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Report on the National Survey of Lead-Based Paint in Housing

Base Report

REPORT ON THE NATIONAL SURVEY

OF LEAD-BASED PAINT IN HOUSING

Base Report

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EXECUTIVE SUMMARY

Lead is a powerful toxin that attacks the central nervous system and is particularly damaging to the developing nervous systems of young children. High levels of lead in the blood can result in convulsions, mental retardation, and even death. Further, recent medical research has found that low levels of lead exposure have more serious health consequences that previously thought. Effects include reductions in intelligence and short-term memory, slower reaction times, and poorer hand-eye coordination.[1]

Although there are many sources of lead in the environment, including drinking water, food, emissions from gasoline combustion, and industrial emissions, it is clear that lead-based paint plays a major role in high blood lead levels. Recent research indicates that dust and soil may be the most significant pathway for low-level lead exposure, and that lead-based paint is an important source of household dust lead.[2,3]

The 1987 amendments to the Lead-Based Paint Poisoning Prevention Act required the Secretary of Housing and Urban Development (HUD) to prepare and transmit to Congress "a comprehensive and workable plan" for the abatement of lead-based paint in housing and "an estimate of the amount, characteristics and regional distribution of housing in the United States that contains lead-based paint hazards at differing levels of contamination." In response to this mandate, HUD sponsored a national survey of lead-based paint in housing and delivered a Report to Congress on a *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately Owned Housing* in December, 1990. The *Comprehensive and Workable Plan* report was completed under a tight, Congressionally mandated schedule and focused on motivating, developing and presenting the comprehensive plan required by Congress. As such, it only reported the estimates of the extent of lead-based paint in housing required by Congress and provided a brief description of the survey methodology.

This report, sponsored by the Environmental Protection Agency, is a comprehensive technical report on the HUD-sponsored national survey of lead-based paint in housing. It provides a detailed description of the survey methodology. It reports on wide ranging analyses of the national survey data. It reports revised estimates of the extent of lead-based paint in housing, based on a thorough investigation of the multiple sources of error - variability and bias - in the data. These error sources include nonresponse biases, sampling variability between housing units, sampling variability within housing units, X-ray fluorescence device (XRF) measurement error, and laboratory analysis error. The analysis underlying the estimates presented in the *Comprehensive and Workable Plan (CWP)* report incorporated only sampling variability between housing units.

Extent of Lead-based Paint in Housing - Revised Estimates

The number of housing units classified as having lead-based paint depends on the definition employed to classify a housing unit as having lead-based paint. The definition used here classifies a home

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[1] Fowler, Bruce et al, "Measuring Lead Exposure in Infants, Children, and Other Sensitive Populations," National Academy Press, Washington, D.C.

[2] Bornschein R.L., Hammond P. B., Dietrich K. N., Succop P., Krafft K., Clark S., Berger O., Pearson D., and Que Hee S. (1985). The Cincinnati prospective study of low-level lead exposure and its effects on child development: Protocol and status report. Environmental Research 38, 4-18.

[3] Bornschein R.L., Succop P. A., Dietrich K. N., Clark C. S., Hee Q. S. and Hammond P. B. (1985). The influence of social and environmental factors on dust lead, hand lead, and blood lead levels in young children. Environmental Research 38, 108-118.

as having lead-based paint if the measured lead concentration on any painted surface is 1.0 mg/cm^2, or greater.

As reported in the CWP report, lead-based paint is widespread in housing. The revised estimate is that 64 million homes (± 7 million)[4], 83 percent (± 9%) of the privately owned housing units built before 1980, have lead-based paint somewhere in the building. (Fifty-seven million (± 5 million) homes, or 74 percent (± 6%), were reported in the CWP.) Twelve million (± 1 million) of these homes are occupied by families with children under the age of seven years old. An estimated 49 million (± 7 million) privately owned homes have lead-based paint in their interiors. There are no statistically significant differences in the prevalence of lead-based paint by type of housing, market value of the home, amount of rent payment, household income, or geographic region.

Seventeen percent of the pre-1980 housing stock have dust lead levels in excess of the federal guidelines[5], independent of the presence or absence of lead-based paint. However, excessive dust lead levels are associated with the presence of *damaged* lead-based paint. Fourteen million homes, 19 percent of the pre-1980 housing stock, have more than five square feet of damaged lead-based paint. Nearly half of them (47 percent) have excessive dust lead levels.

Excessive soil lead levels[6] are also associated with the presence of damaged lead-based paint. While 21 percent of all pre-1980 homes have excessive soil lead levels, nearly half of the 10 million homes with non-intact lead-based paint on exterior walls have excessive soil lead levels.

Although a large majority of pre-1980 homes have lead-based paint, most of them have relatively small areas of it. The average privately-owned housing unit with lead-based paint has an estimated 601 square feet of it on interior surfaces and 869 square feet on exterior surfaces. Over half of the leaded paint is on walls, ceilings, and floors. (For comparison, the walls in a room 10' by 12', with an 8' ceiling, have an area of 352 square feet.) The amounts of lead-based paint per housing unit vary with the age of the dwelling unit. Pre-1940 units have, on average, about three times as much lead-based paint as units built between 1960 and 1979.

Lead paint is even more widespread in public housing; 86 percent (± 8%) of all pre-1980 public housing family units have lead-based paint somewhere in the building. While most public housing units have some lead-based paint, most of them have small areas of surfaces covered with it. The average public housing unit with lead-based paint has an estimated 367 square feet on interior surfaces and 133 square feet on exterior surfaces. Most of the interior lead-based paint is on walls, while very little of the exterior walls are painted.

Survey Methodology

The objective of the national survey of lead-based paint in housing was to obtain data for estimating: (1) the number of housing units with lead-based paint; (2) the surface area of lead-based paint in housing, to develop an estimate of national abatement costs; (3) the condition of the paint; (4) the prevalence of lead in dust in housing units and in soil around the perimeter of residential structures; and (5) the characteristics of housing with varying levels of potential hazard, to examine possible priorities for abatement.

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[4]The numbers in parentheses are 95% confidence intervals.

[5]The federal guidelines vary with the location of the dust: 200 micrograms of lead per square foot for floor samples, 500 µg/sq ft for window sills and 800 µg/sq ft for window wells.

[6]EPA interim guidelines for soil lead action levels are 500 ppm for residential soil associated with Superfund sites.

The study population consisted of nearly all housing in the United States constructed before 1980. Vacant housing, group quarters, Alaska and Hawaii were excluded for operational reasons. Newer houses were presumed to be lead-free because, in 1978, the Consumer Product Safety Commission banned the sale of lead-based paint to consumers and the use of such paint in residences. The survey was conducted between December 1989 and March 1990 in 30 counties across the 48 contiguous states, selected to represent the entire United States housing stock, both public and privately-owned. The total sample size is 381 dwelling units, 284 privately owned and 97 publicly owned. The sample was small, but it provided estimates that were sufficiently precise to develop the CWP for private and public housing.

Within each housing unit, two rooms were randomly selected for inspection; one room with plumbing (wet) and one room without plumbing (dry). In each of these two rooms, the field technicians inventoried painted surfaces, measured their dimensions, and assessed the condition of the paint; they measured the lead concentration in randomly selected painted surfaces; and they gathered samples of dust.

Since not all rooms in a dwelling unit were inspected, it is possible to miss lead-based paint when it is really present somewhere else in the dwelling unit. To reduce the chances of misclassifying a dwelling unit with lead-based paint as lead-free, additional lead readings, termed purposive readings, were taken on surfaces that, in the opinion of the field technicians, were most likely to have lead-based paint. In some dwelling units, these additional purposive samples did, indeed, find lead-based paint in dwelling units where no lead-based paint had been found in the randomly selected rooms.

Exterior painted surfaces were inventoried and measured and lead readings taken according to protocols similar to those used in the interior. Soil samples were also taken at selected locations around the building exterior. Common areas were also sampled and inspected.

Lead in paint measurements were made with portable Scitec MAP-3 spectrum analyzer XRF devices (MAP/XRFs), which NIST had determined to be more accurate and more precise than the direct-reading XRFs used in earlier surveys. Although the MAP/XRFs were an improvement over the earlier direct-reading XRFs, they still had limitations. In particular, MAP/XRF measurements made over brick or concrete were less accurate and less precise than those made over wood or plaster. These limitations notwithstanding, portable MAP/XRF technology was used because the survey included occupied dwellings where it was not feasible to take paint scrapings for laboratory analysis.

Data were collected on lead in dust and soil in a number of locations in each sampled dwelling unit. Dust samples were collected by vacuuming randomly selected floor locations, window sills and window wells in the wet room and again in the dry room. In addition, a dust sample was collected from the floor just inside the main entrance to the dwelling unit. Soil samples were taken outside the main entrance to the building, at a selected location along the drip line of the sampled exterior painted surface, and at a remote location away from the building but still on the property. Dust and soil samples were analyzed for lead concentration.

Analyses of the Sources of Error

Nonresponse analysis. An analysis was conducted of the private housing nonresponse in the national survey to estimate the potential for nonresponse bias. This analysis was necessary because intrusive studies that impose significant burdens on the respondents tend to have lower response rates than less burdensome studies and, therefore greater potential for nonresponse biases. In this survey, 53 percent of the homes asked to permit the inspection visits cooperated fully with the study. The nonresponse analyses did not reveal any evidence of potential non-response biases associated with ethnicity, building age, or family income. There were statistically significant associations between the response rates and monthly rent in tenant-occupied housing units and current market value in owner-occupied housing; the lower ends of both distributions were somewhat under represented. There was a strong positive correlation between inspected housing units in the same census block with respect to the presence of lead in paint, dust, and soil. On balance, these findings suggest that the potential bias due to nonresponse is likely to be small.

Correction for measurement bias. The MAP/XRF measurement equipment used to detect and quantify lead in paint tended to yield readings that were biased, i.e., systematically different from the actual lead concentrations measured. Quality assurance (QA) data collected daily during the national survey field period permitted the estimation of the MAP/XRF bias. MAP/XRF readings were made on shims of known lead concentration placed over selected substrate materials. A shim is a piece of hard paper painted with lead-based paint. There were four substrate materials, wood, drywall, steel, and concrete, selected to represent the typical range of substrate materials encountered in residential construction. Statistical techniques were applied to the QA data to develop calibration equations for adjusting the MAP/XRF readings for measurement bias. The MAP/XRF readings taken in the housing units were therefore adjusted to statistically correct for measurement bias.

Correction for misclassification errors. There are two major factors that induce misclassification errors. First, the MAP/XRF equipment also has random variability in its measurements. This variation can induce a classification bias, that is, a bias in the estimated prevalence of housing units with lead-based paint. Second, the protocol for inspecting a housing unit for lead-based paint provided for sampling painted surfaces for MAP/XRF measurement, rather than measuring the lead content of every painted surface in the housing unit. Under this inspection protocol, it is possible for a housing unit to have some surfaces with lead-based paint, other painted surfaces without lead-based paint, and only the lead-free surfaces selected for MAP/XRF measurement. Such housing units would be incorrectly classified as not having lead-based paint.

To adjust for these classification biases, the distribution of lead concentrations on the untested painted surfaces, in the sampled rooms and in the unsampled rooms, in each household was simulated. (No applicable, adequate data set existed to permit the direct estimation of these biases.) This extension from the measured surfaces to all surfaces in the unit was based on (1) data on the number of rooms in the unit, (2) data on the number of surfaces per room, and (3) assumptions about the relationship of the lead concentrations on unmeasured surfaces to those on the sampled and measured surfaces. The model was observed to be consistent with the National Survey data. The misclassification rates were estimated for the simulated housing units, and used to adjust the prevalence estimates accordingly.

Impact on the national survey findings. All findings on the lead hazard in homes reported elsewhere in this report incorporate the results of this error analyses. That is, the raw MAP/XRF readings have been statistically corrected for measurement bias and the misclassifications due to measurement variation and sampling within dwelling units have been corrected. The national estimate of prevalence of lead-based paint in privately-owned housing is 83 percent. Without the statistical corrections described above, the estimate would have been 74 percent.

1. INTRODUCTION

The National Survey of Lead-Based Paint in Housing was conducted under the sponsorship of the Department of Housing and Urban Development to provide basic data for comprehensive and workable plans (CWPs) for the prompt and cost-effective inspection and abatement of lead-based paint hazards in private and public housing. The CWPs were required by the Lead-Based Paint Poisoning Prevention Act (LPPPA), as amended by Section 566 of the Housing and Community Development Act of 1987.[1] The CWP for private housing was issued to Congress in December, 1990.[2] The CWP for public housing is forthcoming.

1.1 Background

This section presents the background for the national survey. It briefly describes the data available prior to the national survey on lead-based paint hazards.

Previous Surveys

There were four notable surveys of lead-based paint in housing before the national survey. Three local surveys, in Washington, D.C., Pittsburgh, and Phoenix, were conducted in the mid-1970s, and one national survey of public housing was carried out in the 1980s.

The Washington, DC, survey, conducted in 1973 by the National Bureau of Standards (now the National Institute of Standards and Technology [NIST]) had a sample of 233 housing units representing the city of Washington.[3] This survey also acted as a HUD-sponsored field test for a Pittsburgh survey conducted a year later.

