# Executive Summary

## Purpose

The 1987 amendments to the Lead-Based Paint Poisoning Prevention Act required the Department of Housing and Urban Development (HUD) to prepare and transmit to Congress "an estimate of the amount, characteristics and regional distribution of housing in the United States that contains lead-based paint hazards." In response to this mandate, HUD sponsored a national survey of lead-based paint in housing. HUD's *Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately-Owned Housing: A Report to Congress* and EPA's *Report On The National Survey Of Lead-Based Paint In Housing* documents the survey and presents considerable data on the extent and characteristics of the lead paint hazard in homes. The purpose of this study is to supplement the prior reports through additional data analyses focusing on the contribution of lead in exterior soil to the lead hazard in homes.

The specific objectives of this study are two-fold: First, to conduct analyses of the statistical associations among the soil, dust, and paint data from the national survey. Many researchers believe that lead contamination in soil originates mainly from paint lead and automobile emissions. Similarly, interior dust lead is believed to come principally from paint lead and soil lead. The objective is to explore these hypotheses through a statistical analyses of the national survey data. Second, to present an analytical description of the soil and dust data, including sampling and measurement errors in the data, in order to evaluate the suitability of the soil and dust data for future data analyses.

The statistical analyses reported here focus on techniques that identify the variables that "best predict" soil lead and dust lead levels. It is to be noted that a strong statistical association among these variables does not, by itself, prove that one variable represents a source of the lead measured by another, e.g., that exterior soil lead is a source of interior dust lead. Both soil and dust lead contamination levels may be caused by a third source of lead such as paint lead, or automobile emissions.

## National Survey Methodology

The study population for the national survey consisted of nearly all housing units in the United States built before 1980. (Newer homes were excluded because the Consumer Product Safety Commission banned the use of lead-based paint in residences in 1978.) The national survey was conducted in 381 housing units, 284 privately-owned and 97 public housing units, selected to represent the entire pre-1980 United States housing stock. This report focuses on the soil and dust data from privately owned housing.

In each sampled housing unit, one room with plumbing ("wet") and one room without plumbing ("dry") were randomly selected for inspection. Painted surfaces were inventoried and measured, and their conditions assessed. An exterior wall was similarly selected and inspected. Paint lead measurements were obtained *in situ* on interior and exterior surfaces using portable X-ray fluorescence (XRF) spectrum analyzers. The analyzers measured area concentrations, described as milligrams of lead per square centimeter of painted surface ($mg/cm^2$).

Soil samples were collected at three exterior locations on the property of each dwelling: (1) a *drip-line* sample near an exterior wall of the dwelling, potentially contaminated with deteriorated lead-based paint; (2) an *entrance* sample collected near the most commonly used entrance, to measure the potential associations with track-in lead; and (3) a *remote* sample, intended to measure background lead from sources other than lead-based paint.

Dust samples were collected with a vacuum sampler at seven interior locations within each home: from floors, window wells (the place at the bottom of the window where the sash rests when it is closed), and window sills (the part inside the room) in the sampled wet and dry rooms; and from the floor just inside the main entrance to the housing unit. Lead loading levels (area concentrations) were determined--micrograms of lead per square foot of surface (ug/ft $^2$), along with mass concentrations of dust lead in ppm.

Soil and dust samples were sent to laboratories and analyzed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) and by graphite furnace atomic absorption (GFAA) spectroscopy, respectively.

### Sources of Soil Lead

Equations were developed to statistically relate the soil lead levels to a number of potential sources of soil lead and related factors, including exterior and interior paint lead loadings, percentage of damaged paint, and surface areas covered with paint; dwelling unit age and other descriptors of the housing unit; number of rooms, local traffic volumes, county of residence, and 1920-1990 decennial Census populations. Combined, these potential sources of soil lead account for over 50 percent of the statistical variation in the lead in soil data.

The most significant predictors of soil lead concentrations at all three soil sample locations are dwelling unit age and county of residence. Soil lead concentrations increase with dwelling unit age. Dwelling unit age measures the length of time since the construction of the building and, in most cases, the last major disturbance of the soil. Thus, dwelling unit age measures the length of time lead deposits -- from whatever source -- have been accumulating on the soil. The county of residence effect may be due to many factors including regional variations in population density, population growth, background soil lead levels, traffic, and home building and painting practices. Local traffic volumes are significantly related to soil lead at the remote and drip line locations.

