3.0 EXPOSURE ASSESSMENT

CHAPTER 3 SUMMARY

The goals of this exposure assessment are to document the important sources of lead in the environment, to document the major pathways by which children are exposed to lead, to characterize the current distribution of environmental-lead levels in the nation's housing stock, and to characterize the current distribution of average blood-lead concentration among the nation's children. Information from the exposure assessment is used with the findings of hazard identification (Chapter 2) and dose response assessment (Chapter 4) to provide input to the risk characterization (Chapter 5) and analysis of example options for risk management (Chapter 6).

Residential paint, dust, and soil are among those sources of lead which contribute most significantly to overall lead exposure in humans. Several lead exposure studies have concluded that the pathway of lead-contaminated soil and dust to children's blood is an important means by which young children are exposed to lead from lead-based paint hazards. Studies such as the Baltimore Repair and Maintenance Study and the Rochester Lead-in-Dust Study conclude that elevated lead levels in paint, dust, and soil continue to exist in residential environments, particularly in older homes. Even at low to moderate levels, lead in residential dust can affect children's blood-lead concentration.

The HUD National Survey of Lead-Based Paint in Housing was selected as the data source for characterizing environmental-lead levels in the nation's housing stock in this risk assessment. According to this survey, 83% of occupied units built prior to 1980 are expected to contain lead-based paint, and 18% are expected to contain more than five square feet of deteriorated lead-based paint. Dust- and soil-lead concentrations and dust-lead loadings tend to increase with age of unit.

The baseline distribution of blood-lead concentration within children aged 1 to 2 years is derived in this risk assessment from data collected in Phase 2 of the Third National Health and Nutrition Examination Survey (NHANES III). The geometric mean blood-lead concentration for these children is 3.1 µg/dL, with a 95% confidence interval of 2.8-3.5 µg/dL. Approximately 6% of these children are estimated to have blood-lead concentrations greater than or equal to 10 µg/dL.

Figure 3-1 outlines the approach for the exposure assessment. Conclusions from the exposure assessment are presented in Section 3.5.

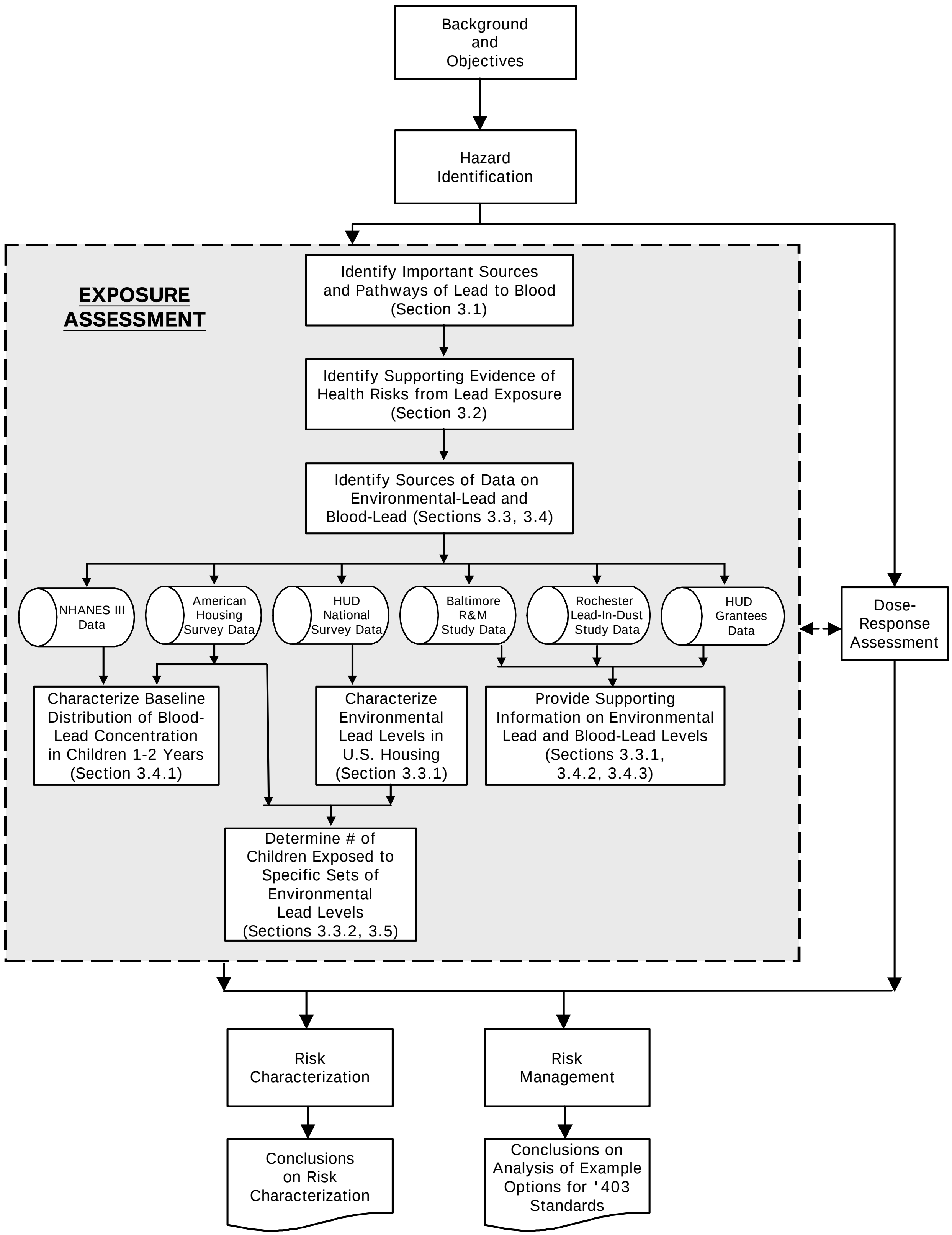

Figure 3-1. Detailed Flowchart of the Approach to Exposure Assessment.

This exposure assessment seeks to answer the following questions:

1. Do the predominant sources of residential lead exposure to children include lead-based paint hazards, including lead-contaminated dust and lead-contaminated soil?

2. What is the distribution of environmental-lead levels in dust and soil in the nation's housing stock?

3. Is there evidence of a relationship between lead-based paint exposures in residential environments and children's blood-lead concentration?

4. What is the baseline distribution of blood-lead concentration in the representative population (children aged 1-2 years)?

Information from the exposure assessment is used with the findings of hazard identification (Chapter 2) and dose response assessment (Chapter 4) to provide input to the risk characterization (Chapter 5) and risk management (Chapter 6).

Figure 3-1 presents the overall risk analysis approach, with the approach for the exposure assessment detailed. This chapter is formatted similar to the outline in Figure 3-1. Section 3.1 provides documented sources and pathways of lead exposure in the nation's residential environment. A number of lead exposure studies have investigated the extent to which lead is present in certain residential environments and how this lead exposure is reflected in blood-lead concentration in children. These studies are introduced and summarized in Section 3.2. Section 3.3 characterizes lead exposure in that portion of the national housing stock in which children reside or can potentially reside (hereafter referred to simply as the "national housing stock"). Section 3.4 characterizes the distribution of childhood blood-lead concentrations in children aged 1-2 years. The characterizations in Sections 3.3 and 3.4 are provided for 1997, prior to when regulations developed in response to §403 are expected to be proposed.

Answers to the above questions are summarized in Section 3.5, along with key results to be used in the risk characterization and any limitations associated with the data sources or approaches used to obtain these results.

This chapter identifies the best sources of available data on housing stock characteristics, population estimates, and environmental-lead levels in housing units, in order to make inferences on residential lead exposure to children in the United States. The extent to which any exposure assessment accurately portrays the exposure scenario of interest depends on the relevance and representativeness of the data used in the analyses and in the methods applied to these data to meet the objectives of the exposure assessment. Therefore, an effort has been made in this chapter to present the methods used, to identify assumptions and approximations made in the analysis and when they were made, and to identify uncertainties and limitations in the data. Supporting information and detailed results to accompany the information in this chapter are presented in Appendices C1 and C2.

3.1 SOURCES AND PATHWAYS OF LEAD

Lead is a heavy, stable element occurring naturally in the earth's crust. Through natural activity such as crustal weathering and human activity such as mining, this metal has been distributed throughout the human environment. Lead's historic use as a raw material in various manufactured and refined products has increased its introduction into the environment. As a result, lead has been detected in water, soil, air, plants, animals, and humans. As lead does not naturally biodegrade, its exposure potential tends to accumulate over time as more and more lead is deposited in the environment.

Research has identified a variety of environmental sources and reservoirs of lead which can contribute to overall lead exposure in a child. Figure 3-2 illustrates the major sources and reservoirs of lead, how lead is introduced into the human environment, and various pathways of human exposure. According to this figure, both natural sources (e.g., crustal weathering) and sources resulting from human activity (e.g., auto and industrial emissions, paint and industrial dusts, solder, lead glazes) have contributed lead to various components of the human environment. Lead in such media as inhaled air, dusts, food, or drinking water contributes to human lead exposure via direct pathways between these reservoirs and man. As data supporting the dangers of lead exposure have been identified, a combination of state and Federal action has curtailed the impact of certain sources and reservoirs of lead in the environment, resulting in a change in the predominance of historically significant sources.

In the scientific literature (e.g., Bornschein et al., 1986), quantitative exposure models, or *pathways models*, have been applied to data from environmental-lead studies to identify the most significant pathways by which residential, childhood environmental-lead exposure occurs and to provide quantitative estimates of the relative contributions of the numerous hypothesized exposure paths. One such set of environmental pathways, as reported by Bornschein et al., 1986, upon analysis of data from the Cincinnati Longitudinal Study (Section 3.2.2.5), is shown in Figure 3-3.

The information that follows provides the current status of the sources of lead included in Figure 3-2 that have historically been recognized in the scientific literature as most associated with elevated blood-lead concentrations in children. Most of the information comes from detailed investigations on sources of lead documented in USEPA (1986), CDC (1991), and ATSDR (1993).