The Pittsburgh survey, conducted in 1974 and 1975 by the Allegheny County (PA) Health Department for the National Bureau of Standards under HUD sponsorship, is by far the largest study of its type ever conducted. The survey completed inspections in approximately 3,300 housing units from the entire Pittsburgh urban area.[4]

The Phoenix survey, conducted in 1976 by the Arizona Department of Health Services, had a sample of 268 units. The sample represented a single Phoenix Census tract that was chosen because of a high number of both pre-1940 units and children under five years old.[5]

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[1] Amendment in Section 566 of the Housing and Community Development Act of 1987 (Public Law 100-242).

[2] U.S. Department of Housing and Urban Development, Office of Policy Development and Research (1990), *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately Owned Housing: Report to Congress.*

[3] Hall, William; and Ayers, Tyrone (1974), *Survey Plans and Data Collection and Analysis Methodologies: Results of a Pre-Survey for the Magnitude and Extent of the Lead-Based Paint Hazard in Housing* (NBSIR 74-426), U.S. Department of Commerce, National Bureau of Standards.

[4] Shier, Douglas R.; and Hall, William G. (1977), *Analysis of Housing Data Collected in a Lead-Based Paint Survey in Pittsburgh, Pennsylvania, Parts I and II* (NBSIR 77-1250 and 77-1293), U.S. Department of Commerce, National Bureau of Standards.

[5] Arizona Department of Health Services, Division of Environmental Health, Bureau of Sanitation (1976), "Lead-Based Paint: Report of Findings to the State Legislature" (mimeo).

The fourth survey was part of a national survey conducted in 1984-1985 to address modernization needs of public housing. Two hundred and sixty-two public housing units (apartments) plus associated common areas (i.e., hallways, playgrounds) were inspected in 131 public housing projects in 34 cities.[6]

Limitations of Previous Surveys

As a basis for national estimates of the number of housing units with lead-based paint, analyzing other lead hazards in housing, and estimating the cost of abatement, these prior surveys are limited.

Sample Limitation. Because of the limited geographic coverage of most of the surveys, there is no way of knowing the extent to which the findings are representative of housing in the nation.

Wide Divergence in Estimates of Homes with Lead. The four prior surveys' estimates for the percentage of homes with lead varied immensely. For housing built prior to 1940, the estimates ranged from 71 to 100 percent; for homes built between 1940 and 1959, the range was 64 to 92 percent; and for units built between 1960 and 1977, the range was 48 to 76 percent.

Measurement Imprecision. The portable X-ray fluorescence (XRF) analyzers used to measure the lead content of paint in all of the surveys have subsequently been found by NIST to be highly imprecise at the 1.0 mg/cm^2 (milligrams of lead per square centimeter of painted surfaces) level[7], which is the Federal threshold for lead-based paint.

Lack of Dust and Soil Lead Data. The prior surveys provide no information on the prevalence of lead in house dust and exterior soil--two sources identified in the literature as important pathways of lead. Therefore, they cannot be used to analyze the prevalence of lead in dust and soil, or the association between lead-based paint and lead in dust and soil.

Studies of Lead in Surface Dust and Soil

A large number of studies published during the past two decades have indicated an association between lead dust and childhood blood lead. Three studies established the apparent importance of lead dust as a pathway for lead-based paint. In 1980, Charney and colleagues concluded that, although several factors accounted for childhood lead poisoning, lead dust and "hand" lead (i.e., lead that clings to fingers and hands) were strongly correlated with blood lead, and that interior lead dust should be taken into account in attempting to reduce lead hazards in residential environments.[8]

In 1983, based on a HUD-funded study in Baltimore, Charney and colleagues analyzed whether dust control measures, in addition to treatment of potential lead-based paint hazards, would lower blood levels. They concluded "that a focused dust-control program can reduce blood lead levels more than standard lead removal in the home."[9]

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[6]Wallace, James E. (1986), *The Cost of Lead-Based Paint Abatement in Public Housing*, U.S. Department of Housing and Urban Development.

[7]McKnight, Mary E.; Byrd, Eric W.; Roberts, Willard E.; and Lagergren, Eric S. (December 1989), *Methods for Measuring Lead Concentrations in Paint Films* (NISTIR 89-4209), U.S. Department of Commerce, National Institute of Standards and Technology.

[8]Charney, E.; Sayre, J.; and Coulter, M. (February 1980), "Increased Lead Absorption in Inner City Children: Where Does the Lead Come From?", *Pediatrics*, 65(2).

[9]Charney, E.; Kessler, B; Farfel, M.; and Jackson, D. (1983), "Childhood Lead Poisoning: A Controlled Trial of the Effect of Dust-Control Measures on Blood Lead Levels," *New England Journal of Medicine* 309(18):1089-1093.

Bellinger and colleagues (1986) enrolled 249 metropolitan Boston children with low-to-moderate blood lead levels at one month of age and collected a wide range of data semiannually. Environmental lead and mouthing behavior were significantly associated with blood lead, but home environment/care giving, child development, and sociodemographic characteristics were not. Dust lead was the most important environmental variable, although refinishing and month of sample selection were significant.[10]

Studies of Pathways Between Paint Lead and Blood Lead

Bornschein, et al. (1986)[11] studied the relationship between children's blood lead levels and measures of the extent of lead-based paint in dwelling units. They found that lead in paint does not directly impact blood lead levels, but it does impact them through the pathways:

- Lead-based paint hazard —> dust lead —> blood lead, and
- Lead-based paint hazard —> dust lead —> hand lead —> blood lead.

The conclusion is that, except for children with pica, an abnormal craving to eat non-food substances, dust is the major immediate source of lead for children, and that lead-based paint is a primary contributor to dust lead.

1.2 Report Organization

In the sections that follow, this document presents the design, methodology, findings and conclusions of the survey, and discusses quality assurance and sources of error in the survey data. The presentation begins with discussions of the national estimates of prevalence, amounts, and hazards of lead in paint, dust, and soil in private and public housing. Next, a discussion of research design addresses sample design, data collection protocols, and quality assurance. Finally, this report addresses the major conclusions to be drawn from the national survey and its findings.

1.3 Objectives of National Survey of Lead-Based Paint in Housing

The objectives of the national survey were based on Section 302 of the Lead-Based Paint Poison Prevention Act of 1971, as amended. The informational requirements set forth in that Act are:

- An estimate of the amount, characteristics, and regional distribution of housing in the United States that contains lead-based paint hazards at differing levels of contamination.
- A comprehensive and workable plan for the cost-effective inspection and abatement of public housing..., including an estimate of the total cost of abatement.[12]

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[10] Bellinger, D.; Leviton, A.; Rabinowitz, M.; Needleman, H.; and Waternaux, C. (1986), "Correlates of Low-Level Lead Exposure in Urban Children at 2 Years of Age," *Pediatrics* 77(6):826-833.

[11] Bornschein, R.L; Hammond, P.D.; Dietrich, K.N.; Succop, P.A.; Krafft, K.M.; Clark, C.S.; Pearson, D.; and Que Hee, S.S. (1985), "The Cincinnati Prospective Study of Low-Level Lead Exposure and Its Effect on Child Development Protocol and Status Report," *Environmental Research* 38: 4-18.

[12] Estimates of the costs of abatement are reported in the U.S. Department of Housing and Urban Development reports: *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately Owned Housing: Report to Congress (1990)* and *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Public Housing* (forthcoming). They are not included in this report.

- A comprehensive and workable plan, including any recommendations for changes in legislation, for the prompt and cost-effective inspection and abatement of privately-owned single family and multi-family housing, including housing assisted under Section 8 of the U.S. Housing Act of 1937.

Toward these objectives, the National Survey of Lead-Based Paint in Housing was designed to obtain data for estimating:

- The number of dwelling units in the United States with interior and exterior lead-based paint, by year built, type of housing, level of lead loading, and census region (see Section 1.4 for an explanation of lead loading).

- The number of multi-family (private and public) residences with lead-based paint in common areas, by year built, level of lead loading, and census region.

- The extent of surface area of lead-based paint in order to estimate national abatement costs in public and privately owned housing.

- The prevalence of damaged lead-based paint.

- The prevalence of lead in dust in dwelling units and in soil around the perimeter of residential structures.

- The characteristics of housing with varying levels of hazard to examine possible priorities for abatement.

The information was needed to support a number of research questions. These included: analysis of the relationship among sources and pathways of lead in the residential environment; analysis of the characteristics of housing with varying hazard levels; development of indices of lead hazard; analysis of the costs, effectiveness and benefits of alternative strategies of reducing lead-based paint hazards: and the identification of the dimensions of each of these issues.

1.4 Lead Standards and Guidelines

The Federal Government has set standards and guidelines for lead hazards in paint, dust and soil. They are briefly discussed here.

The amount of lead in the paint, expressed as the paint lead loading on a surface, is an important factor in determining the potential exposure level of hazard. For this study, the Federal standard (set by HUD) is 1.0 milligrams of lead per square centimeter of painted surface (1.0 mg/cm^2), and is used to classify a painted surface as "with" or "without" lead-based paint. Therefore, painted surfaces with 0.9 mg/cm^2 of lead are classified as having no detectable lead; and painted surfaces measured at 1.0 mg/cm^2 are considered to have lead. At the same time, painted surfaces with lead as high as or in excess of 5.0 mg/cm^2 (more common in older homes) are classified in the same way--as having lead-based paint. It should also be noted that the Federal standard for paint lead loading is *not* a health-based standard, implying 1.0 mg/cm^2 is not necessarily a threshold for determining safe or unsafe conditions. EPA, along with other Federal agencies, is currently developing a health-based standard for paint lead, along with standardized measurement techniques.

Dust lead levels presented in this report are a "loading" and soil lead levels are a "concentration". Dust loadings refer to the mass of lead per square area of surface, expressed as micrograms of lead per square foot of surface (µg/ft²). The HUD Guidelines state that no more than 200 µg/ft² on floors, 500 µg/ft² on windowsills and 800 µg/ft² on window wells is allowed inside a home after lead paint abatement takes place. (Windowsills are defined by HUD as the lower part of a window inside the room, and window wells are the bottom of a window between the glass and screen.)

For dust, the guidelines are set by HUD, and were developed for clearance purposes only, i.e., declaring an abated residence ready for re-occupancy after lead paint abatement. They were not developed for determining the presence or absence of health hazards. In addition, readers should be cautious when comparing the national survey dust iead results to the HUD guidelines because dust samples in the survey were collected with a vacuum sampling technique and the HUD guidelines were developed for a wipe sampling technique. The comparability between the two techniques is unknown, i.e., each technique may give very different results when samples are collected side-by-side. There is evidence that wipe samples tend to result in higher lead loading then vacuum samples.

Soil concentration is reported as the mass of lead per unit mass of soil, usually expressed as micrograms of lead per gram of soil (µg/g), or the equivalent parts per million (ppm). The guidelines for soil lead used in this report (500 ppm) were derived from the EPA's *Interim Guidance on Establishing Soil Lead Cleanup Levels at Superfund Sites* and do not necessarily reflect the potential exposures to occupants near residential structures.

Although the paint, dust, and soil guidelines are not health-based, they do provide a framework to compare the relative differences among differing characteristics between homes, such as whether lead-based paint is intact or non-intact. As noted for paint lead standards, EPA is currently developing health-based lead standards for dust and soil.

2. NATIONAL ESTIMATES OF PREVALENCE

This chapter presents findings on the lead hazard in homes. Some of the estimates are revised from the estimates reported in the *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately Owned Housing: Report to Congress* (CWP Report) in light of the measurement error analyses reported in Appendix II, Chapter 3.

2.1 Major Findings and Discussion

An estimated 64 million (77 million to 81 million)[13] or 83 percent (± 9%) of private housing units in the United States built before 1980 have lead-based paint on either interior painted surfaces, exterior painted surfaces, or both, (57 million (± 5 million), or 74 percent (± 6%) was reported in the CWP Report). Approximately 782,000 (± 77,000) or 86 percent (± 8%) of pre-1980 public housing units also have lead-based paint on their surfaces. Although these numbers are vast, they do not necessarily suggest that each home is an immediate hazard to its occupants. There are many potential factors which determine the hazards posed by lead-based paint. Several are discussed below.

In addition to the lead loading levels, the condition of the paint is also a factor in determining the hazards from lead-based paint. Except during renovations, intact lead-based paint probably poses little immediate risks to occupants; however, peeling, chipping, or otherwise deteriorating paint (non-intact) may present an immediate danger to occupants. An estimated 14 million or 19 percent of pre-1980 private housing units have non-intact lead-based paint on their surfaces. This is significant not only because peeling and chipping paint may be directly ingested by children, but it is more likely to break-off and contaminate house dust and soil. Young children ingest large amounts of dust and soil every day through normal hand-to-mouth contact. Because of this normal activity, dust and soil are considered to be the most significant routes of lead exposure to children. Therefore, understanding lead pathways resulting in exposure is essential to preventing childhood lead poisoning, and was a major goal of this study.

The national survey also examined lead in house dust and in soil next to residential structures. Thirteen million or 17 percent of private housing units have interior dust lead levels above Federal guidelines. Similarly, 16 million, or 21 percent, of private housing units have soil lead levels above guidelines.