The soil lead concentrations at all three sampling locations were closely related to the overall dwelling unit paint lead loadings (represented by the geometric mean of the paint lead loadings on the wet room, dry room, and exterior surfaces). The results suggest that paint lead from dwelling surfaces contribute more to the entrance and drip line soil lead samples than to the remote sample. This finding was expected because entrance and drip-line samples are closer to painted structures than are remote samples. While both interior and exterior paint lead relate significantly to soil lead, exterior paint lead is more strongly associated with soil lead than is interior paint.

### Sources of Dust Lead

The statistical relationships were studied between interior dust lead levels -- for all seven dust sample locations -- and a number of possible sources of dust lead and related factors, including housing unit paint lead loadings (the area weighted average across all painted surfaces), percentage of damaged paint, and surface area covered with paint; dwelling unit age and other descriptors of the housing unit; and all three soil samples. Generally, the dust lead has more variation than the soil lead data. This makes it more difficult to identify and assess significant sources of dust lead. The dust lead equations account for only 16 to 27 percent of the statistical variation in the dust lead data. The findings regarding sources of dust lead are therefore more tentative and less conclusive than those regarding the sources of soil lead. Nevertheless, some significant factors relating to dust lead have been identified.

Floor dust lead at the main entrance is statistically associated primarily with exterior soil lead and, to some extent, exterior paint that is both leaded and damaged. It appears that the soil lead contribution comes mainly from the entrance soil samples. However, both close-in soil sample locations (entrance and drip line) contribute to dust lead concentrations just inside the main entrance.

Floor dust lead in the wet and dry rooms appears to come more from soil lead at the two close-in locations than directly from paint lead. That is, while there is clear evidence of a statistical association between soil lead and floor dust lead, the evidence is less clear of a direct association between floor dust lead and paint lead. There is one exception to this: floor dust lead in the wet room is significantly associated with wet room paint lead. However, as described in the previous section, soil lead is related to overall paint lead. This suggests that, over time, lead migrates from paint, to soil, to floor dust.

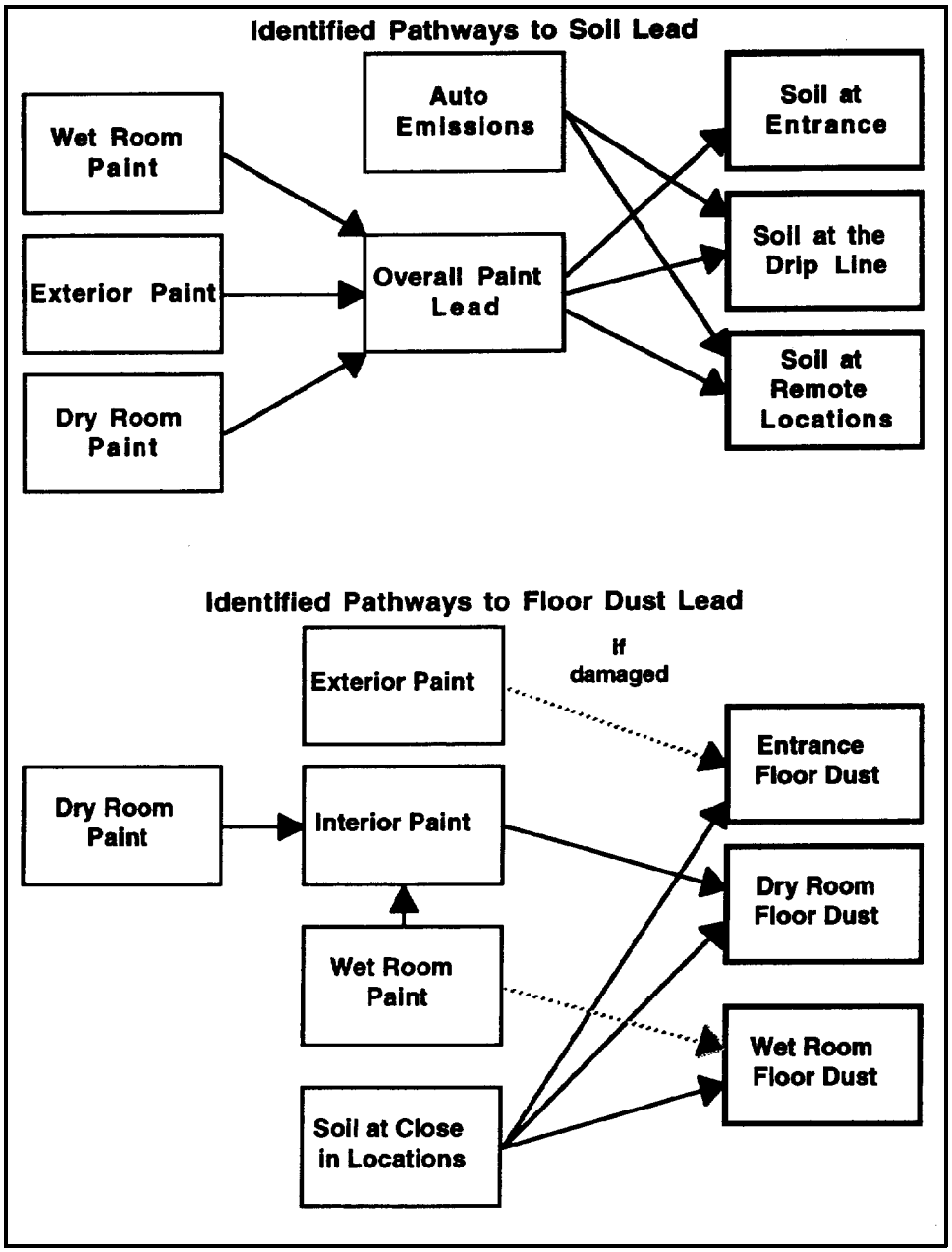
Soil lead concentrations at the close-in locations are significant predictors of dry room window sill dust lead concentrations. Interior, but not exterior, paint lead is also associated with dry room window sill dust. Wet room window sill dust lead is significantly related to interior paint lead, especially in the wet room.