Airborne Lead

Historically, emissions from lead smelters, battery manufacturing plants, solid waste incinerators, and automobiles have made major contributions to airborne lead levels. Fallout of atmospheric lead contributes to lead levels in soil, household dust, and street dust. Lead is deposited on soil, plants, and animals, which thereby is incorporated into the food chain.

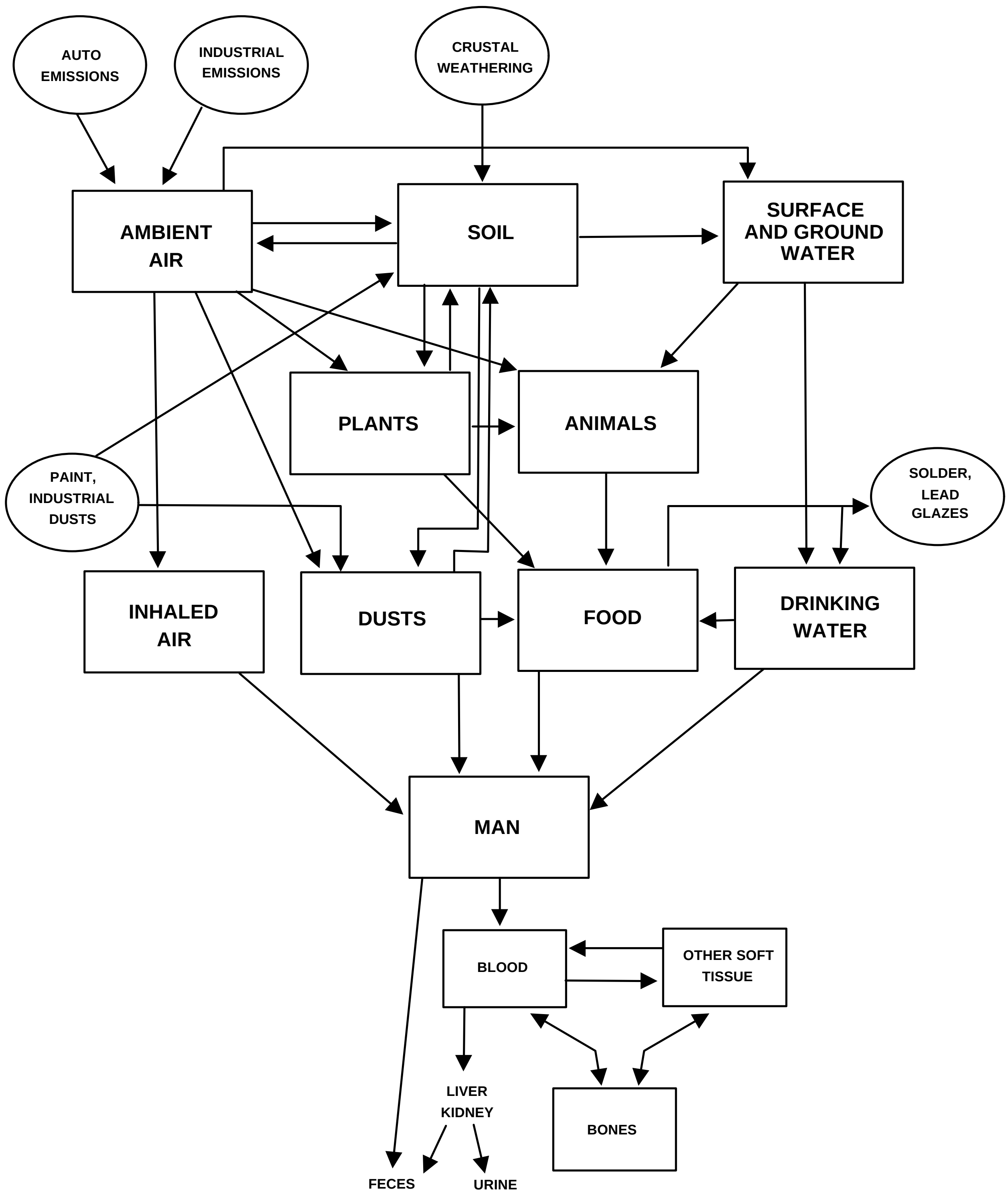

Figure 3-2. Pathways of Lead from the Environment to Humans, Main Organs of Absorption and Retention, and Main Routes of Excretion.

(Sources: USEPA, 1986; USEPA, 1996a)

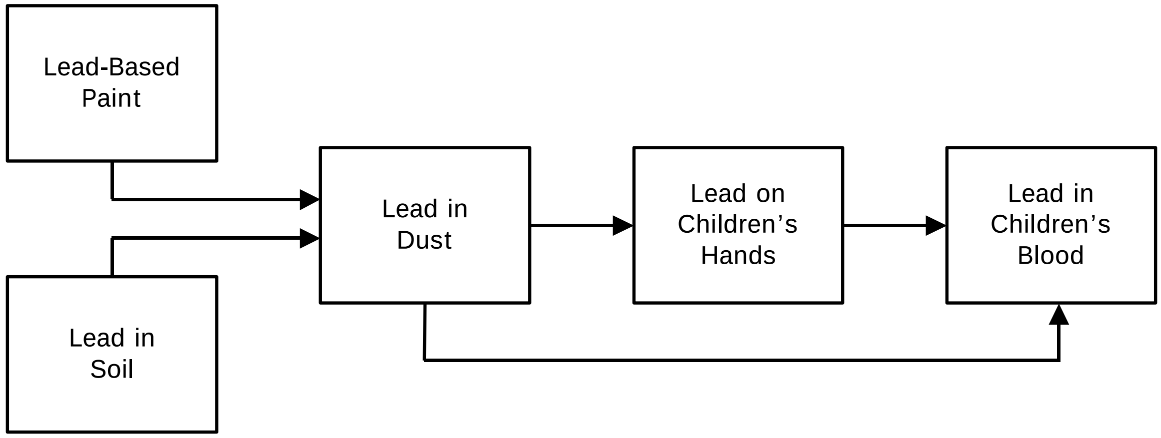

Figure 3-3. Set of Environmental Pathways Reported by Bornschein et al., 1986, Upon Analysis of Data from the Cincinnati Longitudinal Study (Children Aged 18 Months).

Until recently, leaded gasoline emissions was one of the primary sources of lead exposure in the United States. Under Title II of the 1990 amendments to the Clean Air Act (42 U.S.C. 7545), EPA specified lead as a pollutant compound of concern and instituted a controlled phase-out of leaded gasoline by December 31, 1995 (§211(n) of Title II). As a result, there was a 73% reduction in lead consumed in gasoline from 1975 to 1984 (USEPA, 1986) and a 64% reduction in national lead emissions from 1985 to 1989 (ATSDR, 1993). This reduction has corresponded to a similarly dramatic decrease in average lead concentration in children's blood (CDC, 1991; Annest, 1983). The phase-out of leaded gasoline has contributed to airborne lead's becoming only a minor lead-exposure pathway for children not exposed to specific point-emitting lead sources (CDC, 1991).

Even in the absence of a point-emitting lead source, indoor air may be considered an important indirect lead-exposure pathway when lead-based paint or lead-contaminated dust or soil is disturbed during renovation and remodeling activities. Inadequate dust control or use of paint stripping techniques that vaporize lead in paint are ways that lead contaminates breathable air during renovation and remodeling activities (USEPA, 1994b).

EPA has set a National Ambient Air Quality Standard of 1.5 µg of lead per cubic meter of air (40 CFR 50.12). This standard is compared to the average of 15-16 air samples, each taken for a 24-hour duration over a period of three months, to determine air quality compliance.

Drinking and Cooking Water

Detectable levels of lead are rare in surface and ground water that serve as sources of drinking water in this country. Typically, lead contamination of drinking water occurs after the water leaves the treatment plant (CDC, 1991). By traveling within service lines and household plumbing, drinking water can become contaminated upon encounter with lead pipes, connectors, and solder. At a residence, water can also become contaminated by the lead or brass components of water fountains, coolers, faucets, and other fixtures. Through the authority of the 1986 Safe Drinking Water Act and its amendments, EPA banned the use of lead materials and solders in new plumbing and plumbing repairs, required that public water suppliers notify the public about lead presence in drinking water, and encouraged local government measures to test and remediate lead-contaminated drinking water in schools and day-care centers. As a result, drinking and cooking water from municipal and other large drinking water distribution systems is generally not a predominant source of lead exposure among lead-poisoned children (CDC, 1991).

Analysis of environmental-lead data from several studies, including the Baltimore R&M Study and the Rochester Lead-in-Dust Study (Section 3.2), concluded that lead levels in drinking water generally do not have a statistically significant effect on blood-lead concentrations. In both of these studies, however, lead levels in water were low. However, due to the high absorption rate of lead in water, lead in drinking water is still considered an important exposure source when present (CDC, 1991).

As required by the Safe Drinking Water Act, the National Primary Drinking Water Regulations (NPDWRs) for Lead and Copper (56 FR 26460, June 7, 1991) set an action level for lead in drinking water of 15 ppb and specified a maximum percentage of homes in a water service area that could exceed this action level. Those systems that do not meet these standards must inform the public, while taking measures to reduce lead levels and continue monitoring procedures. The NPDWRs for Lead and Copper also set maximum contaminant level goals (MCLGs). This rule set the MCLG for lead within drinking water at the tap to be 0 ppb (40 CFR 141,142).

Food

Many studies have shown that children's dietary intake of lead has receded over recent years. For example, data from the U.S. Food and Drug Administration (FDA) indicate that dietary lead intake in two-year-old children has declined from an approximate average of 30 µg/day in 1982 to 5 µg/day in the period 1986-1988 (CDC, 1991). U.S. FDA intervention and outreach activities, along with reduced lead entering the food chain due to the phase-out of leaded gasoline, have contributed to this decline. The phase-out of lead-soldered food cans (1.4% of the U.S.-produced food and soft drink cans in 1989, compared to 47% of such cans produced in 1980), along with public education on proper food storage and cooking techniques, have made large contributions to reducing the amount of lead ingested with food (CDC, 1991). Education is especially important in those areas of the country with traditions of using lead-containing pottery in cooking and preparing folk remedies containing lead.