National public housing estimates for non-intact lead-based paint were not calculated from the national survey data because less than 10 homes in the survey had non-intact paint. Dust and soil lead data also are not presented for public housing because of situations encountered during the field operations; the dust lead data is suspect because a large number of vacant apartments were inspected. About 70 percent of the units sampled did not have exposed soil nearby to collect samples -- they were surrounded by pavement. With sample sizes this small, it was not possible to project national estimates.

The following sections summarize the national survey findings. Section 2.2 discusses private housing and Section 2.3 covers public housing. For a more complete and technical treatment of the results, readers are referred to Appendix II, Chapter 2 of this report.

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[13] The numbers in parentheses are 95% confidence intervals. See Appendix II, Section 3.4.3 for the methodology used to compute with the confidence intervals.

2.2 Lead Paint Hazard in Private Housing

Table 2-1 summarizes data collected and analyzed for the national survey. Among several characteristics, the data suggests that older homes are more likely to have lead-based paint than newer homes. An estimated 76 percent (± 12%) of the housing units built between 1960 and 1979 have lead-contaminated paint on their surfaces, but the percentage increases to 90 percent (± 8%) for homes built before 1960. Also, 12 million (± 1 million) of the homes determined to have lead-based paint are occupied by families with children under the age of seven. This is an important statistic because childhood lead poisoning is thought to be the most common and preventable public health concern in our country today.[14]

Figure 2-1 shows the prevalence of lead-based paint by location in private housing. In the figure, the entire circle (pie chart) represents all privately-owned houses in the United States built before 1980 (about 77 million from Table 2-1). An estimated 17 percent of these have no lead-based paint at all (the white "none" area in the pie chart), while the remainder, or 83 percent of the total, have lead-based paint somewhere on the building. As is evident from the figure, most houses with lead-based paint have it on both the interior and the exterior surfaces (53 percent).

It is evident from Figure 2-2 that older homes have considerably more dust and soil lead than newer homes. The percentage of homes over the guidelines increases from less than 10 percent for post-1960 homes to about 50 percent for pre-1940 homes. House dust characteristics are further described in Figure 2-3. Loadings below and above HUD's guidelines are presented by a bar graph in relation to the location of lead-based paint and whether it is intact or non-intact. It is important to note that the graph compares two pieces of information: the estimated number of houses containing lead-based paint relative to the total number of housing units projected, and the comparison between houses with dust lead within and exceeding guidelines (the clear bar vs. the black bar). As the bar graph shows, units with *intact* lead-based paint are less likely to exceed dust lead guidelines than units with *non-intact* lead-based paint. In fact, more than half of the homes with non-intact exterior lead-based paint are estimated to have dust lead loadings above HUD's Guidelines.

Figure 2-4 shows the same type of information for soil as Figure 2-3 presented for dust. Again, one half of the private housing units in the United States with non-intact exterior lead-based paint have soil lead concentrations above 500 ppm.

Figures 2-5 and 2-6 are pie charts that show the amounts of lead-based paint on interior and exterior private housing surfaces for different types of painted architectural components. An estimated 29 billion square feet or 12 percent of all painted interior surfaces are covered with lead-based paint and an estimated 49 billion square feet or 44 percent of all painted exterior surfaces are covered with lead-based paint. On average, each private housing unit with lead-based paint has approximately 601 square feet of the lead paint on the interior and 869 square feet on the exterior. As is evident from the figures, most of the interior paint is on the walls, ceilings, or floors.

The amounts of lead-based paint in private housing units are further displayed in Figure 2-7. The bar graph shows that older homes are covered with more square feet of lead-based paint than newer homes. Figure 2-8 is similar to Figure 2-7, however, it shows the average amount of lead per square centimeter of painted surface (more precisely, geometric mean paint lead loadings [mg/cm^2]) on houses with lead-based paint. The bar graph clearly displays older homes with more lead contamination in their paint.

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[14]CDC [1991]. *Preventing Lead Poisoning in Young Children.* U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control.

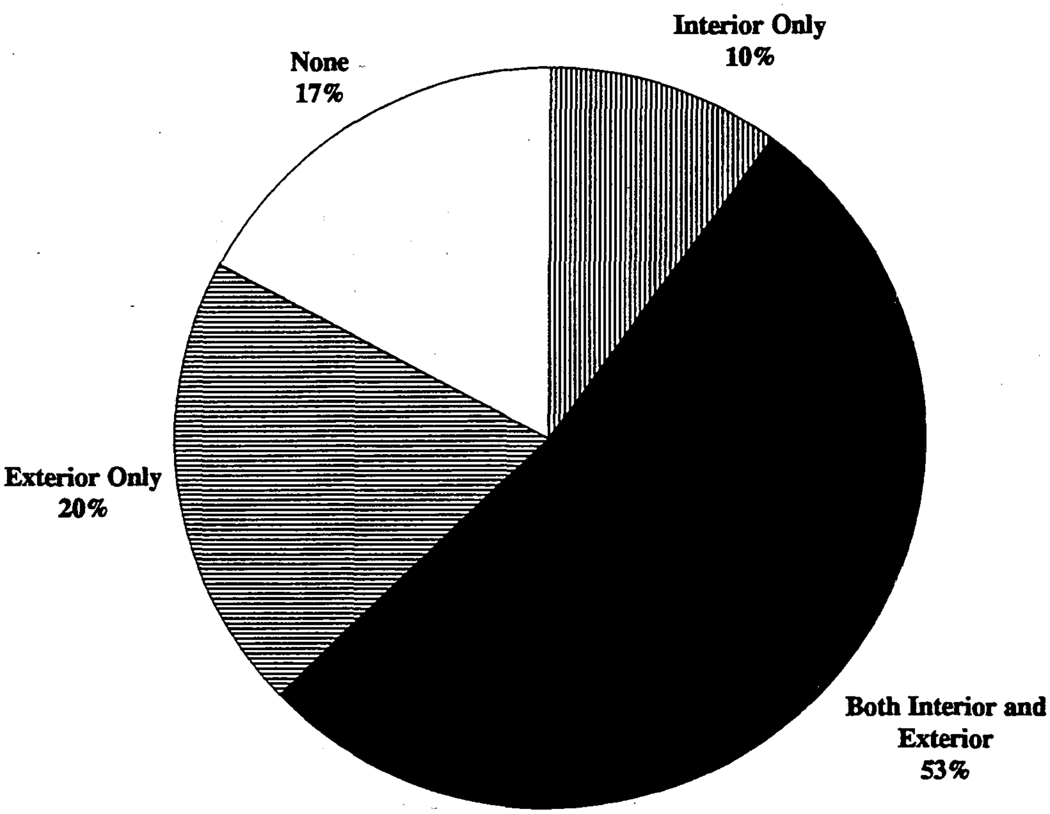
TABLE 2-1

ESTIMATED NUMBER OF PRIVATELY OWNED OCCUPIED HOUSING UNITS BUILT BEFORE 1980 WITH LEAD-BASED PAINT, BY SELECTED CHARACTERISTICS (Paint Lead Concentration > = 1.0 mg/sq cm)

Characteristic	Total Occupied Housing Units (000) (1)	Housing Units With Lead-Based Paint Somewhere in Building		Number of Housing Units in Sample (2)
		Percent	Number (000)	
Total Occupied Housing Units Built Before 1980	77,177 100%	83% (9%)	64,443 (6,946)	284
Construction Year:				
1960-1979	35,681 46%	76% (12%)	27,275 (4,282)	120
1940-1959	20,476 27%	92% (8%)	18,742 (1,638)	87
Before 1940	21,018 27%	88% (9%)	18,424 (1,892)	77
Housing Type				
Single Family	66,418 86%	85% (9%)	56,130 (5,978)	227
Multifamily	10,759 14%	77% (17%)	8,308 (1,829)	57
One or More Children Under Age 7	13,912 18%	89% (9%)	12,425 (1,252)	90
Census Region				
Northeast	16,963 22%	86% (13%)	14,605 (2,205)	53
Midwest	19,848 26%	91% (10%)	18,115 (1,985)	69
South	24,967 32%	82% (10%)	20,393 (2,497)	116
West	15,399 20%	73% (18%)	11,298 (2,772)	46
Owner-Occupied (2)	50,554	84% (9%)	42,516 (4,550)	179
Market Value of Home				
Less than $40,000	11,885 24%	92% (12%)	10,888 (1,426)	39
$40,000 to $79,999	19,401 38%	90% (10%)	17,550 (1,976)	46
$80,000 to $149,999	11,863 23%	68% (18%)	8,093 (2,135)	45
$150,000 and up	7,405 15%	85% (15%)	6,276 (1,111)	42
Renter-Occupied (2)	24,734	82% (11%)	20,329 (2,721)	105
Monthly Rent Payment				
Less than $400	16,339 66%	85% (14%)	13,811 (2,287)	59
$400 and up	8,395 34%	81% (15%)	6,822 (1,259)	40
Household Income (2)				
Less than $30,000	46,126 60%	85% (10%)	39,032 (4,613)	156
$30,000 and up	31,048 40%	81% (11%)	25,121 (3,415)	127

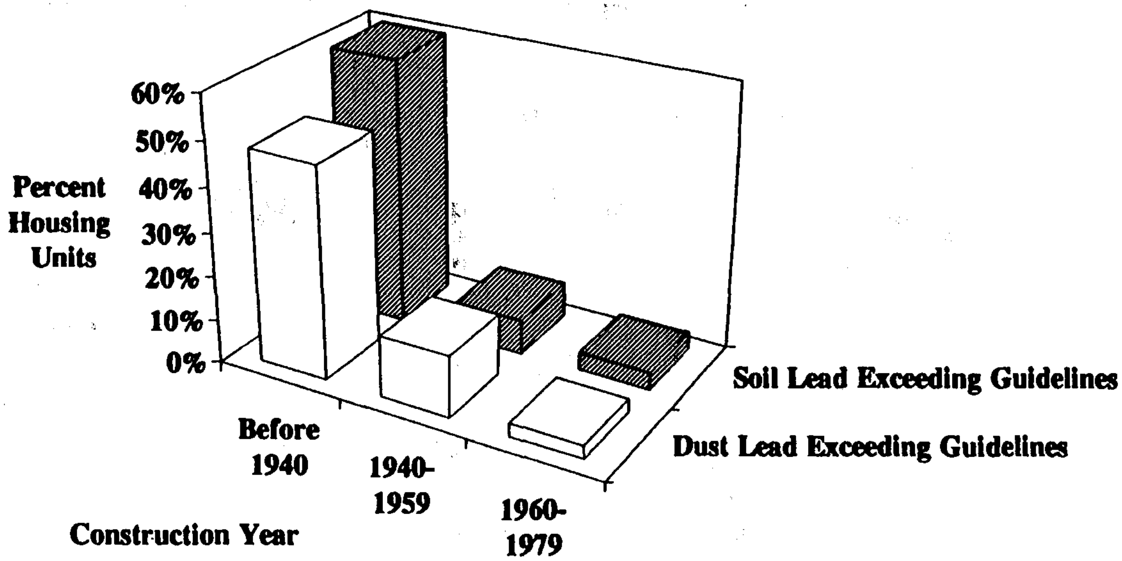
(1) Total units data are from the 1987 American Housing Survey.
(2) Some respondents did not respond to the questions on economic variables. Therefore, counts for disaggregation may not add to corresponding aggregate counts.
Note: Numbers in parentheses are approximate half-widths of 95% confidence intervals for the estimated percents and numbers. For example, the approximate 95% confidence interval for the percent of housing units with some lead-based paint is 83% + / -9% or 74% to 92%.