There were fewer window well dust samples to analyze and these are the most variable of the dust samples; consequently, the statistical analyses do not permit any assessment of the sources of wet or dry room well dust lead levels. However, the fact that dust lead concentrations in window wells are significantly higher than soil lead concentrations suggests that other sources, such as paint, contribute much more lead to window well dust than does soil.

Note that the dust lead concentrations increase significantly with age of the dwelling unit, as do the soil lead concentrations. However, in the statistical analysis, age was not significant in predicting dust lead concentrations, indicating that other factors that were also related to age, such as soil lead concentrations and paint lead loadings, were adequate to predict the dust lead concentrations without an additional age term.

## Pathways

The relational analyses described above suggest certain conclusions concerning the pathways by which lead migrates from paint, automobile emissions, and other sources to exterior soil and interior dust. These conclusions are summarized in the following diagrams of identified pathways of lead from these sources to soil and floor dust. The diagram shows only pathways identified as significant in the analysis of the national survey data. Additional pathways, not identifiable from the national survey data, may exist. The solid arrows indicate clearly identified paths; the dotted lines indicate paths for which the evidence in the national survey data is less clear.



**Soil Lead Data Analysis**

The soil lead data for each sample location can be statistically described by a log normal distribution (i.e., the logarithm of the measured lead concentrations have a normal or "bell-shaped" distribution). No individual observations can be clearly identified as outliers. Therefore, all of the soil measurements are included in the analyses in this report.

The arithmetic means for the entrance, drip-line, and remote samples are 295, 415, and 170 ppm, respectively; the geometric means are 83, 72, and 47 ppm, respectively. While the measurement error is relatively large (about 95 percent of soil lead measurements will be within a factor of 2.7 of the true concentration), it is small compared to the differences in soil lead concentrations between locations. In spite of the measurement error, significant correlations and differences can be found. In particular, the lead concentrations at the entrance and drip-line locations are, on average, significantly higher than at the remote sample location ($p < 0.001$). However, the entrance and drip-line samples are not significantly different from each other. The measurements at the three locations are also all highly correlated with each other; that is, housing units that have higher (lower) lead concentrations at one of the locations also tend to have higher (lower) concentrations at the other two. The soil lead measurements also vary significantly with the age of the dwelling unit. Homes built before 1940 have, on average, the largest soil lead concentrations; after 1940, the average concentrations decline with each successive decade.