While production of lead-soldered food and soft drink cans have been virtually eliminated in the U.S., such cans may still be used by other countries who export food to the U.S. In addition, lead can be introduced to food grown in lead-contaminated soil. Improper handling of food in the home (e.g., storing food in containers such as lead-soldered cans and lead-glazed pottery) can cause food to be a source of lead exposure. Thus, while lead exposures through food ingestion have declined considerably in recent years, these exposures can still occur if proper precautions are not addressed.

Lead-Based Paint

Lead-based paint (LBP) is currently considered the most significant high-dose source of lead exposure in pre-school children (CDC, 1991). (Other sources such as lead plumbing and historic reservoirs of lead deposited in soil and in house dust remain important for a significant minority, especially in some non-urban areas.) From the turn of the century through the 1940's, paint manufacturers used lead as a primary ingredient in many oil-based interior and exterior house paints. Usage gradually decreased through the 1950s and 1960s, as largely lead-free latex paints and exterior paint with lower lead concentrations were manufactured. In 1978, the Consumer Product Safety Commission (CPSC) ruled that paint used for residence, toys, furniture, and public areas must not contain more than 0.06% lead by weight. Nevertheless, the presence of lead-based paint in the nation's housing stock remains high. An estimated 64 million (or 83% of) privately-owned, occupied housing units built prior to 1980 contain some components covered with lead-based paint (USEPA, 1995a), defined as containing at least 1.0 mg lead per square centimeter of painted surface. Approximately 12 million of these units contain at least one child under the age of seven years. The estimated percentage of public housing units in this category is even higher: 86% (USEPA, 1995a).

Human exposure to lead from lead-based paint is believed to be higher when the paint is in a deteriorated state or is found on accessible, chewable, impact, or friction surfaces (USEPA, 1986; CDC, 1991). Thus, young children are especially susceptible to lead poisoning from lead-based paint, as they may ingest lead-based paint chips or come into contact with dust or soil that has been contaminated by deteriorated lead-based paint (see below). Both adults and children can be exposed to hazardous levels of lead by ingesting paint-dust during hand-to-mouth activities. The U.S. Department of Housing and Urban Development (HUD) has prepared guidelines on controlling lead-based paint hazards, as improper control procedures can actually increase the threat of lead-based paint exposure by dispersing fine lead dust particles in the air and over accessible household surfaces (USHUD, 1995b; Farfel and Chisolm, 1990). The potential for lead-based paint to contaminate a variety of environmental media within a household makes lead-based paint the greatest source of public health concern regarding lead exposure (CDC, 1991).

Contaminated Dust and Soil

While enforcement of national air quality standards continues to reduce the threat of lead exposure via air from point sources, the fallout of atmospheric lead over time has resulted in a continued exposure route through soil (USEPA, 1986). In addition, soil can become contaminated by deteriorated lead-based paint or by the improper removal of lead-based paint from a housing unit. The same soil, once tracked indoors, can become a component of household dust causing yet another source of lead exposure. Children are exposed to lead from soil or dust in their homes during typical hand-to-mouth activities.

Lead-contaminated soil and dust are thought to be the major pathway by which young children are exposed to lead from lead-based paint hazards (USEPA, 1986). Exterior house paint can flake off or leach into the soil around the outside of a home, contaminating children's play areas. Indoors, normal wear of lead-based paint (especially around windows and doors) and contaminated soil tracked into the house can contaminate interior dust. Lead-based paint takes the form of paint chips or tiny, exfoliated flakes when contaminating interior dust; the contribution of these two forms to contaminated dust has not been studied in great detail. When lead takes the form of small particles, as it typically does when found within household dust (Que Hee et al., 1985), it is more easily absorbed into the body (Mahaffey, 1977).

A number of studies have assessed the effect of dust- and soil-lead levels on childhood blood-lead concentrations. A few studies have concluded that the effect of residential lead-based paint on blood-lead levels occurs via the pathway of dust- and soil-lead to blood. For example, the pathways diagram in Figure 3-3 indicated that a significant lead pathway from exterior dust to interior dust to hands to blood was identified through analysis of data from the Cincinnati Longitudinal Study (Section 3.2.2.5), with lead in paint and soil contributing to lead in exterior dust (Bornschein et al., 1986). Analysis of data from the Brigham and Women's Hospital Longitudinal Study (Section 3.2.2.6) concluded that the pathway from soil to window sill-dust to floor-dust to blood was statistically significant (Menton et al., 1995). It is likely that exposure of young children to lead in dust and soil is primarily due to their propensity to mouth fingers, toys, and other nonfood items that contain contaminated dust. Pathways analyses of data from such studies as the Cincinnati Longitudinal Study (Bornschein et al., 1986) found a significant pathway of lead from hand dust to blood, suggesting that hand-to-mouth activities are an important contributor to childhood blood-lead concentrations.

3.2 SUPPORTING EVIDENCE IN LEAD EXPOSURE STUDIES

To determine the extent to which lead-based paint hazards are associated with elevated blood-lead concentrations in children residing in the nation's housing stock, this exposure assessment has documented evidence as reported within a vast library of government reports, published articles, and proceedings. Section 3.2.1 identifies recent human characterization and intervention studies that address the relationship between childhood blood-lead concentration and environmental-lead levels in the nation's housing, along with their general findings. A selected number of these studies provide the most useful information for this risk assessment; these studies are presented in greater detail in Section 3.2.2.

3.2.1 Weight of Evidence on the Relationship between Environmental-Lead Exposures and Increased Blood-Lead Concentrations

Extensive evidence of the relationship between childhood blood-lead concentrations and environmental-lead levels is offered in the scientific literature. Evidence from two types of studies is available. *Human characterization studies* investigate the association between elevated blood-lead concentrations and elevated levels of lead in a child's residential environment. *Intervention studies* investigate the impact on children's blood-lead concentrations of reducing childhood lead exposure via a range of intervention strategies. Human characterization studies have demonstrated that elevated blood-lead concentrations are associated with elevated lead levels in the dust, paint, and soil of the surrounding environment. Intervention studies can contribute to conclusions about causation. If children receiving an intervention strategy that targets a particular lead exposure source (e.g., paint, dust, or soil) exhibit greater reductions in blood-lead concentrations than those reported for a suitable control population, then the targeted source may be at least partially responsible for the prior exposure.

A review of intervention studies (USEPA, 1995b) concluded that reductions in blood-lead concentrations have occurred following interventions aimed at lead in paint, dust, and soil. While such studies suggest causation, their results are not necessarily indicative of the magnitude of the association between the levels of lead in targeted environmental media and blood-lead concentrations. This is because intervention studies typically examine children already exposed to environmental lead. Exposed children retain a store of lead in their tissues that routinely mobilizes into the blood (Gulson et al., 1995). This mobilization may be heightened following an intervention (Schroeder and Tipton, 1968; Rabinowitz, 1991) as the change in exposure caused by the intervention disrupts the body's equilibrium. Blood-lead concentrations following the intervention, therefore, represent a combination of the now reduced environmental lead exposure and the increasingly (at least temporarily) mobilized lead stores.

During the past 25 years, studies have been conducted to investigate the sources responsible for lead exposure in children. These studies include investigations of the sources and extent of lead exposure in both urban and ore-processing communities. The studies listed in Tables 3-1 and 3-2 provide evidence regarding associations between childhood blood-lead concentrations and environmental-lead levels in urban and ore-processing communities, respectively. Many of these studies are limited, small, or not relevant to the current exposure situation. However, the results of these studies are qualitatively similar in that the association between environmental-lead levels and blood-lead concentration is consistently positive and, when considered without the confounding from additional variables, usually found to be statistically significant given the collected data. When confounding variables (e.g., age, race or ethnicity, socioeconomic status, housing condition) are included in the analysis of data from these studies, the estimated strength of the relationship between blood-lead and environmental-lead levels is modified, and, sometimes, is no longer significant given the collected data. It is difficult to combine results from multiple studies into one representative, quantitative measure of the relationship between blood-lead concentration and environmental-lead levels, due to the qualitative dissimilarities among the studies (e.g., differences in sampling and analysis methods, sampling locations, target populations, and types of communities).

Early childhood lead exposure studies emphasized exposure to lead in paint, leaded gasoline emissions, and emissions from industrial sources. These studies, therefore, measured lead levels in these media and sought to relate them directly to resident children’s blood-lead concentrations. Due to the assessment by many researchers in childhood lead exposure that ingestion of dust and soil via hand-to-mouth behavior represents the principal mechanism of lead exposure in young children today (CDC, 1991), more recent studies have focused principally on lead exposure from residential soil and dust. As indicated in Figure 3-2, residential soil and dust are assumed to have been contaminated by these same original sources: lead-based paint, industrial emissions or tailings, and leaded gasoline emissions.

Table 3-1. Childhood Lead Exposure Studies Conducted in Urban Communities That Present Evidence of the Relationship Between Environmental-Lead Levels and Blood-Lead Concentrations.

