\sqrt{\hat{E}_{ij}}$$

The replicate sample weights provide a way to calculate confidence intervals for the estimates from the measurement error adjustment. However, these calculations were not conducted as part of this effort.

D.9 Fitting Models to Different Subsets of the Data

If there were no missing data, the same model can be used for all homes. The models that explain most of the variation in the data fit separate means for each home along with fitting other factors. For homes in which there are no measurements (for example, soil samples might not be collected due to thunderstorms), a different model is fit. That model has the year category in which the home was built as the primary predictor, along with other factors.

D.10 Soil, Dust, and Paint Specific Details of the Measurement Error Correction

D.10.1 Paint

Due to problems with modeling the distribution of the XRF readings, C for the transformation was set to 1.0 based on the plot of the replicate versus original XRF readings. Figure 7.1 presented in Volume I was prepared using different values of D. For the value that was chosen, the variability of the measurements was reasonably constant over the range of the data. The variances using different values of C showed no useful pattern for selecting D. The model for the variances used both the construction year category and the quartile of the average XRF reading within the home. Both of these factors were significant for predicting variance differences in the residuals.

According to the algorithm, 30% of the XRF readings (in homes with positive XRF readings) are outliers. This high proportion of outliers has significant effects on the measurement error analysis. A plot of the residuals shows that the residuals do not have a normal distribution. The assumptions behind the measurement error correction appear to provide a very poor description of the distribution of the XRF readings. Some attempt was made to find alternate assumptions that might provide a better fit to the data or a better assessment of the effect of measurement error. In the end it was decided that, without additional data or insight into the processes that result in the apparent outliers, we could not develop an improved model.

The square of the percent deterioration was used in the model to assess if the relationship between deterioration and paint lead loading was linear. The parameter estimate suggested that there was significant curvature that might be solved by a transformation. The selection of the cubic transformation was based on data analysis but, in the end, was somewhat arbitrary. Since the model had many parameters and had significant problems with outliers, it was decided to not include squared and cubic terms to model the relationship, but to only include one term. The decision to use only the cube of the percent deterioration is expected to make little practical difference to the model.

The XRF calibration data were analyzed to determine if the XRF instruments were biased or gave readings that might be judged as outliers. Although differences among instruments were statistically significant, the magnitude of the differences was small relative to the precision with which the test surfaces were prepared. It was not possible to conclude that the differences were not due to differences in the lead loadings on the test surfaces. Therefore, the XRF readings were used as reported, assuming they were unbiased. No patterns were found that would suggest that the XRF instruments provided unusual readings.

D.10.2 Dust

For the floor dust, 3% of the data and 4% of the replicate measurements were judged to be outliers. The distribution of the residuals was reasonably normal. For the transformation, C = .3.

For the window dust, 3% of the data and 14% of the replicate measurements were judged to be outliers. The distribution of the residuals was reasonably normal. For the transformation, C = .1.

D.10.3 Soil

The lead value of interest is the average soil lead concentration across the areas sampling locations: entrance, dripline, and midyard. The average is assumed to cover multiple sides of the home. If samples were collected on two sides of the home in the midyard, the midyard data for the measurement error analysis is the average of the two midyard samples. The difference among the midyard samples provides one degree of freedom for estimating the measurement error. Based on an analysis of variance components, the variance among replicate samples on the same side of the home and samples from two different sides of the home are not significantly different. Therefore, all samples at the same location were used to estimate measurement error, including replicate samples and samples from two sides of the home. To properly estimate the adjusted soil lead concentration, the equation for G_{ij} was adjusted as follows:

$$G_{ij} = \sqrt{\frac{\hat{E}_{ij} - \dfrac{\hat{M}_{ij}}{n_{ij}} - \hat{A}_{ij}}{\hat{O}_{ij}}}$$

Where n_{ij} is the number of replicate measurements (including measurements on different sides of the home). The other terms in the equation above are defined in Sections D.2 and D.5.

For the soil analysis, the transformation constant, C, was set to zero (i.e., a log transformation) and measurements below 5 were set to 5. The detection limit, based on tests performed at the lab was judged to be 20 ppm.

Seven percent of the replicate data and three percent of the data were judged to be outliers. The distribution of the residuals was reasonably normal.