## Dust Lead Data Analysis

The dust lead data can also be statistically described by a log normal distribution for each sample location. About one percent of the individual observations can be clearly identified as outliers -- observations that are extremely unusual when compared to other observations made under comparable conditions. These observations have been removed from the analyses reported here because they could have obscured and distorted the relational analyses. In general, the dust lead data is noticeably more variable than the soil lead data, with the window locations more variable than the floor locations.

On average, the wet and dry room floor dust levels are similar to each other, while the entrance way dust lead level is significantly greater. The difference may represent what is tracked into the house from outside. All of the window dust lead levels are significantly greater than any of the floor lead levels. Further, the window well lead levels are usually greater than the lead levels on the same window sills. There are no significant differences between corresponding locations in the wet and dry rooms. The measurements at the seven dust sampling locations are also all highly correlated with each other.

There is no one widely-accepted dust sample collection protocol. Consequently, researchers in different studies may use different methods; which means that data reported by two different researchers may not be comparable. In particular, some researchers use wet wipes to collect dust samples. There is evidence that wet wipe samples tend to yield higher dust lead loadings than the vacuum used in the national survey. Consequently, caution must be taken in comparing these results with other studies.

## Limitations Of The Analysis Results

Although appropriate for the objectives of the original survey, the data provided limited ability to identify possible sources of soil and dust lead. As a result of (1) the limited number of XRF measurements, soil measurements, and dust measurements, (2) the lack of information on the behavior of household occupants, and (3) inherent variability in the sampling and measurement process, the possibilities for identifying the sources of lead in soil and dust are limited and the conclusions are subject to interpretation. That the models cannot accurately predict lead concentrations in homes suggests that the lead levels in dust and soil are determined, in part, by factors that were not recorded in the survey or are difficult to quantify, such as small-scale local factors and the behavior of the occupants. Nevertheless, the statistical procedures identified some significant relationships in the data, support conclusions reached by other researchers, and provide valuable descriptive statistics for describing homes nationally, statistics that are not available from other sources.

## Summary

The overall summary of the report's findings are presented below in the form of general questions that might be asked of the reports conclusions, and brief answers to these questions.

1) What are the main contributors of lead to soil?

The analysis suggests that both paint lead and lead from traffic-related sources have contributed to soil lead, with traffic-related sources being more important at locations away from buildings and paint sources more important next to buildings, at the drip line and entrance. In addition, the soil lead concentrations increase significantly with increasing dwelling unit age due to factors that cannot be identified by this analysis.

2) Based on these analyses, are automobile emissions still a key contributor to soil lead? If so, how much?

Although the results suggest that automobile emissions have contributed lead to soil, particularly in soil around older homes, the contribution of additional lead from automobile emissions today cannot be determined from the survey data.

3) How accurate are the conclusions based on the analysis?

The statistical conclusions provide support to generally accepted hypotheses about the sources of lead in soil and dust. They provide some indication of the relative magnitude of the contribution from different sources. The results are not accurate enough to identify lead sources and pathways with confidence, to identify the less important lead sources, or to predict dust and soil lead concentrations in individual homes.

4) Based on these analyses, what is the main contributor to dust lead inside the home, paint or soil?

The results suggest that, in general, soil is more important than paint as a source of lead in floor dust. The relative importance of paint as a source of lead in dust increases if the paint is damaged. However, the importance of paint damage cannot be reliably determined from the data. No conclusions can be reached about window sill and well dust; however, the high lead concentrations in window well dust suggest that paint, rather than soil or floor dust sources, contributes most of the lead to window well dust.

5) Are there any major findings of this report that could be used to combat our lead poisoning problem?

The analysis suggests that the dust lead concentration is statistically independent of the dust loading. Lead loading, thought to be most closely related to a child's risk of lead poisoning, can be expressed as the product of the lead concentration and the dust loading. Therefore reducing either the dust loading, perhaps by frequent vacuuming, or the lead concentration, perhaps by removing lead sources, can reduce lead loading and lead poisoning risk. The study suggests that soil dust lead is the major contributor of lead to floor dust. Therefore, effective measures to reduce the movement of soil into the home can also help control floor dust lead.