Study/Community	Study Duration	Study Type	Reference(s)
Baltimore (MD) Lead-Based Paint Abatement and Repair and Maintenance Study	1992-1997	Intervention (Abatement Efficacy)	Farfel and Lim, 1995 USEPA, 1996b
Rochester (NY) Lead-in-Dust Study	1993	Human Characterization	USHUD, 1995a; Lanphear et al., 1995 Lanphear et al., 1996a Lanphear et al., 1996b Emond et al., 1997
Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program	1994-present	Intervention (cost and effectiveness)	NCLSH and UCDEH, 1997 NCLSH and UCDEH, 1994
Baltimore (MD) Urban Soil Lead Abatement Demonstration Project (USLADP)	1988-1991	Intervention (Soil Abatement Efficacy)	USEPA, 1996a; Weitzman et al., 1993; Aschengrau et al., 1994
Boston (MA) USLADP	1989-1991		
Cincinnati (OH) USLADP	1989-1991		
Birmingham (UK) Urban Lead Uptake Study	1984-1985	Human Characterization	Davies et al., 1990; Thornton et al., 1990; Davies et al., 1987
Cincinnati (OH) Longitudinal Study	1980-1987	Human Characterization	Bornschein et al., 1985a; Que Hee et al., 1985; Bornschein et al., 1985b; Bornschein et al., 1986
Brigham and Women's Hospital Longitudinal Study (Boston, MA)	1980-1983	Human Characterization	Bellinger et al., 1986b; Rabinowitz et al., 1985a; Rabinowitz et al., 1985b; Rabinowitz et al., 1984a; Rabinowitz et al., 1984b; Rabinowitz et al., 1982
New Haven, CT	1977	Human Characterization	Stark et al., 1982; Stark et al., 1978
Omaha, NE	1970-1977	Human Characterization	Angle and McIntire, 1979; Angle et al., 1974; Angle et al., 1984

Table 3-2. Childhood Lead Exposure Studies Conducted in Ore-Processing Communities That Present Evidence of the Relationship Between Environmental-Lead Levels and Blood-Lead Concentrations.

Study/Community	Study Duration	Study Type	Reference(s)
Palmerton (PA) Lead Exposure Study	1994	Human Characterization	Bornschein, 1996a
Bingham Creek (UT) Environmental and Human Health Lead and Arsenic Study	1993	Human Characterization	Bornschein, 1996b
Leadville/Lake County (CO) Environmental Health Study	1991	Human Characterization	Bornschein, 1997
Granite City (IL) Educational Intervention Study	1991	Intervention	Kimbrough et al., 1994
Butte-Silver Bow (MT) Environmental Health Study	1990	Human Characterization	Butte-Silver Bow Dept. of Health, et al., 1991
Clear Creek/Central City (CO) Mine Waste Exposure Study	1990	Human Characterization	ATSDR, 1992
Midvale (UT) Community Lead Study	1989	Human Characterization	Bornschein et al., 1990
Child Lead Exposure Study (Leeds, AL)	1989	Human Characterization	ATSDR, 1991a
Philadelphia (PA) Neighborhood Lead Study	1989	Human Characterization	ATSDR, 1991b
Leadville (CO) Metals Exposure Study	1988	Human Characterization	Colorado Dept. Of Health, et al., 1990
Silver Creek Mine Tailings Exposure Study (Park City, UT)	1987	Human Characterization	ATSDR, 1988b
Telluride, ID	1986	Human Characterization	Bornschein et al., 1989
Kellogg (ID) Revisited	1983	Human Characterization	Panhandle District Health Dept. et al., 1986
Helena Valley (MT) Child Lead Study	1983	Human Characterization	Lewis and Clark County Health Dept. et al., 1986
El Paso, TX	1971-1973	Human Characterization	Landrigan et al., 1975

Due to the reduction in lead sources such as gasoline emissions over time, the most recent lead exposure studies provide a more accurate picture of the relationship between child blood-lead concentrations and lead-based paint hazards. Additionally, while deteriorated lead-based paint is a common lead source in older, ore-processing communities, studies in these communities provide less evidence than general urban studies as to the association between elevated blood-lead concentrations and lead-based paint hazards, due to the presence of hazards from industrial sources. Consequently, this risk assessment has relied primarily on information from recent studies conducted in urban areas in the absence of specific point emission sources. While this approach may underestimate the exposure of some high-risk subpopulations heavily exposed to area sources such as leaded gasoline depositions near highways, bridge and structure painting and refinishing, and low-level non-ferrous metal processing operations (e.g., battery recycling and radiator shops), it is consistent with the intent of Title X to reduce hazards associated with lead-based paint.

3.2.2 More Detailed Description of the Most Useful Studies for This Risk Assessment

Upon review of the design, analysis approach, and conclusions of the ten studies listed in Table 3-1, nine studies were identified as most relevant to address the questions on childhood lead exposure presented at the beginning of this exposure assessment chapter. These studies were

- the Baltimore Lead-Based Paint Repair and Maintenance (R&M) study (pre-intervention phase);
- the Rochester Lead-in-Dust Study;
- Evaluation of the HUD Lead-Based Paint Control Grant Program (HUD Grantees);
- the three studies constituting the Urban Soil Lead Abatement Demonstration Project (USLADP);
- the Birmingham Urban Lead Uptake study;
- the Cincinnati Longitudinal study, and
- the Brigham and Women's Hospital Longitudinal study.

Three of these nine studies, the Baltimore R&M Study (Section 3.2.2.1), the Rochester Lead-in-Dust Study (Section 3.2.2.2), and the HUD Grantees Program (Section 3.2.2.3), provide the most useful and available data on the relationship between environmental-lead levels and childhood blood-lead concentration, while the HUD National Survey of Lead-Based Paint in Housing (Section 3.3) was the primary source of environmental-lead data used in this risk analysis. Summaries of housing units and children sampled in these four studies and the approach to blood sampling are presented in Table 3-3a through 3-3c, while summaries of the approach to collecting environmental-lead data in these studies are presented in Tables 3-3d through 3-3f. (No blood-lead data were collected in the HUD National Survey.) Environmental-lead data from these studies are summarized in Section 3.3, while children's blood-lead concentrations are summarized in Section 3.4. These four studies were selected to provide data for this risk analysis for the following reasons:

- The studies had available data for lead in paint, dust, and soil.
- The Baltimore R&M study, the Rochester study, and the HUD Grantees program also had data available on lead in children's blood.
- These studies were conducted recently.
- These studies were not conducted in locations with a specific point source of lead.
- These studies were conducted in the United States (source control may be different in other countries).

The remaining six studies in the above list provided useful information to this exposure assessment on the relationship between environmental-lead levels and children's blood-lead concentration. However, data from these studies were not used in this risk analysis for the following reasons:

- As the three USLADP studies were longitudinal intervention studies, their designs and implementation were not appropriate for assessing general residential lead exposure (Section 3.2.2.4). In addition, dust samples were collected in two of these studies using a Sirchee-Spittler vacuum method. No method was available for converting lead loadings in these dust samples to corresponding loadings based on a wipe dust collection technique, which was necessary for such data to be used in this risk assessment.
- The Birmingham Urban Lead Uptake study was conducted outside of the U.S. and over ten years ago, thus considered less representative of current childhood lead exposure in the U.S. as compared to more recent studies.
- The Cincinnati Longitudinal Study and the Brigham and Women's Hospital Longitudinal Study were conducted too long ago for their data to be considered in this risk assessment.

Table 3-3a. Summary Information on Housing Surveyed in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey.

Information on Housing	Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
Eligibility	Structurally sound houses in Baltimore, MD, with at least one eligible child. Houses slated for R&M interventions must have lead-based paint on at least one surface or be built prior to 1941. Previously-abated houses built prior to 1941 were abated from 5/88 to 2/91. Modern urban units were built after 1979 and located within a single urban neighborhood.	Houses in Rochester, NY, with eligible children born at hospitals and clinics that provided necessary information for enrollment.	Privately-owned, low- and middle-income houses likely to contain lead-based paint hazards and on which interventions could be performed in this program. Housing eligibility differed among the 14 participating grantees (see Table 3-4).	Occupied permanent housing in the 48 conterminous states built prior to 1980 with the potential for containing children
# of housing units surveyed	At enrollment: Occupied / vacant; Later dropped from study R&M units: 56 / 39 / 20 Previously-abated units: 16 / 0 / 0 Modern urban units: 16 / 0 / 0	205	4,999 housing units enrolled	284
Year surveyed housing was built	R&M units and previously-abated units were built prior to 1941. Modern urban units were built after 1979.	Pre-1940: 84% 1940-1969: 11% 1970-1979: < 1% Post-1979: 5%	Pre-1940: 89.6% 1940-1959: 9.2% 1960-1977: 0.9% Post-1977: 0.3% (522 housing units had no age specified)	Pre-1940: 27% 1940-1959: 31% 1960-1979: 42%
Dates of environmental and blood sampling	R&M units: 3/93 to 11/94 All other units: 1/93 to 7/93	8/93 to 11/93	2/94 to 9/97 (environmental sampling) 5/94 to 8/97 (blood sampling)	11/89 to 3/90 (environmental sampling only)

Table 3-3b. Summary Information on Children Surveyed in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey. (Continued)

Table 3-3b. Summary Information on Children Surveyed in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey.

Information on Children	Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
Group being considered in this table	Children living in units at the time of enrollment and prior to any interventions performed in the study, and having blood sample data at pre-intervention	Children contributing blood samples in the surveyed units	Children contributing blood samples in the surveyed units prior to intervention	Children less than seven years of age who are the youngest residents in a surveyed housing unit (no blood sampling was done in this study)
Number of children in the above group	115 children in 87 units (16 modern urban units, 15 previously-abated units, and 56 R&M units; from 1 to 4 children sampled per unit). Note: Excluded from the above group are 48 children whose first blood sample in the study was taken prior to moving into a vacant study unit in which R&M interventions were complete.	205 (one per housing unit)	1,306 children in 830 housing units (from 1 to 5 children per housing unit)	90 (i.e., 90 housing units had at least one child less than seven years of age)
Age breakdown in the above group	Age at blood draw 0-12 months: 11% 13-24 months: 30% 25-36 months: 29% 37-72 months: 30%	12-18 months: 44% 18-24 months: 28% 24-30 months: 28%	<1 year: 5% 1-2 years: 38% 3-4 years: 36% >4 years: 21% (66 children had no age specified)	0-11 months: 11% 12-23 months: 17% 24-35 months: 19% 36-47 months: 16% 48-59 months: 17% 60-71 months: 10% 72-83 months: 11%
Racial breakdown of the above group	African-American: 100%	African-American: 42% White: 42% Puerto Rican/Hispanic: 8% Other: 8%	African-American: 44% White: 26% Hispanic: 15% Asian: 10% Native American: 1% Other: 4% (75 children had no race specified)	White, non-Hispanic: 67% Hispanic: 18% African-American: 11% Other: 2% Asian/Pacific: 1% No information: 1%
Frequency of paint pica activity in the above group	Pica never occurs: 87% Pica <1 day per month: 3.5% Pica <1 day per week: 3.5% Pica >1 day per week: 3.5% Daily pica: 2% Pica never observed: 1%	Pica never occurs; 90% Pica rarely occurs: 6% Pica sometimes occurs: <1% Pica often occurs: 2% Pica always occurs: <1%	No information collected	No information collected

Table 3-3b. Summary Information on Children Surveyed in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey. (Continued)

Information on Children	Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
Frequency of soil pica activity in the above group	Pica never occurs: 82.5% Pica < 1 day per month: 5% Pica < 1 day per week: 4% Pica > 1 day per week: 3.5% Daily pica: 3% Pica never observed/other: 2%	Pica never occurs; 52% Pica rarely occurs: 22% Pica sometimes occurs: 22% Pica often occurs: 4% Pica always occurs: 1%	No information collected	No information collected

Table 3-3c. Information on Blood Sampling and Analysis in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, and the HUD Grantees Program.