Figure 2-1
Prevalence of Lead-Based Paint by Location in Privately Owned Occupied Housing Units



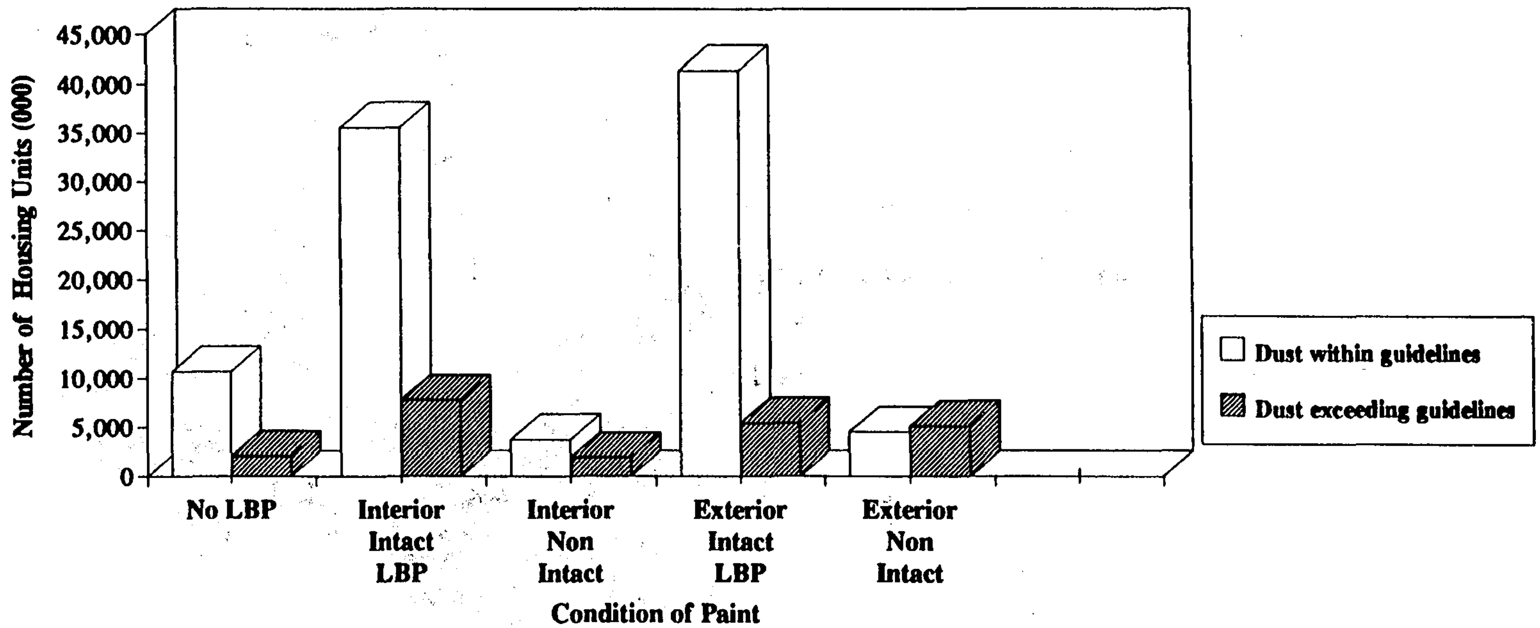
See Appendix II, Table A-1 for underlying data

Figure 2-2
Estimated Percent of Privately Owned Housing Units with Dust and Soil Lead Exceeding Guidelines by Construction Year



(1) Surface dust lead guidelines are 200 ug/sq. ft. on floors, 500 ug/sq. ft. on window sills and 800 ug/sq. ft. in window wells
(2) Soil lead guideline levels are 500 ppm.
(3) See Appendix II, Table 2-25, and Table 2-27 for underlying data

Figure 2-3
Number of Privately Owned Housing Units with Interior Dust Lead Levels Above Guidelines by Presence and Condition of Lead-Based Paint (LBP)

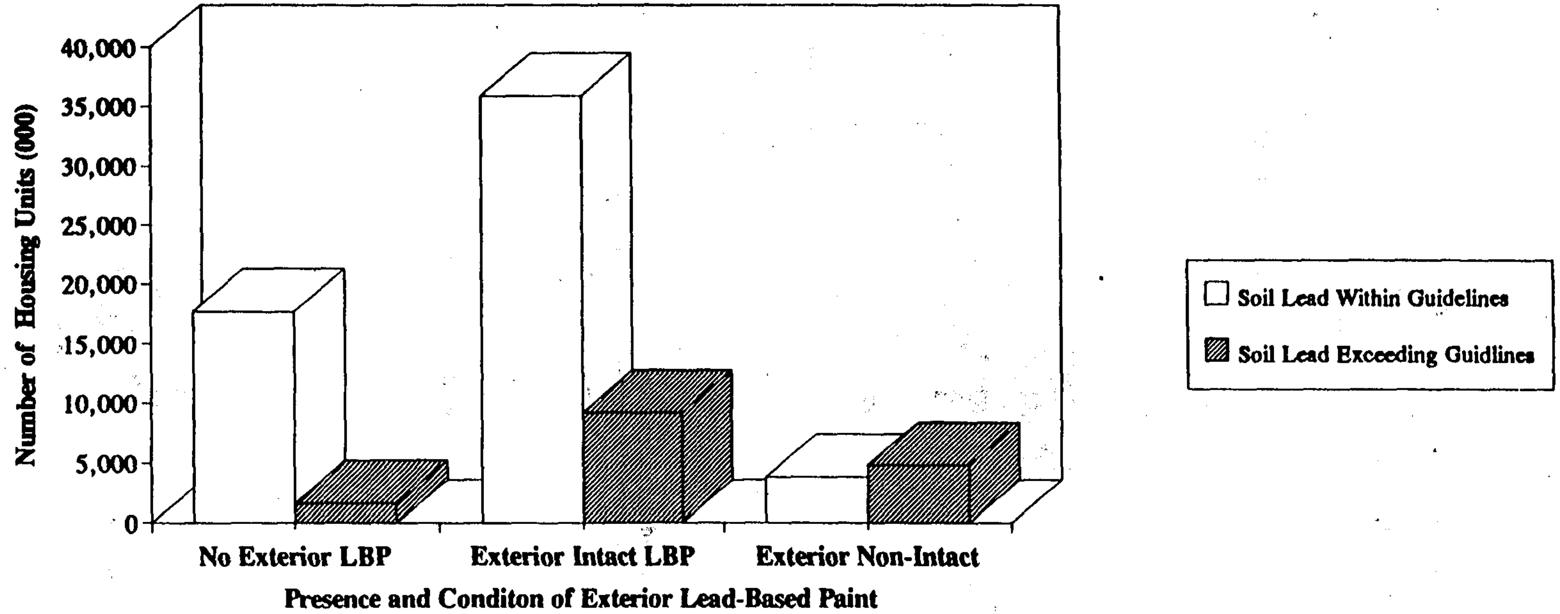


(1) "Within Guidelines" means that surface dust lead does not exceed 200 ug/sq. ft. on floors, 500 ug/sq. ft. on window sills, and 800 ug/sq. ft. in window wells. See HUD Interim Guidelines

(2) A housing unit has non-intact interior LBP if there are more than 5 sq. ft. of damaged interior LBP.

(3) See Appendix II, Table 2-6 for underlying data

Figure 2-4
Number of Privately Owned Housing Units with Lead in Soil by Presence and Condition of Exterior Lead-Based Paint

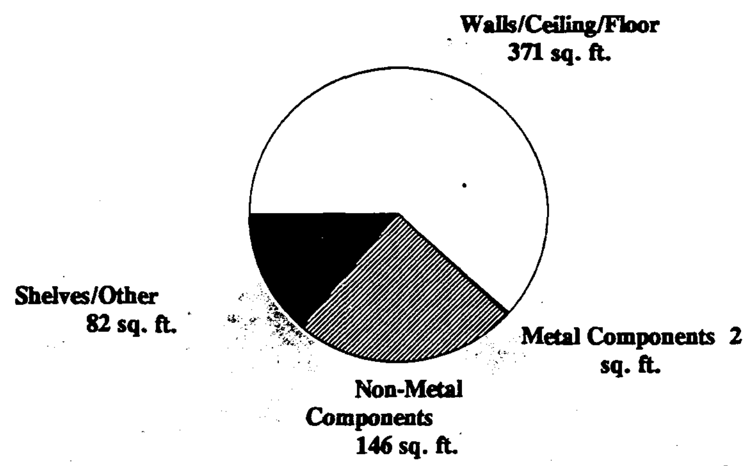


(1) "Within Guidelines" means soil lead is less than 500ppm

(2) A housing unit has non intact exterior lead based paint if there are more than 5 sq. ft. of damaged exterior LBP.

(3) See Appendix II, Table 2-7 for underlying data

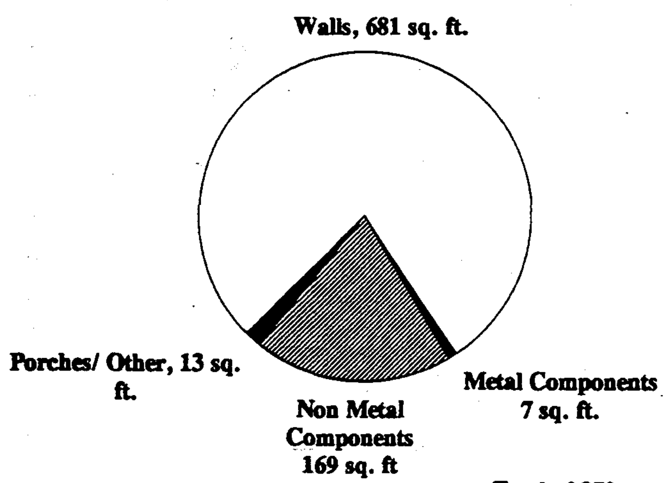
Figure 2-5
Average Amount of Lead-Based Paint (LBP) Per Housing Unit on Interior Surfaces by Painted Component for Privately Owned Housing Units
(LBP) Concentration > = 1.0 mg/sq cm)



Total of 601 square feet per housing unit, average

See Appendix II, Table 2-9 for underlying data

Figure 2-6
Average Amount of Lead-Based Paint (LBP) Per Privately Owned Housing Unit on Exterior Surfaces by Painted Component
(LBP concentrations >= 1.0 mg/sq cm)



Total of 870 square feet per housing unit, average

See Appendix II, Table 2-10 for underlying data

2.3 Lead Paint Hazard in Public Housing

Table 2-2 shows that an estimated 782,000 units, or 86 percent of the pre-1980 housing stock have lead-based paint somewhere in the unit. As with private housing, older public housing units are more likely than newer ones to have lead-based paint. In fact, nearly all (97 percent) of pre-1950 public housing has some lead-based paint.

Figure 2-9 shows the distribution of lead-based paint on public housing units. The data shows that interiors have more lead-based paint than exteriors. This is the opposite of the private housing results, where more lead-based paint was estimated to be on the exteriors of dwellings.

While most of the interior lead-based paint in public housing (like private housing) is on the walls, ceilings or floors (Figure 2-10), exteriors in public housing show a different trend. Figure 2-11 shows that most of the paint on public housing exteriors is on non-metal components, including such items as trim, window molding, doors, soffit, and fascia, (not exterior walls). This finding may reflect a majority of public housing units with unpainted brick or concrete exterior walls.

Figure 2-12 for public housing parallels Figures 2-8 for private housing. Figure 2-12 shows that age contributes to the amount of lead on the painted surfaces, similar to Private housing. Geometric mean paint lead loading levels are higher for the pre-1950 dwelling units.

TABLE 2-2

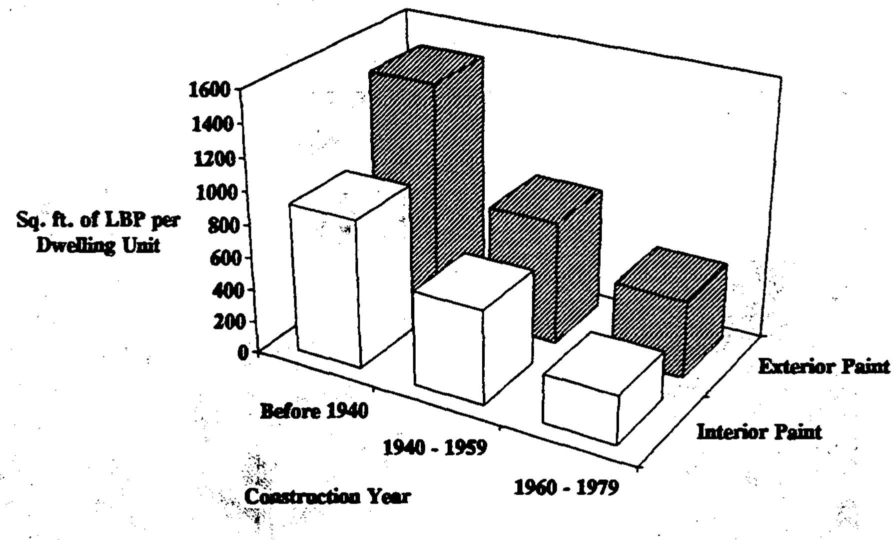
ESTIMATED NUMBER AND PERCENT OF PUBLIC HOUSING UNITS BUILT BEFORE 1980 WITH LEAD-BASED PAINT, BY SELECTED CHARACTERISTICS

(Paint Lead Concentration >= 1.0 mg/sq cm)

Characteristic		Total Public Housing Units (000)	Housing Units With Lead-Based Paint Somewhere in Building: Percent	Housing Units With Lead-Based Paint Somewhere in Building: Number (000)	Number of Housing Units in Sample
Total Public Housing Units Built Before 1980		910	86%	782	97
		100%	(78% - 94%)	(705 - 858)	
Construction Year:	1960-1979	455	79%	359	43
		50%	(66% - 92%)	(299 - 419)	
	1950-1959	273	90%	246	24
		30%	(77% - 100%)	(209 - 273)	
	Before 1950	182	97%	177	30
		20%	(88% - 100%)	(160 - 182)	

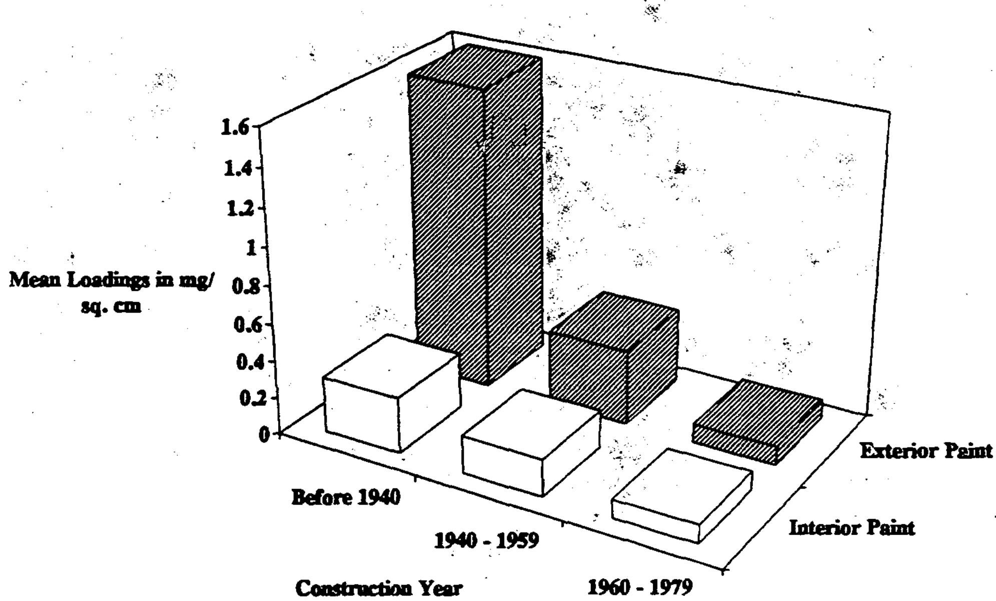
Notes: (1) Numbers in parentheses are 95% confidence intervals for the estimated percents and numbers.
(2) Categories with small sample sizes should be interpreted with caution.