Information on Blood Sampling and Analysis	Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)
Eligibility (see above for numbers of children sampled and demographic breakdowns)	! 6-60 months of age (at enrollment) ! no disability ! spent at least 75% of time at the unit ! no definite and immediate plans to move from the unit at the time of enrollment Note: No restriction was placed on the minimum amount of time that the child has lived in the given housing unit.	! 12-31 months of age ! resided in same house since six months of age ! spent at least 20 hours per week at primary residence ! exclusions were made if confounding factors could affect blood-lead conc.	Eligibility is dependent on the participating grantee
Method of blood sampling	Venipuncture	Venipuncture	Venipuncture: 877 children (67.2%) Fingerstick: 429 children (32.8%)
Chemical analysis method	GFAA/ASV	GFAA	GFAAS/ASV

Note: No blood samples were collected in the HUD National Survey.

Table 3-3d. Summary of Approaches for Soil Sampling and Analysis in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey.

Exterior Soil Sampling and Analysis	Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
# composite samples from dripline	1 per housing unit in 28 units	1 per housing unit in 186 units	1 per housing unit in 557 units	1 per housing unit in 249 units
# composite samples from entryway	--	--	--	1 per housing unit in 260 units
# composite samples from remote areas	--	--	--	1 per housing unit in 253 units
# composite samples from play areas	--	1 per housing unit in 87 units	1 per housing unit in 330 units	1 to 3 per housing unit in 6 units (total of 11 samples)
# core samples per composite	3	12 (dripline samples) 8-10 (play area samples)	5-10	3
depth of core samples	0.5 in.	0.5 in.	0.5 - 1.0 in.	10 cm
sampling approach/method	Core samples taken from randomly-determined areas using a 6" stainless steel recovery probe and collected into a polystyrene liner	3 dripline core samples were taken at each side of the unit and composited. Samples were composited in polyethylene bags.	5-10 dripline samples were taken from all sides of the building (2' from foundation and 2' from each other). 5-10 samples from play areas were collected along x-shaped grids (each sample at least 1' from each other).	Dripline core samples were taken from a common side of the unit. Remote samples were taken halfway between the unit and its property boundary.
laboratory sample preparation	Samples were dried, sieved, and homogenized. Samples were digested using SW 846-3015 and SW 846-3051.	Samples were mixed and sieved into fine (250 µm) and coarse (2 mm) fractions. Each fraction was digested using SW 846-3050 and analyzed separately.	No information	SW-846 digestion protocol used
laboratory analysis method	GFAA (SW 846-7421)	FAA (method 239.1)	EPA (method SW-846)	ICP-AES

Table 3-3e. Summary of Approaches for Dust Sampling and Analysis in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey.

Dust Sampling and Analysis		Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
FLOORS	Rooms sampled	All interior rooms	Child's bedroom, kitchen, play area, living room, entryway	Entryway, children's principal play room, kitchen, up to two children's bedrooms (one or more additional rooms were occasionally sampled)	One wet room, one dry room (both selected randomly from all such rooms), and entryway. (See Glossary in Appendix A for definitions of wet and dry rooms) Note: Common areas in multifamily units were also sampled, but their data were not used in this risk analysis.
	# samples collected per room	2 (from randomly-determined areas along the perimeter of the room)	3 from 1 ft^2 areas, one per sampling method, taken side-by-side in the midpoint of the room or where the child plays most frequently	From 1 to 5 dust sample results were reported per room (98% of rooms had one sample result).	1 (each from a 1 ft^2 area)
	Sample compositing	3 composites were formed per unit: ! Samples from all first-story rooms with windows ! Samples from all second-story rooms with windows ! Samples from all rooms with no windows	No compositing done	No compositing done.	No compositing done
	# samples analyzed from floors	490 composite samples in at least 122 housing units (includes composites containing dust from both carpeted and uncarpeted floors)	817 samples in 205 housing units	12,260 samples in 2,846 housing units	838 samples taken from 282 housing units (includes samples from floor surfaces with no recorded surface type)
	# samples analyzed from floors labeled as uncarpeted	352 samples in 122 housing units (composite dust samples from uncarpeted floors only)	405 samples in 205 housing units	9,044 samples in 2,797 housing units	335 samples taken from 214 housing units
	# samples analyzed from floors labeled as carpeted	53 composite samples in 34 housing units (composite dust samples from carpeted floors only)	412 samples in 205 housing units	3,216 samples in 1,396 housing units	470 samples taken from 241 housing units

Table 3-3e. Summary of Approaches for Dust Sampling and Analysis in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey. (Continued)

Dust Sampling and Analysis		Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
WINDOW SILLS	Rooms sampled	All interior rooms with windows	Child's bedroom, play area, living room	Kitchen, bedrooms, principal play room, up to two additional bedrooms (one or more additional rooms were occasionally sampled)	One wet room and one dry room (selected randomly from all such rooms) <u>Note</u>: Common areas in multifamily units were also sampled, but their data were not used in this risk analysis.
	# samples collected per room	Equal to the number of windows in the room available for sampling	3 (one per sampling method on a common window sill)	1 or 2 dust sample results were reported per room (99% of rooms had one sample result).	1
	Sample compositing approach	All window sill dust samples were composited into a single sample	No compositing done	No compositing done	No compositing done
	# samples analyzed	268 samples in 135 housing units	363 samples in 205 housing units	5,526 samples in 2,702 housing units	392 samples in 245 housing units
Sample collection method(s)		BRM vacuum sampler	BRM vacuum sampler DVM vacuum sampler Wipe sampling	Wipe sampling on floors and window sills DVM vacuum sampler on some carpeted floors	Blue Nozzle vacuum sampler
laboratory sample preparation		Digested using SW 846-3015 and SW 846-3051.	Digested using SW846-3051	Digested using SW846	SW-846 digestion protocol used
laboratory analysis method		ICP-AES (SW 846-6010) (GFAA (SW846-7421) was used if levels were below the ICP limit of quantitation)	FAA (method 239.1) (GFAA (method 239.2) was used if levels were below FAA detection limits)	Flame AA or ICP	GFAA

Table 3-3f. Summary of Approaches for Paint Sampling and Analysis in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey.

Paint Sampling and Analysis	Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
Interior rooms sampled	No specified rooms or components were identified for paint sampling in the study protocol. Paint sampling was done as a screening procedure to determine the presence of lead-based paint in only those units slated for R&M intervention. Sampled components were not selected randomly or by any other sampling protocol.	Kitchen, child's bedroom, play area, entryway	Extensive sampling of painted components in all interior rooms, on the building's exterior, and on various painted exterior surfaces associated with the unit, was done to determine the presence and location of lead-based paint. Within a room, components with different painting histories were to be tested separately.	One wet room and one dry room. Also one common area room in multifamily units. One room of each type was selected randomly from all such rooms.
Interior components sampled		Components sampled at a minimum: window sill, window sash, window well, trim, door, door jamb, painted floor		Painted components were grouped into four strata: ! Walls, ceilings, and floors ! Metal substrates ! Nonmetal substrates ! Other components In each sampled room, one component from each stratum was sampled. Then, an additional component anywhere in the unit was sampled.
Exterior components sampled		Components sampled at a minimum: door, door jamb, siding, masonry		Painted components on a single exterior wall were grouped into four strata: ! Wall ! Metal substrates ! Nonmetal substrates ! Other components On this wall, one component from each stratum was sampled (if available). Then, an additional component anywhere on the wall was sampled.
# of sampled components per housing unit		No more than 15 samples were to be taken per unit.		From 1 to 34 (average of 17 per unit)

Table 3-3f. Summary of Approaches for Paint Sampling and Analysis in the Baltimore R&M Study (pre-intervention phase), Rochester Lead-in-Dust Study, HUD Grantees Program, and the HUD National Survey. (Continued)

Paint Sampling and Analysis	Baltimore R&M Study (pre-intervention phase)	Rochester Lead-in-Dust Study	HUD Grantees Program (pre-intervention phase, as of 9/97)	HUD National Survey (privately-owned units only)
in situ measurement device used	XRF	Microlead I XRF	XRF (device type may vary among the grantees)	MAP-3 XRF
laboratory measurement device used	--	AAS or ICP (used only when *in situ* XRF could not be used)	Not specified (up to 10 paint chip samples could be taken from each unit for laboratory analyses when XRF results fall between 0.4 and 1.5 mg/cm^2)	
Method to rating paint condition	Paint condition was specified at the housing unit level for older housing only at enrollment: none/little peeling paint (65 of 125 units) vs. extensive peeling paint (12 of 125 units)	Three categories: ! Good (0-5% deteriorated) ! Fair (5-15% deteriorated) ! Poor (>15% deteriorated) Only sampled components were rated.	Three categories: • Good: Paint intact does not chalk • Fair: Largely intact with cracks and chipping • Poor: Peeling, chalking, blistering, flaking	Four categories: ! 0% deteriorated ! Less than 10% deteriorated ! 10-25% deteriorated ! >25% deteriorated Total square feet of deteriorated paint was recorded for some (not all) sampled components containing lead-based paint.

The remaining subsections provide details on key objectives and conclusions on the effects of childhood lead exposure along with an overview of the sampling designs, for the above nine studies.

3.2.2.1 Baltimore Repair and Maintenance (R&M) Study

The objectives of the Lead-Based Paint Abatement and Repair and Maintenance Study (USEPA, 1996b), cited as the "Baltimore R&M Study" in this document, were to characterize the efficacy of comprehensive lead-based paint abatement for up to six years after the abatements and to characterize the efficacy and costs of three levels (low, medium and high) of less costly Repair and Maintenance interventions. Environmental-lead and blood-lead data measured prior to performing interventions in this study were used in this risk analysis (USEPA, 1996b). These data were provided by Kennedy Krieger Institute, who was responsible for the overall design and conduct of the study.

In 1992, three groups of housing units were recruited for this study. In the first group, 16 dwellings were chosen from 90 occupied, low-income housing units that were built prior to 1941 and were abated between May, 1988, and April, 1992, as part of the Baltimore City and Kennedy Krieger Institute Pilot Abatement Projects. The second group, slated to receive R&M interventions in this study, consisted of 95 vacant or occupied, low-income dwellings in Baltimore City built prior to 1941. Twenty of these housing units were later removed from the study. Finally, 16 occupied, modern urban dwellings believed to be free of lead-based paint were chosen as control units. These units were chosen from clusters of urban houses built after 1979. At enrollment, all occupied units had to include at least one eligible child aged 6 to 60 months who spent most of his/her time at the unit. All vacant units were to become occupied following R&M interventions. All children in this study were African-American.

Prior to any intervention in this study, blood-lead concentrations were measured for 115 children that lived in 87 of the housing units at the time of enrollment. In addition, blood-lead concentrations were measured on 48 children before they moved into one of 39 housing units that were vacant at the time of enrollment and that had R&M interventions performed in this study prior to being occupied. These blood-lead concentration data and environmental-lead data from samples collected prior to any R&M intervention performed in this study were used in this risk assessment.

The BRM vacuum method, consisting of a modified HVS3 cyclone collector, was the primary dust sampling method used in the R&M Study (USEPA, 1995c). Within each housing unit, rooms were divided into three groups: first-story rooms with windows, second-story rooms with windows, and all rooms with no windows. Within each group of rooms, a composite sample of floor dust from multiple areas along the perimeter of each room was collected. In addition, the following four composite dust samples were collected in each unit: dust from first-story window sills, dust from first-story window wells, dust from second-story window sills, and dust from second-story window wells.

Lead levels in paint were measured through *in situ* x-ray fluorescence (XRF) measurement in only those units slated for R&M intervention, in order to determine whether lead-based paint existed in these units. Only those components suspected of being covered with lead-contaminated paint were measured, and no specified protocol was followed to take these measurements. As a result, paint-lead measurements in this study do not represent a random sampling of painted surfaces in a housing unit and should be not used to make generalizations on lead levels in paint within these types of housing.

At 28 units, three soil samples were taken from (½ inch) soil cores collected at the foundation (dripline) and composited. The number of units with soil samples was small due to the lack of available dripline soil to sample. Two-hour stagnation drinking water samples were also collected from units occupied prior to interventions. Dust, soil, and water samples were analyzed for lead using inductively coupled plasma-atomic emission spectrometry or graphite furnace atomic absorption spectroscopy. A structured questionnaire collected information on study children and the households.

The primary conclusions made from summary and analysis of the pre-intervention data in this study were as follows:

- Pre-intervention dust-lead loadings in units slated for R&M interventions in this study were higher than those in previously-abated units by approximately one to two orders of magnitude. Furthermore, dust-lead concentrations in previously-abated units were higher than those in modern urban units by approximately two to three orders of magnitude. Differences of approximately one order of magnitude were observed in pre-intervention dust-lead concentration between units slated for R&M interventions and previously-abated units, and between previously-abated units and modern urban units.

- Dust-lead levels in previously-abated units were moderately elevated, despite the abatement efforts on these units that preceded this study by two to four years. This can be partially due to the location of these units in older neighborhoods, or to residual contamination from abatement.

- Blood-lead concentrations were low for children living in modern urban units compared to units slated for R&M intervention and previously-abated units. The continued presence of elevated blood-lead concentrations in previously-abated units implies that the abatement effort performed in these units prior to this study did not necessarily reduce blood-lead concentrations to acceptable levels in these units.

- Significant linear correlation was observed between blood-lead concentrations and environmental-lead levels when considering all children regardless of housing group.

- Lead levels in drinking water were very low and considered not to be a lead hazard to children in this study.

Details on pre-intervention environmental-lead levels and blood-lead concentrations in this study are presented in Sections 3.3.1.2 and 3.4.2, respectively.

3.2.2.2 Rochester Lead-in-Dust Study

The Rochester study (USHUD, 1995a and Lanphear et al., 1995), conducted in 1993, was a cross-sectional design study whose primary objective was to obtain information on the association between lead levels in house dust and blood-lead concentrations of resident children. Children between the ages of 12 and 31 months and living in the city of Rochester, NY, were eligible for this study, provided:

- they or their environment had not undergone recent interventions that were likely to alter blood or dust lead (e.g., major renovation, recent ingestion of prescribed iron products, or any medical or environmental intervention for an elevated blood-lead level),

- they did not spend more than 20 hours per week away from home, and

- they did not live with an adult exposed to lead from an occupational or recreational activity (Lanphear et al., 1995).

Random sampling techniques were used to recruit children born from March 1, 1991, to September 30, 1992, at either Rochester General Hospital, Strong Memorial Hospital, or St. Mary's Hospital. Data for 205 families and children were included in the analysis. Succinct descriptions of the quality control procedures employed for all laboratory samples during the Rochester Lead-in-Dust Study are given in Lanphear et al., 1995. The Rochester study dataset is publicly available and can be obtained from the National Center for Lead-Safe Housing.

During visits to the home of each study participant, an environmental health team obtained a venipuncture blood sample from the eligible child, completed a behavioral questionnaire for the household regarding lead exposure, collected environmental samples (interior dust, exterior soil, water), and took *in situ* measurements of lead in paint. The dust samples were collected from floors, window sills, and window wells within rooms in which the child was frequently present. This risk analysis considered only dust-lead loading results from samples collected using wipe techniques (“Little Ones” baby wipes). However, because a secondary objective of the Rochester study was to evaluate various dust sampling methods relative to predicting children's blood lead levels, dust samples were also collected using the University of Cincinnati Dust Vacuum Method (DVM) and the BRM vacuum (USEPA, 1995c). Lead concentrations of dust samples collected using the BRM vacuum are also summarized. Side-by-side dust samples were collected at specific locations, with each sample corresponding to a particular collection method and the wipe sample being the first to be collected. Dust samples were analyzed using either flame or graphite furnace atomic absorption spectroscopy. Soil samples, taken at the play area and dripline, were analyzed using flame atomic absorption spectroscopy. Further details on sample collection are available in Lanphear et al., 1995.

Children enrolled in the Rochester study were not specifically recruited because of elevated blood-lead concentrations. However, a disproportionate percentage of these children exhibited two risk factors associated with elevated blood-lead concentrations: residing in older housing (at least 84% of the homes were built prior to 1940) and belonging to low-income families (55% of households had incomes below $15,500).

Based on analysis of the public dataset, the geometric mean blood-lead concentration for the 205 children in the Rochester study was 6.38 µg/dL, with a geometric standard deviation of 1.85. Twenty-three percent of the children had blood-lead concentrations above 10 µg/dL, 8% above 15 µg/dL, and 3% above 20 µg/dL. Further summaries of blood-lead concentrations in this study are presented in Section 3.4.3.

A statistical approach using linear regression techniques (Neter and Wasserman, 1974) was used to determine those environmental variables and questionnaire variables most important to predicting blood-lead concentration in children (USHUD, 1995a and Lanphear et al., 1995). In addition to wipe dust-lead loading, the following factors were significantly associated with increased blood-lead concentrations among children: African-American race, children engaging in soil pica, single parent household, and high ferritin levels. Adjusting for these factors, wipe dust-lead loading accounted for 10.1% of the variation in blood-lead concentrations (USHUD, 1995a and Lanphear et al., 1995).

The Rochester study also investigated the relationship between soil-lead concentration and children’s blood-lead concentration. One composite soil sample was obtained from a maximum of 12 core samples (3 per side of house) taken two feet away from the foundation, and a second composite sample was obtained from 8-10 samples taken where the child frequently played. A coring device was used to take samples at a depth of ½ inches only where bare soil was present. When asked “How often does [the study child] put dirt or sand in his/her mouth,” 27% of the home interview respondents indicated that the study child for which they were responding “sometimes,” “often,” or “always” did. The remaining 53% indicated the study child “never” or “rarely” did (USHUD 1995a). Soil-lead concentration was a significant (positive) predictor of blood-lead concentration, even when adjusting for dust-lead loading (USHUD, 1995a).

The Rochester study concluded that lead-contaminated dust significantly contributes to children's blood-lead concentrations, even when those concentrations are in the low to moderate range (Lanphear et al., 1996b). This relationship differs according to the dust sampling method and the type of surface sampled. At the relatively low levels of dust-lead loadings and concentrations in this study, dust-lead loadings were found to be a better predictor of blood-lead concentration than were dust-lead concentrations. Of the three dust collection methods considered, dust-lead loadings from samples collected using either wipe or BRM-vacuum methods were more highly correlated with blood-lead concentrations than were loadings from DVM dust samples (Lanphear et al., 1995). As data were collected in late summer and autumn, the seasonal effect on these relationships could not be measured.