Figure 2-7
Amounts of Lead-Based Paint by Location and Construction Year for Privately Owned Housing Units
(LBP Concentration >= 1.0)



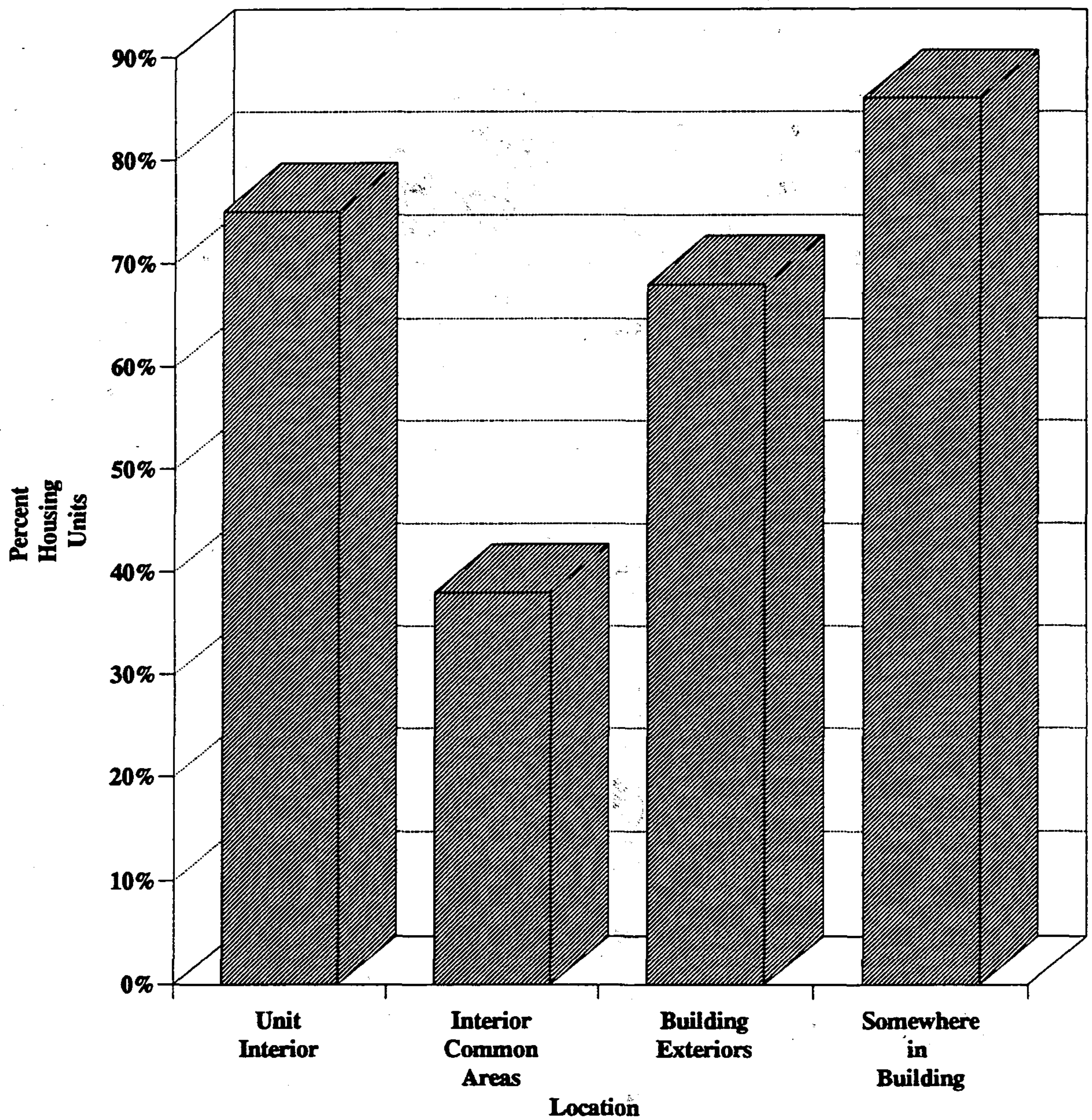
See Appendix II, Table A-6 & A-7 for underlying data

Figure 2-8
Geometric Mean Paint Lead Loadings in Privately Owned Housing Units by Location and Construction Year
(LBP Concentration >= 1.0 mg/ sq.cm)



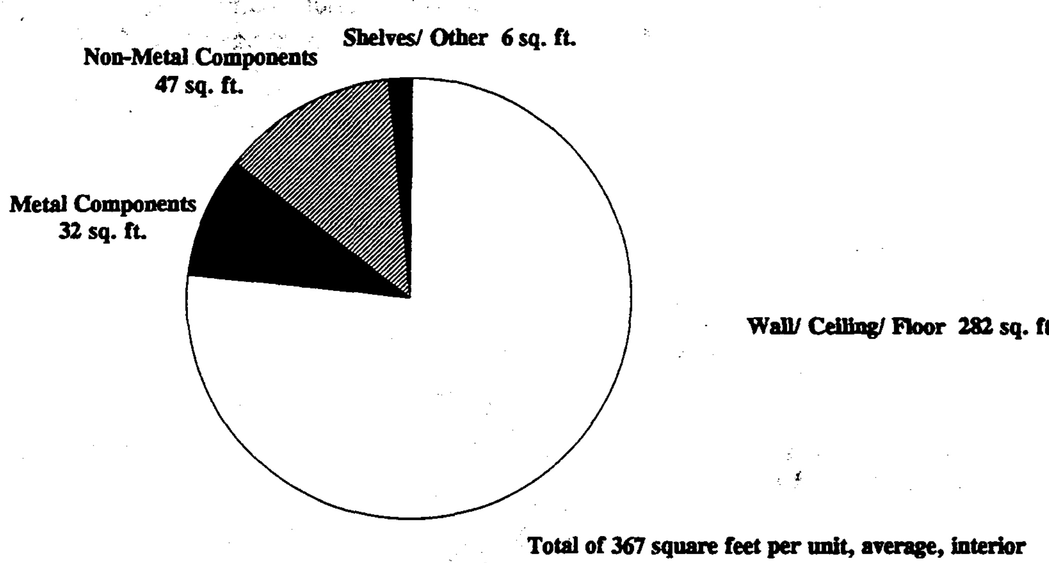
See Appendix II, Table A-8 for underlying data

Figure 2-9
Percent of Public Housing Units with Lead-Based Paint (LBP) by Location
(LBP Concentration >= 1.0 mg/ sq. cm)



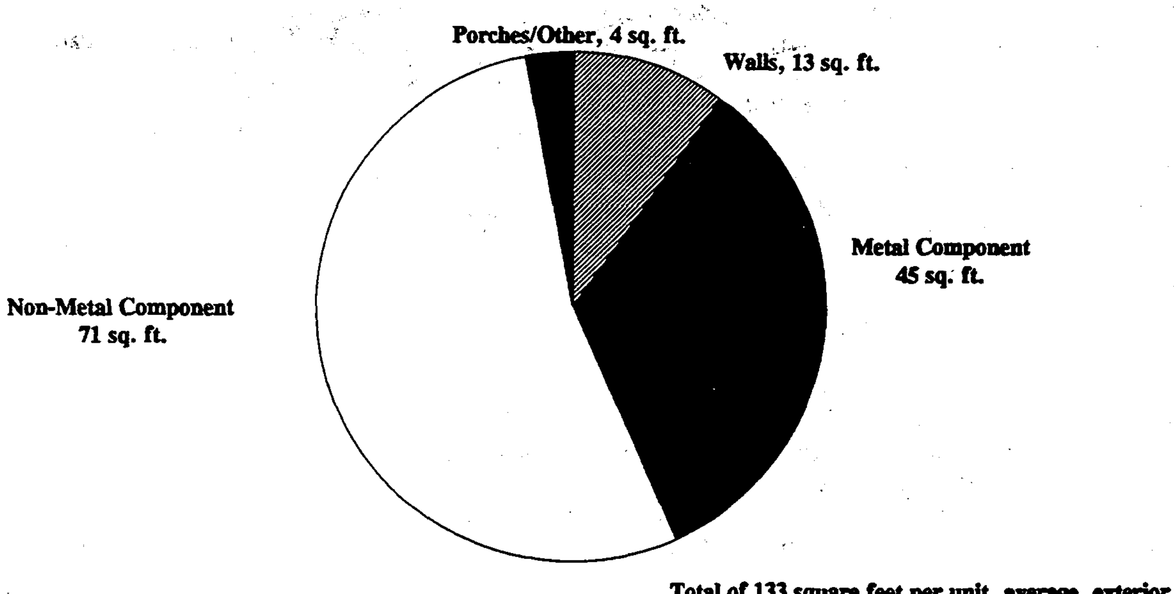
See Appendix II, Table 2-30 for underlying data

Figure 2-10
Average Amounts of Lead-Based Paint (LBP) per Public Housing Unit on Interior Surfaces by Architectural Component
(LBP Concentration >= 1.0 mg/sq cm)



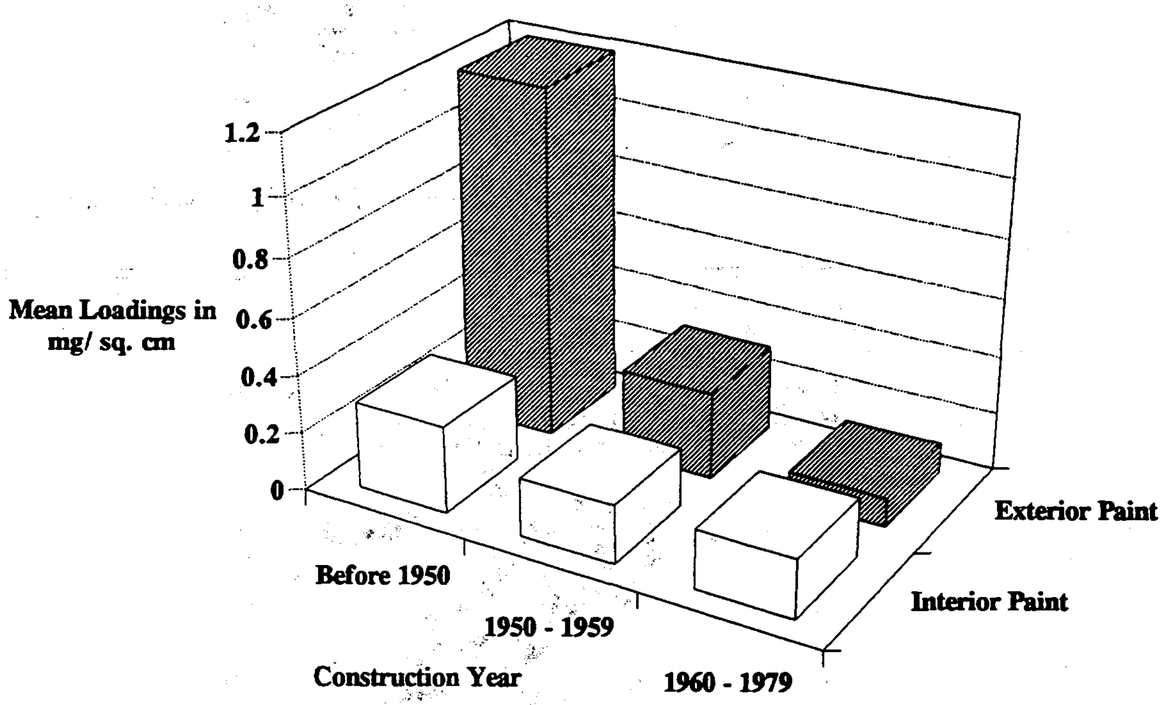
See Appendix II, Table 2-31 for underlying data

Figure 2-11
Average Amount of Lead-Based Paint (LBP) in Publicly Owned Housing Units on Exterior Surfaces by Architectural Component
(LBP concentrations >= 1.0 mg/sq. cm)



See Appendix II, Table 2-32 for underlying data

Figure 2-12
Geometric Mean Paint Lead Loadings in Publicly Owned Housing Units by Location and Construction Year
(LBP Concentration > = 1.0 mg/ sq.cm)



See Appendix II, Table B-4 for underlying data

3. RESEARCH DESIGN

This chapter presents a brief description of the research design for the national survey of lead-based paint in housing. A complete technical discussion can be found in Appendix I of this report. The study population consisted of nearly all housing in the United States constructed before 1980. Newer houses were presumed to be no detectable lead because, in 1978, the Consumer Product Safety Commission banned the sale of lead-based paint to consumers and the use of such paint in residences. Group quarters (e.g., dormitories and jails) and projects that are occupied exclusively by the elderly were excluded from the survey, because the primary public health concern was lead poisoning in children. Also excluded for operational reasons were vacation homes, homes in Alaska and Hawaii, and military housing.