Summaries of environmental-lead levels observed in the Rochester study are presented in Section 3.3.1.3. Data from the Rochester study were employed to develop the empirical model used in this risk assessment (Section 4.2).

3.2.2.3 Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program ("HUD Grantees")

Since 1994, grantees participating in the HUD Lead-Based Paint Hazard Control Grant Program have conducted interventions in privately-owned low- and middle-income housing to control lead-based paint hazards. The grantees are primarily affiliated with states and local governments. In this program, HUD has supplied an additional grant to the National Center for Lead-Safe Housing (NCLSH) to evaluate the cost and efficacy of the interventions being conducted. In this evaluation, fourteen grantees are collecting data on environmental, biological, demographic, housing, cost, and hazard-control aspects of the interventions they are performing. NCLSH is conducting this evaluation with the Department of Environmental Health at the University of Cincinnati (UCDEH).

Among the data being collected in this evaluation are the following:

! lead loadings in dust samples using wipe collection techniques, determined prior to and following any environmental intervention in a housing unit. Carpeted or uncarpeted floors, window sills, and window wells were sampled. Rooms sampled included entryways, children's principal play room (or living room), kitchen, and up to two children's bedrooms. The DVM sampler was occasionally used on carpets, but these data were not considered in this exposure assessment.

! blood-lead concentration for children between the ages of six months and six years, determined prior to and following any environmental intervention in a housing unit. While the program recommended venipuncture collection techniques, some grantees are using fingerstick methods. Blood samples were analyzed by graphite furnace atomic absorption spectrophotometry (GFAAS) or by anodic stripping voltammetry (ASV).

! lead levels on painted surfaces prior to intervention to determine the presence and location of lead-based paint. Portable XRF measurement techniques were used, but laboratory testing of paint chips was also employed when XRF measurements were indeterminant.

! soil-lead concentration prior to and following any environmental intervention, where composite soil samples were collected from the dripline (foundation) and from children's play areas. As soil sampling was optional in this program, the availability of soil-lead concentration data is limited.

! demographic information on the household and on the resident children, such as income level, age of house, age of child, and mouthing behavior.

Only pre-intervention data collected from February, 1994, to September, 1997, were available for this exposure assessment. These data provide some of the most recent information on environmental-lead measurements in housing units with high potential for containing lead-based paint hazards, and the relationship of these measurements with children's blood-lead concentration.

The grantees followed specified sampling protocols and used standard data collection forms developed specifically for this evaluation (NCLSH and UCDEH, 1994). However, as it was HUD's desire to emphasize local control of the individual programs, each grantee was given some freedom in developing their approach to recruitment and enrollment. Some grantees targeted high-risk neighborhoods, while others enrolled only homes with a lead-poisoned child, while still others considered unsolicited applications. The locations at which data were collected, along with the enrollment criteria, are summarized in Table 3-4.

Preliminary conclusions made on the pre-intervention data from the HUD Grantees evaluation program are as follows:

! Blood-lead concentrations and environmental-lead levels tend to vary widely across grantee locations, primarily due to how housing units were targeted for enrollment by each grantee, and methods used to obtain and analyze the samples.

! Compared to the national housing stock as a whole, housing units enrolled in the evaluation program are more likely to contain lead-based paint hazards (e.g., older or low-income housing, or the neighborhood has a history of lead-based paint hazards) or to contain children with elevated blood-lead concentrations. As a result, blood-lead concentrations and environmental-lead levels tended to be high for most housing units. However, when interpreting results of any analyses of data from this program, one should be aware of regional or strategy selection biases that may be present.

Results of interim comparisons of environmental-lead levels and blood-lead concentrations between pre-intervention and post-intervention periods are found in NCLSH and UCDEH, 1997.

Summaries of pre-intervention environmental-lead measurements from the HUD Grantees evaluation program are presented in Section 3.3.1.4, while pre-intervention blood-lead concentrations and their observed relationships with selected environmental-lead parameters are summarized in Section 3.4.3. Note that these data are considered preliminary, as only data collected through September, 1997, were available to this exposure assessment.

Table 3-4. Location of Grantees Participating in HUD Grantee Program Evaluation, and Grantees' Criteria for Enrollment/Recruitment of Housing Units.

Location of Grantee	Enrollment Plan	# Units Enrolled[1]
Alameda County[2]	Targeting 4 high-risk cities (Alameda, Berkeley, Emeryville, Oakland); many units contain a lead-poisoned child	334
Baltimore	Targeting 3 neighborhoods, 2 of which have histories of lead-poisoning; predominantly rowhouses	649
Boston	Enrolling only units which have received an order to abate based on the identification of a lead-poisoned child	158
California[2]	Targeting older homes in low-income neighborhoods	186
Chicago	Targeting 5 neighborhoods; units are selected based on reports of a lead-poisoned child and after a special compliance hearing is held	185
Cleveland[2]	Using two criteria independently: one targets units with a lead-poisoned child, and the other targets homes in a single neighborhood	264
Massachusetts	Primarily enrolling units under existing orders to abate because of the presence, at some time, of a lead-poisoned child (Brockton, Chelsea, Lawrence, and Worchester)	327
Milwaukee[2]	Targeting several of the lowest income neighborhoods in the city; units are selected from referrals of families with a lead-poisoned child	477
Minnesota[2]	Minneapolis/St. Paul: targeting units with a lead-poisoned child Duluth: targeting units with deteriorated housing conditions	282
New Jersey[3]	Selecting units in conjunction with concurrent comprehensive housing renovation/rehabilitation	119
New York City[3]	Targeting neighborhoods with the highest percentages of lead poisonings; one of two programs is specifically targeting families with newborn babies living in deteriorated housing	387
Rhode Island[2]	Enrolling only units that meet Section 8 Housing Quality Standards, and the owner cannot own more than 12 units	383
Vermont[2]	Considering referrals of families with lead-poisoned children, non-profit housing developers who learn of the program when applying for federal HOME funds, and unsolicited applications	954
Wisconsin[2]	Each of the 12 sub-grantees within the state (not counting Milwaukee) use own criteria (no information given)	294
TOTAL NUMBER OF HOUSING UNITS ENROLLED[1]		4999

[1] Through September, 1997. Environmental-lead and/or blood-lead data were not available for some units.
[2] Grantee collected soil samples as well as samples of other environmental media.
[3] Grantee did not collect blood samples.

3.2.2.4 Urban Soil Lead Abatement Demonstration Project (USLADP)

The USLADP, authorized in 1986 under the Superfund Amendments and Reauthorization Act, was conducted in 1988-1991 to determine whether reducing lead levels in soil accessible to children decreases their blood-lead concentration (USEPA, 1996a). While other observational studies of childhood lead exposure such as the Rochester study have shown that differences in soil lead exposure are associated with differences in blood-lead concentration, this project specifically addressed whether controlled reductions in external soil lead exposure were associated with reductions in blood-lead concentrations. The USLADP consisted of three studies conducted in Baltimore, MD, Boston, MA, and Cincinnati, OH. This project considered soil abatements in urban areas and focused on inner-city children. The USLADP Integrated Report (USEPA, 1996a) is the source for study details reported here.

In Baltimore, data were analyzed for 185 children aged 6 to 72 months. These children resided in either the study area (expectation of moderate risk of lead poisoning) or a control area. The Boston study included 149 children aged 6 to 48 months, considered to be at risk for lead exposure and residing in one of the study areas (history of high incidence of lead poisoning). Only children with blood-lead concentrations ranging from 7 to 24 µg/dL were included in the Boston study. In Cincinnati, families with children under five years of age and residing in one of the study areas (selected as having similar socioeconomic and housing type characteristics) were enrolled in the study. Data for 206 children were analyzed from the Cincinnati study.

Within each city, a series of neighborhoods were considered in the study from which the participating households were selected. Selected units within certain neighborhoods were to have interventions performed, while units in other neighborhoods were selected as control units. For purposes of data summary and analysis, study units were grouped according to intervention strategy. Environmental media sampled included dust, soil, drinking water, and paint. Household interviews were also conducted to obtain information on such factors as household behavior and socioeconomic status.

The following two main conclusions were drawn from the USLADP (USEPA, 1996a):

1. *"When soil is a significant source of lead in the child's environment, under certain conditions, the abatement of that soil will result in a reduction in exposure that will cause a reduction in childhood blood lead concentrations."*

2. *"Although these conditions for a reduction in blood are not fully understood, it is likely that five factors are important in determining the magnitude of any possible reduction: (1) the past history of exposure of the child to lead, as reflected in the pre-abatement blood lead; (2) the initial soil lead concentration and the magnitude of the reduction in soil lead concentrations; (3) the initial interior house dust lead loading and the magnitude of reduction in house dust lead loading; (4) the magnitude of other sources of lead exposure, relative to soil; and (5) the strength of the exposure pathway between soil and the child relative to other lead exposure pathways in the child's environment."*

The five factors specified in the second conclusion contributed to differences among the studies on the impact of soil abatement. The Baltimore and Cincinnati studies concluded that the impact of soil abatement on blood-lead concentrations was limited, in part due to low pre-intervention soil-lead concentrations and the extent to which soil was contributing to lead in house dust. Soil-lead concentrations were higher in the Boston study, where soil abatement was associated with declines in blood-lead concentration. However, researchers in the Boston study concluded that these declines are generally modest, and as a result, may not warrant the resources required to conduct a soil abatement when only low levels of lead exposure are present (Weitzman et al., 1993).

The entire soil region surrounding the residence was partitioned into distinct areas (e.g., front, back), and samples were taken from each partition. At each core sample, the top 2" and bottom 2" of the sample core were retained. A single core sample was taken when less than two meters in either direction were available for sampling. Larger areas had core samples taken at the foundation and at the boundary.