The broad elements of the design included:

- A national area probability multi-stage sample survey of lead-based paint in homes, to permit statistically valid estimates of the parameters required for the development of federal policy.
- In-person visits to the sampled homes to identify, describe, and measure painted surfaces and to measure the lead content of the paint.
- Collection and laboratory analysis of dust and soil samples in and around each sampled home, to permit the statistical analysis of the associations among lead in paint, dust and soil.

3.1 Sample Design

This section presents the sample design of the national survey. Private and public housing were sampled, using somewhat different methodologies. This section covers both.

In order to optimize the Congressionally required estimates (see Chapter 1), a design stratified on dwelling unit age and type was constructed. Dwelling units were grouped into three types of housing -- privately-owned single family, multifamily, and public housing -- and three age categories. Table 3-1 displays the national distribution of pre-1980 dwelling units. The survey was conducted between December 1989 and March 1990. The final sample contained 284 privately-owned dwelling units and 97 public housing units, for a total sample size of 381 dwelling units. Table 3-2 displays the distribution of the final sample across the strata.

The sample design was the result of compromise between funding availability and the research objectives. The sample was affordable and provided the statistical accuracy needed to develop national estimates upon which government policy could be based. It provided estimates that were sufficiently precise for the comprehensive and workable plans for private and public housing. For example, 95 percent confidence intervals for estimates of the incidence of lead-based paint in private housing in any of the three periods of construction used in Table 3-1 were within plus or minus 10 percent.

The multi-stage design outlined below was chosen over other approaches because it efficiently and economically satisfied the major operational requirements of the study. The objectives and design of the study required in-person visits to the sampled dwelling units. The geographic clustering of homes allowed those visits to be conducted much more economically. Also, a survey sample requires a sampling frame, i.e., a list of all dwelling units eligible for the survey. For private housing, no such list exists nationally, or even in many localities. In light of time and cost constraints, the required number of lists was minimized

Table 3-1
National Distribution of Dwelling Units Built Before 1980

Number of Pre-1980 Dwelling Units (000)				
	Construction Year			
Type	1960-1979	1940-1959	pre-1940	Total
Privately Owned- Occupied				
Single Family	29,137	18,782	18,499	66,418
Multifamily	6,548	1,690	2,521	10,759
Sub-Total	35,685	20,472	21,020	77,177
	1960-1979	1950-1959	pre-1950	Total
All Public, Family Units	182	278	346	807
Total	35,867	20,750	21,366	77,984

Source: 1987 American Housing Survey.

Table 3-2
Distribution of Completed Inspections
By Construction Year and Dwelling Unit Type

Completed Inspection Visits				
	Construction Year			
Type	1960-1979	1940-1959	pre-1940	Total
Privately Owned- Occupied				
Single Family	94	72	61	227
Multifamily	26	15	16	57
Sub-Total	120	87	77	284
	1960-1979	1950-1959	pre-1950	Total
All Public, Family Units	30	24	43	97
Total	150	111	120	381

by using the multi-stage area probability sample for the private housing. A geographic clustering of the sampled homes was deemed to be operationally efficient and statistically acceptable. Also, tying the development of the public housing list frame to the same localities as used for the private housing extended the efficiency of the clustering of the whole survey operation.

The first stage of the sample selection consisted of selecting 30 counties – stratified by region and climate, and selected with probability proportional to the 1980 population – from approximately 3,000 counties in the United States. A survey sample requires a sampling frame, that is, a list of all dwelling units eligible for the survey. Although no such list exists for private housing, HUD maintains a list of public housing projects suitable for use as a frame. Thus, private and public housing were sampled using different within-county designs. The different ownership structures between public and private housing also required different approaches for the owners and occupants. These two approaches are summarized below.

Privately Owned Housing. A multistage area probability design was developed and employed to sample private housing and approach the occupants. A description of the design and its within-county implementation follows.

- Five census blocks were statistically selected in each of the 30 counties. To ensure that the full spectrum of income levels would be represented in the sample, a measure of wealth was computed for each census block. One census block was selected from each one-fifth of the range of this wealth measure.

- Field interviewers were sent to each of the 150 census blocks to list every dwelling unit. This process created a frame for the sampling of dwelling units. The interviewers listed 27,833 dwelling units, an average of 186 per census block.

- Samples of dwelling units were selected from the lists. A brief in-person screening interview was conducted with an adult occupant in each sampled dwelling unit to determine if the unit was eligible for the survey and, if so, which of the six age/type strata in Table 3-1 it belonged to.

- A sample of dwelling units was randomly selected from the eligible homes according to the survey design in a manner that ensured that all eligible segments were represented in the sample.

- Telephone calls were made to the sampled homes to collect basic information about the dwelling unit and the occupants and to schedule an appointment to visit the dwelling unit. An incentive of $50 was paid to each respondent who permitted a completed inspection.

Public Housing. The public housing sample was designed in a somewhat different manner than the private housing sample. All projects in the 30 sampled counties were extracted from the public housing data tape supplied by HUD. The cognizant public housing authorities (PHAs) were contacted and asked to verify and/or correct the frame data (primarily address and number of family units) for their projects. A substantial number of additions, deletions and modifications were made to the 30-county public housing frame. Projects were then sampled with probability proportional to the number of family units, and according to the construction year strata in Table 3-2. Finally, individual housing units within projects were selected with equal probability. It was necessary to work through the chain-of-command to contact the sampled projects and make appointments to inspect sampled units. The chain of command typically included the HUD regional office, the PHA headquarters, and the project manager. Public housing tenants who consented to the inspection received the same $50 incentive as private housing occupants.

3.2 Inspection Protocol

Resource limitations did not permit the complete identification, inspection, quantification, and testing of every painted surface in every inspected dwelling unit. Fortunately, the objectives of the study did not require such thorough inspections. It is possible in survey statistics to develop a good, clear picture of the aggregate population with only limited information on each sampled individual. Consequently, the limited inspection protocol described below was followed in each dwelling unit. The inspection protocol was the same for both public and private housing units.

The inspection visits were performed by a two-person team: a field interviewer who interviewed the occupant and collected and recorded the information; and a technician who performed x-ray fluorescence (XRF) testing of the lead content of the paint and collected the dust and soil samples.

Interior Rooms. The rooms were inventoried and classified into *wet* and *dry* rooms according to the presence or absence of plumbing in the room. One wet room and one dry room were randomly selected. All painted surfaces in each of these two rooms were identified and quantified; the substrate materials were identified; the condition of the paint and substrate materials were noted. Painted surfaces were grouped into four strata of architectural components: walls, ceiling, and floors; trim on metal substrates (molding, window frames, door frames, etc.); trim on nonmetal substrates; and other (built-in shelves, cabinets, etc.) Five surfaces in each room were randomly selected to be tested for lead content. One surface was selected from each of the four strata, with a fifth randomly selected from all four strata. The paint lead measurements were made with Scitec MAP-3 spectrum analyzer X-ray fluorescence devices (MAP/XRFs).

Samples of dust were collected by vacuuming in three locations in each sampled room: the floor, a window sill, and a window well. In addition, a dust sample was collected from the floor near the most-used entrance to the building. The floor is a collection sink for dust and children come into direct contact with it when crawling or playing. The windows are boundaries between the interior of the unit and exterior sources of environmental lead. Because the abrasion of opening and closing windows causes paint dust to collect on horizontal window components, the wells are collection sinks for dust. Entry ways and common heavy traffic areas are more likely to collect deposits of soil tracked in from outside the building. The dust samples were sent directly to a laboratory to be analyzed for their lead content.

Exterior. An exterior wall was randomly selected for inspection. All painted surfaces on the sampled wall were cataloged in the same manner as the interior rooms and subjected to XRF testing. Three exterior soil samples were collected: at the drip line along the sampled wall, at a remote location away from the building, and at the most-used entrance to the dwelling unit. The entry way is a proximate source of exterior soil lead that could be tracked into the interior. The drip line of a wall is the collection point for run-off from painted exterior wall; flaking paint or paint components leached by rainwater can collect in the soil. The remote location provided data on the background contribution of environmental sources of lead not associated with the unit or building itself. The soil samples were also sent to a laboratory for lead content analysis.

Because random techniques were used to sample painted surfaces, there was concern that some lead-based paint in the home might go undetected. To minimize the probability of missing lead-based paint in a home, technicians looked for and tested any painted surface in the dwelling unit deemed likely to contain lead. If the first test failed to find lead, a second surface was tested. Due to practical constraints, the technicians sometimes were limited to searching for lead-based paint in areas of the dwelling unit entered during the course of the inspection and did not wander throughout the dwelling unit looking for lead-based paint. A similar set of one or two purposive samples was taken for the exterior wall.

Common Areas. Common areas were inspected in multifamily residences. If an interior common hall existed, two dust samples were taken: one sample was taken from just outside the dwelling unit and one just inside the main entrance to the building. If the building had common rooms such as a mail room, laundry room, community room, etc., one was randomly selected and was inspected according to the protocol used for the wet and dry rooms. Finally, playgrounds were inspected. Each piece of playground equipment was quantified, described, and tested via XRF. Three soil samples were taken from the playgrounds.

3.3 Environmental Sampling Protocols

Paint Sampling. The lead-based paint testing was accomplished by MAP/XRF devices that estimated the lead content of the paint.[15] The MAP/XRF was equipped with a full-intensity 40-millicurie Co^{57} source. The protocol called for the technician to place the MAP/XRF's scanner against the sampled component, hold it stationary and flat against the surface throughout a 60-second reading, then record the reading from the MAP/XRF's console.

Selection of MAP/XRF Equipment. There were two primary rationales for choosing the MAP/XRF to test for lead in paint. The spectrum analyzer MAP/XRFs were used in preference over direct-read XRFs because the National Institute of Standards and Technology (NIST) had determined them to be more accurate and precise than the direct-reading XRFs used in earlier surveys.[16,17] The MAP/XRF was used in preference to taking paint scraping samples because the survey was conducted in occupied dwellings where it was not feasible to take scrapings for laboratory analysis.

The spectrum analyzer MAP/XRF devices still had limitations. In particular, the MAP/XRF generally produced readings that were systematically different from the amount of lead in paint being tested. The direction and magnitude of the differences were related to the substrate material and the lead loading in the paint. Furthermore, the precision of the readings depended on the substrate. On metallic substrates, the MAP/XRF's readings were systematically higher than the true lead loadings, for all observed levels of lead. On concrete, brick, and other related substrates, the MAP/XRF had great difficulty detecting low to moderate levels of lead in paint, and there was much variation in readings.

Dust Sampling. The dust collection protocol employed a portable vacuum pump fitted with a length of tubing, a filter cassette, and a collection nozzle inserted over the filter cassette. The protocol specified laying down a template that outlined an area of one square foot. The technician vacuumed the area in overlapping passes, first left to right over the entire area and then top and bottom. Care was taken to hold the nozzle level to the surface and to move the nozzle at a steady rate. Next, the template was moved over one foot and the process repeated until four square feet were vacuumed. This protocol required about four minutes. For areas which could not accommodate the template, such as window wells, the entire area was vacuumed and dimensions of the area were recorded.

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[15] Consideration was given to scraping samples of paint for laboratory analysis. Laboratory analysis is more precise and accurate than *in situ* MAP/XRF. However, it requires damaging painted surfaces in people's homes. It was felt that the gain measurement precision and accuracy would be more than offset by effects of a very large refusal rate.

[16] McKnight, Mary E.; Byrd, W. Eric; and Roberts, Willard E. (May 1990), *Measuring Lead Concentrations in Paint Using a Portable Spectrum Analyzer X-Ray Fluorescence Device* (NISTIR W90-650), U.S. Department of Commerce, National Institute of Standards and Technology.

[17] McKnight, Mary E.; Byrd, W. Eric; and Roberts, Willard E. and Lagergren, Eric S. (December 1989), *Methods for Measuring Lead Concentration in Paint Films* (NISTIR 89-4209), U.S. Department of Commerce, National Institute of Standards and Technology.

Soil Sampling. The soil sampling protocol called for the field technicians to use a soil corer with plunger to collect soil. The sample plug was expelled from the corer into a plastic bag. For each sampled location, the technician drew three soil plugs from the ground, the first as close as possible to the targeted sample site, and the other two twenty inches to either side of the first. The protocol defined the soil sample for each location as the blended composite of the three soil plugs.

3.4 Quality Assurance

Quality assurance was an integral component of the study design and execution. This section summarizes the quality assurance procedures employed in the survey.

3.4.1 Measures to Enhance Response Rates

In the national survey, as any survey, maximizing response rates is critical to minimizing bias and maintaining the representativeness of the data. Maintaining participation at the point of the home inspections was particularly important because of the investment of effort that was required to reach that point. For private housing, efforts to ensure participation began with in-person visits to homes for screening purposes. In addition to the personal contact initiated by the interviewer, a letter from HUD explaining the survey and verifying its legitimacy was left with the dwelling unit respondent.

After dwelling units were selected from among the eligible dwelling units, telephone calls were placed to the residents. The interviewers were trained to explain the survey and answer any questions or concerns the resident might have. At times convenient to the respondents, the telephone interviewer scheduled appointments for inspections to occur five to ten days after the phone call. Minimizing the delay between the call and the inspection reduced the opportunity for the respondents to reconsider their agreement to participate. The residents were informed at the time of this call that they would receive a $50 incentive for allowing the home inspection.

3.4.2 Quality Assurance for MAP/XRF Data

Extensive quality assurance (QA) procedures were developed for use of the MAP/XRF in the national survey.

Eight "standards" were developed to conduct quality assurance readings. A "standard" consisted of a small, 3" x 4" plastic sheet (i.e., *shim*) painted with paint containing a known level of lead and placed tightly on a piece of background material (called a substrate). NIST manufactured the shims used in the survey. The substrates of interest were four common dwelling unit building materials: wood, drywall, steel, and cement. All substrates used in the construction of standards had a smooth surface that allowed the shim to be tightly and evenly affixed. Two different shims were used. One shim contained 0.6 mg/cm^2 of lead, the other 2.99 mg/cm^2. The four substrates and two shims were layered in combinations to make eight test standards.

Baseline Readings. Upon receipt from the manufacturer, a quality assurance technician performed eight 60-second readings on each of the eight standards. This produced a baseline of 64 readings of different lead loadings on different substrate materials for each MAP/XRF used in the study. The testing helped establish that each MAP was ready to be used in the field.

Close-out Readings. The above procedures were repeated in full when a MAP/XRF was retired from the field, and before returning it to the manufacturer.

In-Field Readings. In a scaled-down procedure, one reading was taken on each standard for a total of eight readings every day that the MAP/XRF was in the field and in use. This practice had the additional benefit of helping detect machine drift and malfunction. Technicians were instructed to call their supervisor if readings varied from original baseline readings by over 30 percent. The procedure also helped detect if batteries had become low and needed replacement. The in-field QA readings were not used by the technicians to adjust the MAP/XRF readings in the field. Rather, the raw MAP/XRF readings were recorded. During the data analysis, the QA readings were used to develop adjusted MAP/XRF readings.

3.4.3 Field Quality Assurance Measures

Prevention of Contamination of Dwelling Units and Samples. There was concern that the inspection team might bring lead into the home. To help minimize this problem, each team member put paper slippers over his or her shoes before entering the unit. Team members wore rubber gloves during the inspection. The technician discarded the gloves after he took each dust and soil sample, replacing them with new ones. He replaced the dust sampling vacuum nozzle with a clean one after each sample. The technician also cleaned the corer after each soil sample.

Quality Assurance for Field Equipment and Supplies. Efforts were taken to ensure that the equipment or supplies themselves did not introduce lead contamination. Wet wipes used to clean soil sampling equipment were tested for lead. Shavings from the soil sampling equipment, including the painted handle, were tested. Particular caution was observed in testing supplies that technicians were expected to purchase while in the field. Several brands of plastic bags and wet wipes were tested to ensure that commonly available brands would not introduce any lead contamination.

3.5 Limitations of the Study Design

This research design reflects an explicit boundary of the survey. All audiences of the national survey results should be aware it was never the survey's objective for the testing of sampled paint surfaces within homes to be sufficient to prove or disprove if any specific home had a lead hazard, or the potential for such. The data collection was designed to provide the supporting basis for national estimates, not to determine definitively whether a particular house had lead-based paint present.

The statistical sample was specifically designed to permit the development of valid national prevalence estimates, even with limited data on any particular dwelling. Given the ratio of sampled surfaces to the total number of painted surfaces in a home, it is readily conceivable that lead-based paint could be present in a given home but not detected as part of a statistically based sampling procedure. Conversely, the testing protocol could have produced a very high lead reading where there was, in fact, no current hazard (e.g., lead-based paint was present, but was totally enclosed or covered with epoxy or acrylic).

Extensive lead testing designed to say with certainty whether a lead hazard existed in each unit was beyond the scope of the survey and would have substantially increased costs and effort levels. The increased time spent in each unit may have reduced the overall response rate, with a resulting decrease in the quality of the overall data, rather than the increased quality that might be expected from such increased effort.

4. SOURCES OF ERROR IN THE NATIONAL SURVEY DATA

In order to assess the utility of the national survey data for lead research and policy development, an evaluation of the quality of the data is needed. Data quality is determined by the processes and procedures that generated the data including sample design and selection, response rates, field and laboratory measurements.

One primary objective of the national survey was to estimate the nationwide percentage of dwelling units with lead-based paint. A dwelling unit is classified as having lead-based paint if any surface within the dwelling unit has an average paint lead concentration greater than 1.0 mg/sq cm. The determination of whether the average paint lead concentration across a surface was greater than 1.0 mg/sq cm was subject to two sources of error: systematic differences between the MAP/XRF readings and the actual paint lead concentrations; and misclassifications of surfaces due to random variability in the MAP/XRF readings. The classification of a dwelling unit as having lead-based paint was subject to several additional error sources, including: sampling error due to the random sampling of housing units; systematic differences between the study respondents and non-respondents; sampling error due to the random selection of rooms and painted components within rooms for the MAP/XRF measurements; and misclassifications of dwelling units due to the incomplete sampling of rooms. Failure to take these sources of error into account in the data analysis can produce biased prevalence estimates and overestimates of the precision in the estimates.

The difference between an MAP/XRF measurement and the actual lead concentration on the surface being measured is called *measurement error*. The presence of measurement error does not mean that the measurement was incorrectly made, but only that there was a non-zero difference (usually assumed to be random) between the MAP/XRF measurement and the actual concentration. If the average of the measurement errors is zero then the measurements are said to be *unbiased* and individual measurements were sometimes higher and sometimes lower than the actual lead concentrations. If the average of the measurement errors is other than zero, the measurements are said to be *biased*.

This chapter presents a brief discussion of these issues. Both sampling issues and MAP/XRF measurement errors are included. A detailed discussion is presented in Appendix II, Chapter 3.

4.1 Response Rates and Potential for Non-Response Bias

An analysis of response rates was conducted to estimate the potential impact of national survey nonresponse on the estimated prevalence of lead-based paint in housing. The analysis looked at the relationship between response rates and factors such as geographic location, ethnicity, and economic characteristics (e.g., rent, home value, and income) that could potentially influence response rates. In addition, the analysis studied the association between inspected housing units in the same or nearby census blocks with respect to the presence or absence of lead in paint, dust, and soil.

4.1.1 Private Housing

Table 4-1 displays contact, response, and eligibility rates at the national level. The eligibility rate applies only to the screener stage, when in-person interviews were conducted to screen homes for eligibility in the survey. Contact rates were calculated for both the screener and telephone interview stages (when respondents were asked to permit an inspection of their home), whereas response rates were calculated for all stages. The definition of a *completed case* in Table 4-1 varies with the stage of data collection. A case was considered completed at the screener stage if an interview was completed, whether or not the respondent was eligible. The screener response rate thus measures the rate at which a screening interview reaches its logical conclusion (eligible or ineligible), and did not terminate due to other causes (refusals, etc.). At the telephone interview stage, only eligible respondents who completed interviews and scheduled appointments were considered completes. Finally, a case was considered complete at the inspection stage if an inspection was completed.

Table 4-1

National Response, Contact, And Eligibility Rates At Each Data Collection Stage

Data Collection Stage	Contact Rate	Response Rate	Eligibility Rate
Screener	77%	63%	89%
Telephone Interview	83%	55%	–
Inspection	–	90%	–

Notes:

- The Contact Rate is the number of contacted households divided by the in-scope number attempted.
- The screener Eligibility Rate is the number of eligible cases divided by the number of completed screening interviews.
- The Response Rate is the number of completed cases divided by the in-scope number completed.

The ethnic and economic distributions of housing units in the national survey were compared to the corresponding distributions in the 1987 American Housing Survey performed by the Census Bureau and HUD. No significant differences were formed with respect to ethnicity, building age or family income. There were a few instances of significant differences: The national survey had fewer very low rent (< $200 per month) homes than expected, fewer high market value homes (> $150,000) than expected and more homes in the South than expected. There is a strong positive association between inspected housing units in the same census block with respect to the presence or absence of lead in paint, dust, and soil. That is, if one house in a census block has lead-based paint, other houses in the same census block are also likely to have it. These findings suggest that the potential bias from nonresponding housing units is likely to be small. Therefore, the estimates of lead-based paint prevalence were not modified to adjust for non-response.

4.1.2 Public Housing

For the public housing component of the national survey, a sample of 110 projects from a national frame of public housing projects was drawn according to the design described in Chapter 3. The survey was completed in 97 of the sampled projects, indicating negligible potential for non-response bias in the sample of public housing projects.

However, analysis of the sampling of housing units within the public housing projects showed that there was an apparent over-representation of vacant housing units. The public housing survey design called for randomly selecting one housing unit from each sampled project. This design was difficult to implement in the field because a number of the public housing project managers apparently felt it was more convenient to permit the field team to sample vacant housing units. Consequently, there were 44 vacant public housing units in the sample of 97 units. Although a comparison of the prevalence of lead in paint between vacant and occupied housing units showed no significant differences, the impact on other target parameters is unknown. For example, it would be difficult to estimate the percentage of public housing units with lead-based paint and children under age seven because so many vacant apartments made up the sample. Furthermore, dust samples collected in vacant apartments probably do not represent samples collected in occupied apartments. Because the public housing sample sizes were small and the occupied housing unit sizes were even smaller, definitive conclusions resulting in national estimates of dust lead levels are not possible.

4.2 MAP/XRF Measurement Bias

As described in Chapter 3, to assure a continual check of the accuracy and performance of the MAP/XRF analyzers during the national survey, daily validation measurements were made. Statistical analyses were performed on the validation data to estimate the precision and accuracy of the MAP/XRF's readings, and to relate them to the substrate, concentration level, and age of the Co^{57} source. Equations were developed to relate the lead concentrations on the substrates to the MAP/XRF readings. A different equation was developed for each combination of machine and substrate. These equations were inverted to generate equations to statistically calibrate the MAP/XRF readings.

This analysis of the validation data led to the conclusion that the MAP/XRF devices used in the National Survey generally produced readings that were systematically different from the actual amount of lead in the paint. The direction and magnitude of the systematic differences were related to the substrate material, the lead concentration in the paint, and, to a lesser extent, the age of the Co^{57} source. The exact nature of the relationships varied from one individual MAP/XRF to another, sometimes significantly. Furthermore, the precision of the readings depended on the substrate. Specifically, the MAP/XRF tended to under-estimate low levels of lead in paint on wood, drywall, and plaster and over-estimate high levels of lead. Also, the MAP/XRF's readings were systematically greater than the true lead loadings on steel and other metallic substrates and it had great difficulty detecting low or moderate levels of lead in paint on concrete, brick, and other related substrates.

Censoring of the MAP/XRF Readings

Although the cause of biased readings can come from several factors, an important factor in this study is *censoring*. The MAP/XRF instruments used in the national survey were designed to never report a reading below zero even though readings below zero were otherwise possible. These MAP/XRF readings, which would have been below zero but which were recorded as zero, are referred to as *censored* MAP/XRF readings and contribute to bias. In the survey, censoring affected primarily the low readings on concrete substrates. Since this group of readings comprised only a small proportion of all MAP/XRF readings, the effect of censoring on the national estimates is not significant.

4.3 Classification Error Due to MAP/XRF Measurement Variation

Random variation in the MAP/XRF measurements can lead to incorrect classification of a surface as having or not having lead-based paint. The MAP/XRF measurement on a surface with paint lead concentration less than 1.0 mg/sq cm may be greater than 1.0, or vice versa, resulting in a misclassification. If the number of surfaces which are misclassified as having lead based paint is different than the number of surfaces misclassified as *not* having lead based paint, the estimated percentage of surfaces in a dwelling unit with lead-based paint will be biased. This is called *classification bias*. Note that classification biases can exist even when the MAP/XRF measurements are unbiased. Estimates of the percentage of surfaces within a dwelling unit with lead-based paint can be either low or high by as much as eight percent. Estimates of the proportion of surfaces nationally which have lead-based paint will have less than one percent bias.

4.4 Classification Error Due to Dwelling Unit Sampling Procedures

Within each dwelling unit, MAP/XRF measurements were made on randomly selected surfaces within one randomly selected wet room and one randomly selected dry room. However, the classification of a dwelling unit as having lead-based paint depends on the lead concentration on all surfaces within a dwelling unit. Using only the MAP/XRF measurements on the measured surfaces, a dwelling unit might be misclassified as not having lead-based paint when it actually did, because the surfaces with lead-based paint were not among those selected for measurement.

To help accurately predict the prevalence of housing units with lead-based paint and thus, estimate the misclassification rate, it was necessary to develop a mathematical simulation model based on data from the survey and other sources. The model was used to statistically remove the classification biases induced by incomplete sampling of rooms and surfaces within a dwelling unit and by measurement variation. Extending the results from the measured surfaces to all surfaces in the unit was based on: data on the number of rooms in the unit; data on the number of surfaces per room; and assumptions about the relationship of the lead concentrations on unmeasured surfaces to those on the sampled and measured surfaces. The classification of dwelling units as having or not having lead-based paint can be biased downward by 10 to 25 percentage points when only a few surfaces within the dwelling unit are measured.

4.5 Impact on the National Estimates of Prevalence

All statistical findings on the lead hazard in homes reported elsewhere in this report incorporate the results of the analyses of this chapter. That is, the raw MAP/XRF readings have been corrected for measurement bias and censoring, and the misclassifications due to measurement variation and sampling within dwelling units have been corrected. Chapter 2 presents the national estimate (83 percent) of prevalence of lead-based paint in privately-owned housing. Without the corrections of this chapter, the estimate would have been 74 percent.

5. CONCLUSIONS

5.1 Major Conclusions

This section presents a brief discussion of the major conclusions to be derived from the experience of the national survey.

5.1.1 Study Findings

Lead-based paint is widespread in housing. An estimated 64 million (± 7 million) homes, 83 percent (± 9%) of the privately owned housing units built before 1980, have lead-based paint somewhere in the building. Twelve million (± 1 million) of these homes are occupied by families with children under the age of seven years old. An estimated 49 million privately owned homes have lead-based paint in their interiors. There are no significant differences in the prevalence of lead-based paint by type of housing, market value of the home, amount of rent payment, household income, or geographic region.

Thirteen million homes - 17 percent of the pre-1980 stock - have dust lead levels in excess of the federal guidelines, regardless of whether or not they have lead-based paint. However, excessive dust lead levels are associated with the presence of damaged lead-based paint. Fourteen million homes, 19 percent of the pre-1980 housing stock, have more than five square feet of damaged lead-based paint. Nearly half of them (47 percent) have excessive dust lead levels.

Although a large majority of pre-1980 homes have lead-based paint, most of them have relatively small areas of surfaces covered with it. The average privately-owned housing unit with lead-based paint has an estimated 601 square feet of it on interior surfaces and 869 square feet (per unit) on exterior surfaces. Over half of the leaded paint is on walls, ceilings, and floors. The amounts of lead-based paint per housing unit vary with the age of the dwelling unit. Pre-1940 units have, on average, about three times as much lead-based paint as units built between 1960 and 1979.

Lead paint is even more widespread in public housing; 86 percent (± 8%) of all pre-1980 public housing family units have lead-based paint somewhere in the building. While most public housing units have some lead-based paint, most of them have small amounts of it. The average public housing unit with lead-based paint has an estimated 367 square feet on interior surfaces and 133 square feet (per unit) on exterior surfaces. Most of the interior lead-based paint is on walls, while very little of the exterior walls are painted.

5.1.2 Impact of Measurement Error and Lead Loading Variation on the Data Analysis

The data analyses and reports of findings should incorporate instrument and laboratory measurement error. The MAP/XRF instrument produced readings with measurement errors. They were systematically different from the actual lead concentrations in the painted surfaces and had random variation. Similarly, the laboratory protocols used to measure the lead in dust and soil had measurement errors. These measurement errors can induce systematic errors in the estimated extent of the lead hazard from paint, dust and soil, and can also result in underestimates of the uncertainty in the estimated hazard. Therefore, the field procedures must provide for the collection of the QA data necessary to estimate the measurement errors and their impact on the study findings. Further, the data analyses must explicitly estimate and correct for the impact of the measurement errors.

The data analyses and reports of findings should take account of the inherent variation in the painted surfaces. In the national survey, it was not possible to test for the lead content of every painted surface in every sampled housing unit. Consequently, surfaces were sampled. This sampling protocol was designed to control the project costs and respondent burden by controlling the amount of time required for an inspection. However, it did not adequately provide for the estimation of variation in lead concentrations within surfaces, between surfaces in the same room, and between rooms. These sources of variation need to be addressed to produce accurate estimates of the uncertainty in the national estimates. It is therefore recommended that multiple MAP/XRF readings be taken at randomly selected locations on a subset of the selected surfaces; at two or more components of the same type in the same room; and in two wet rooms and two dry rooms. Although it may not be feasible to do this in all homes, a subset should be selected for these additional readings.

5.1.3 Use of the Spectrum Analyzer MAP/XRF

In contrast to the HUD Interim Guidelines, substrate correction was a necessary step in the accurate determination of the presence and amount of lead-based paint on surfaces, when using the MAP/XRF. As discussed in Chapter 4, in the national survey, the MAP/XRF generally produced readings that were systematically different from the amount of lead in the paint being tested. Consequently, substrate corrections are needed to obtain accurate measurements of lead loadings. There are two possible ways to do this:

1. Take frequent validation readings and analytically correct the readings using methods as described in Appendix II. Readings need to be done on three or more different shims, however, not just two shims as in the national survey. With only two shims, only a linear model can be used to correct the MAP/XRF readings. It is possible, however, that a non-linear model better describes the relationship between the readings and the actual lead concentrations in the painted surfaces.

2. Perform substrate corrections in the field. The HUD Interim Guidelines describe substrate correction procedures appropriate for direct reading MAP/XRFs, not the spectrum analyzer MAP/XRF.

5.2 Additional Conclusions and Recommendations

The main purpose of this section is to identify selected lessons learned during the conduct of the national survey and to develop recommendations for future field operations. The objective of the following recommendations is to improve the representativeness and statistical validity of the data, e.g., develop methods to enhance respondent participation. Additional recommendations are presented in Appendix II, Chapter 4.

Applicability of Recommendations

The national survey operated under constraints that are not typical of other lead-based paint studies. Therefore, some of the following recommendations would not be appropriate under other research designs. For example, most lead studies are conducted in a single locality, alleviating the problems associated with moving teams and equipment around the nation under a tight schedule. The units in the national survey were randomly selected from the national population of dwelling units; most other studies limit themselves to a smaller, targeted population of units which have some underlying rationale for being included, e.g., they were FHA-mortgaged properties or they were in a targeted area of an inner city. A rationale for each recommendation is provided and the reader must use his or her judgment in determining if the recommendation is appropriate for another design.

All listing and screening should be completed before beginning unit inspections. Completion of listing and screening before beginning unit inspections means that the full sample frame can be developed before sampling is begun. Because of the tight field schedule of the national survey, it was necessary to begin inspections before listing and screening were completed in some counties. Although it was possible to take samples from completed counties based on estimates of the final national distribution of eligible housing, it was necessary after screening was totally completed to adjust the final sample to the actual distribution. There were two ways to accomplish this: retroactively adjust the sample in the counties which had been previously sampled; or sample the remaining counties to balance the sample to the national distribution. Although the former approach yields a better sample statistically, it would have created costs that were deemed to outweigh the gain in statistical power. The survey adopted the second course, adjusting the sample in the counties that had not yet been sampled.

When dealing with PHAs, interviewers should closely coordinate with the PHA representative. Coordination with the PHA management staff is imperative to effective sampling and inspection of public housing. To ensure that all responsible and affected parties are involved in the process, it is advisable to establish a liaison with both a PHA headquarters representative and the manager of the specific housing project. Often teams met the PHA representative at the PHA office and then went to the site. The PHA staff "smoothed" the way many times. In neighborhoods where the inspection teams felt unsafe, PHA staff provided a vital service as escorts. Because the PHA staff are busy, every effort must be made to accommodate their involvement. For example, PHA offices often are not located close to the dwelling unit. Inspection teams should schedule their time to allow them to meet the PHA staff at the PHA office and go from there to the dwelling unit. The PHA representatives typically tried to inspect as many units on each trip as possible. This consideration, combined with frequent unexpected delays, suggests that the inspection team should not schedule other inspections too soon after the PHA work, to avoid schedule conflicts. Upon meeting a PHA representative in the field, the inspection team should not assume that he or she has been fully briefed on the study or the team's mission. The interviewer needs to go over the objectives and procedures of the survey and the importance of the PHA dwelling unit inspections.

For public housing dwelling unit sampling, several additional weeks should be allowed for dwelling unit sample selection in large PHAs. The larger the PHA, the longer time it took to select the dwelling units. The reasons varied, e.g., the contact was on vacation, there was difficulty finding the contact, the contact needed authorization, etc. Without exception, selection of PHA dwelling units in the five largest PHAs in the sample took several weeks longer than it did for the 25 other PHAs.

Field staff should be trained to respond to anyone's questions concerning what they are doing and what the study is about. Do not attempt to use local police or similar agencies, or the regional HUD office, to substantiate or verify presence or activities. In the national survey each field person carried an ID badge, copies of the license that allowed him to handle the MAP/XRF and its radioactive source, endorsement/introductory letters from survey and agency principals, the 800 number for the survey coordinator, and a number for the Washington HUD representative. Field staff were questioned on several occasions by police officers, building managers, or nearby residents. The documentation materials listed above explained and substantiated the activities of the inspection team and proved invaluable. Although it seems like a good idea, contacting local police in advance and then referring questioners to the police can lead to a bigger problem; i.e., the police contacts inadvertently denying knowledge of the survey. If the person who gets the call at the police station has not been apprised of the study, he or she will deny knowing anything about it, even though the police department has been informed of the activities. There is also a problem with overlapping jurisdictions. The study might notify the county sheriff, although the inquiry comes into the state police.

The analytic model concerning dust analysis and pathways needs to be fully specified before an adequate dust sampling protocol can be designed. Dust sampling and test result analysis are the subject of continuing investigations. Insufficient dust was a recurring problem in the field. Outside of insufficient dust, there were few field problems encountered with dust sampling. A traveling team operates under two major constraints – it must carry its own equipment and it must limit its time in the dwelling unit to a reasonable length. Getting more dust by using a bigger, more powerful vacuum or vacuuming a larger area were limited options. The vacuum carried by the survey team weighed ten pounds, plus tubing, nozzles, and extension cords. The survey found that it took four minutes to completely collect a dust sample (vacuuming and re-vacuuming a 4-square-foot area as specified in the dust sampling protocol). A bigger vacuum or more time spent vacuuming were not reasonable in the context of the national survey. At one point in the procedure design stage it was suggested that in-field technicians evaluate the quantity of dust collected in a cassette. They would collect more dust in the cassette if they determined there was insufficient dust. This suggestion proved to be impractical. First, inspectors could not reliably determine by visual inspection if enough dust had been collected. Second, movement of the cassette while attached to the vacuum could cause dust to fall out of the cassette. Third, allowing the technician individual discretion to collect samples would lead to inconsistencies in the procedure and findings. Last, the amount of time spent vacuuming had to be limited to keep the visit to a reasonable length. Therefore, this suggestion was not implemented in the survey. A final suggested approach to increasing dust sample yield was "wet wipe" testing, used in conjunction with or following vacuuming, to pick up leftover dust. This technique would not have improved effective yield, because wet wipe test results could not be compared or added in any meaningful way to vacuumed dust sampling results. Static electricity posed a problem to the inspection team. Dust would cling to the vacuum nozzle, the edges of the template, etc. Efforts were made to build the template out of a material that did not accumulate static electricity but the phenomenon still occurred.

The MAP/XRF reading can be taken at any convenient place on a sampled architectural component; valid sampling does not require readings of a randomly selected spot on the component. This eliminates readings being taken in hard-to-reach locations, such as corners. The original design called for sampling a random location on the surface of a component for testing. Though this is subject to further verification, it appears that components with common paint history produced similar MAP/XRF readings. Another stage of sampling would significantly burden the inspection process. Correct assessment of "common paint history" is more pivotal here.

All MAP/XRF readings should be recorded on paper by the inspector. The MAP/XRF used in the national survey was programmed to store the spectrum results in memory. Serious problems were encountered, though, when the memory was in use. The memory would fill up rapidly and the MAP/XRF would stop operating. The equipment had to be turned off, and then back on, in order to restore operation. All memory was lost in the process. The need to link readings to a location necessitated recording of a certain amount of data on paper in any event, so that recording MAP/XRF readings on paper involved little extra effort. The equipment problem aside, using the MAP/XRF's on-board electronic storage necessitates some procedures for downloading memory contents during the field period. In practice it did not prove reasonable or practical to return the MAP/XRF to the survey operations office periodically for downloading. Teaching field staff how to download the memory and transmit it to the field operations office would have meant providing them with a properly-configured PC and modem in the field and providing PC training. Adding responsibilities and equipment to the technicians' load was deemed inadvisable.