Dust samples were collected by vacuum methods in all three cities. In Baltimore, the Sirchee-Spittler vacuum sampler was used to collect dust samples from a 4' x 4' sample area demarcated with tape. A minimum of three areas were sampled: the main entrance to the household and two areas often frequented by the child when playing. In Boston, the same sampler and sampling sites were used, but a plastic 25 cm x 25 cm frame was used instead of tape. In Cincinnati, the DVM sampler was used with a plastic 25 cm x 25 cm frame. Dust was sampled from a floor area adjacent to the main entrance from a floormat placed by sample collection personnel. In addition, a composite of dust samples from floors was collected from at least three areas including the child's bedroom and a high traffic area in the main living area, and a composite of dust samples was collected from at least three window well and sill areas including from within the child's bedroom and the main living area. Dustfall and exterior surface dust were also measured.

The design of the USLADP studies allowed EPA to evaluate some of the effects of soil lead abatement. The design and implementation of the study was appropriate for a longitudinal intervention study, and no other uses of the study data were anticipated. As a result, data from these studies were not used for general exposure assessment in this risk analysis. Other reasons for not using these data in the risk analysis are as follows:

1. The housing units and children sampled in the Baltimore study were not intended to represent a cross-section of Baltimore children, nor a cross-section of housing in Baltimore. They were chosen because they had a large number of lower-income pre-school children and were believed to have high yard soil lead concentrations.

2. The Boston study was designed to include only children whose blood lead was not too high (< 24 µg/dL), not too low (at least 7 µg/dL), and who lived in housing with high yard soil lead (in general, at least 1000 µg/g).

3. The Cincinnati study was designed to control for lead paint as a factor that may confound direct or indirect soil lead exposure. The control measure was to include only completely rehabilitated housing, where almost all of the lead-based paint had been stripped off of walls and trim.

4. In the Boston and Baltimore studies, dust samples were collected using the Sirchee-Spittler vacuum method (USEPA, 1995c). No convenient method has been established for converting Sirchee-Spittler dust-lead loadings to wipe dust-lead loadings necessary for the risk analysis.

5. The Cincinnati study collected soil-lead concentrations at the neighborhood level. It is not clear how to relate neighborhood soil-lead measurement concentrations to a specific child's exposure.

6. Age of housing unit is not reported for the majority of units in the USLADP.

3.2.2.5 Birmingham Urban Lead Uptake Study

This study was conducted in Birmingham, England, from 1984-1985, and consisted of 183 randomly-selected children, aged 24 months (± 2 months), born in and still residing in urban Birmingham. A stratified subset of 106 children were selected for the study, of which 97 completed the study. The objective of the study was to simultaneously examine lead uptake via all identified environmental pathways for young children in an urban environment.

Soil samples were collected using a stainless-steel trowel surface scrape (0-5 cm). One composite soil sample was obtained from 25 core samples. A specially adapted vacuum was used to collect dust samples from the child's main play area, the child's bedroom and under the doormat. All exposed floor space was sampled. Samples were also taken from the bag of the vacuum cleaner most often used by the household.

The main conclusion from this study was that childhood blood-lead concentration was found to be significantly associated with a combination of dust-lead loading, the rate of touching objects, water-lead concentration, and smoking habits of the parents. Only an estimated 3% of a child's average total uptake of lead per day was attributed to breathable air; the remainder was attributed to dust, food, and water ingestion.

Because this study was conducted outside of the United States over ten years ago, it was considered less representative of current childhood lead exposure in the United States than more recent studies. Therefore, the data from this study were not used in this risk analysis.

3.2.2.6 Cincinnati Longitudinal Study

Objectives of the Cincinnati Longitudinal study, conducted from 1980-1987, were to provide a complete picture of a child's lead exposure history and to investigate the factors responsible for excessive lead exposure. Approximately 250 expectant mothers residing within a prespecified set of census tracts in the Cincinnati (OH) area were enrolled for this study. These census tracts were identified as having a long history of producing children with elevated blood lead levels. The mothers were patients at one of three prenatal clinics. Once these mothers delivered, blood-lead concentrations were measured in the children from birth through 5 years of age.

Soil samples were collected by surface scrapings. Surface scrapings were collected from the child's play area outside, if one existed. Interior dust samples were collected from areas where the child frequents using a personal sized vacuum within a 484 cm^2 plastic frame. A maximum of five sites were sampled within the home. Each sample entailed three sweeps of the vacuum within the frame. Exterior dust samples were collected via scraping exterior surfaces with a stainless steel spatula. Paint-lead levels from a maximum of 15 surfaces were measured using XRF techniques. Dust collection from children’s hands was performed via repeated wiping with multiple pre-moistened wipes.

This study observed high levels of lead contamination in the residential environments, with most contamination occurring in areas immediately outside of the unit and within the entranceways. Statistical analyses indicated that the pathway from exterior dust to interior dust to hands to blood was of most significance in this study (Figure 3-3).

Due to the age of this study, data were not used in this risk analysis.

3.2.2.7 Brigham and Women’s Hospital Longitudinal Study

The objective of this early study was to examine the relationship between children’s blood-lead levels and various environmental factors from late pregnancy to two years of age. Children were selected from births occurring between April 1979 and April 1981 at Brigham and Women’s Hospital in Boston, MA. Births were categorized into the highest, lowest, and middle deciles of umbilical cord blood lead. The 249 infants selected were nearly equally drawn from three distinct categories of cord blood levels. All families resided in an urban environment within a 12 mile radius of hospital, spoke English as their primary language, and the infants had no serious illness. These families were predominantly white and middle- to upper-middle class. In addition to umbilical cord blood, blood samples were collected at 6, 12, 18, and 24 months of age.

At 18 and 24 months, soil samples were collected at a distance of three meters from any road or structure. Dust samples were collected at 1, 6, 18, and 24 months using wipe techniques from a living room surface (floor or furniture top) and from a window sill. Samples were collected from within a plastic frame having a 930 cm^2 opening (a 465 cm^2 opening for window sills). Lead levels in paint were measured by a PGT model XE-3 XRF instrument. Air samples were collected from personal air monitors, and drinking water samples were collected from the kitchen tap after a 4-liter flush.

Mean blood-lead concentrations at 24 months was 6.8 µg/dL. At 24 months, blood-lead concentration was found to be significantly associated with soil-lead concentration, dust-lead loading, the presence of deteriorated paint, and the occurrence of recent refinishing activities at the residence. Water-lead and airborne-lead levels were not significant factors. These findings agreed with earlier studies which considered children with higher blood-lead concentrations. In addition, blood-lead concentrations were found to be approximately 44% higher within specimens collected in summer months, indicating a possible seasonality factor associated with blood-lead concentration.

Due to the age of the study, data from this study were not used in this risk analysis.

3.3 LEAD IN DUST, SOIL, AND PAINT IN THE NATION'S HOUSING

This section provides information on the distribution of environmental-lead levels in the nation's housing stock, with a focus on lead in residential dust, soil, and paint. This risk analysis uses data from the HUD National Survey of Lead-Based Paint in Housing to characterize the distribution of environmental-lead levels in the nation's occupied housing stock in 1997. These environmental-lead data are summarized in Section 3.3.1. To supplement the national environmental-lead data with data for certain categories of housing units, such as inner-city homes and older homes in an urbanized setting, environmental-lead data from the Baltimore R&M Study (Section 3.2.2.1), the Rochester Lead-in-Dust Study (Section 3.2.2.2), and the HUD Grantees Program (Section 3.2.2.3) are also summarized in this section. Section 3.3.1 also includes estimated numbers of occupied housing units in the 1997 national housing stock.

To provide a link between childhood and residential environmental lead exposures, Section 3.3.2 presents estimated numbers of children of specific age groups in 1997 residing within housing units of specific ages.

3.3.1 The Distribution of Lead Levels in Household Dust, Soil, and Paint

In this section, environmental-lead levels in residences are summarized for four studies. The first study presented, the HUD National Survey, is the primary source of data on environmental-lead levels in the nation's occupied housing stock. While this study was designed to be a nationally-representative study of environmental-lead in the nation's housing built prior to 1980, it is used here to characterize the nation's housing in 1997, prior to §403 interventions. The other three studies, the Baltimore R&M Study, the Rochester study, and the HUD Grantees program, provide supporting information on environmental-lead levels for specific housing groups or exposure conditions.

As discussed in Section 3.2.2, the four studies presented in this section were selected to provide data for this risk analysis for the following reasons:

- The studies had available data for lead in paint, dust, and soil.

- The Baltimore R&M Study, the Rochester study, and the HUD Grantees program also had data available on lead in children's blood.

- These studies were conducted recently.
- These studies were not conducted in locations with a specific point source of lead.
- These studies were conducted in the United States (source control may be different in other countries).

3.3.1.1 HUD National Survey

For this risk analysis, the primary source of information on environmental-lead levels in the national housing stock was the National Survey of Lead-Based Paint in Housing (USEPA, 1995a; USEPA, 1995g; and USEPA 1995h). This survey was sponsored by the U.S. Department of HUD, in response to a mandate in the 1987 amendments to the Lead-Based Paint Poisoning Prevention Act to obtain "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." Conducted in 1989-1990, the privately-owned unit portion of the survey (cited as the "HUD National Survey" in this document) measured lead levels in paint, dust, and soil within 284 privately-owned, occupied housing units. The units were selected via a statistically-based sampling design to represent the national housing stock built prior to 1980. Units built in 1980 or later were not included in the survey, as they were assumed to be free of lead-based paint as a result of the Consumer Product Safety Commission's 1978 regulation on the maximum allowable lead in paint used for residences, toys, furniture, and public areas. CPSC's maximum lead level is below the thresholds usually used to define lead-based paint (1.0 mg/cm^2, or 0.5% lead by weight).

The design of the HUD National Survey stipulated that housing units be distributed across three age categories (pre-1940, 1940-1959, 1960-1979) based on proportions indicated in the 1987 American Housing Survey and that multi-family units be oversampled (USEPA, 1995a; USEPA, 1995g). To take into account the oversampling of multi-family units and the overrepresentation of certain demographic groups in the final sample, the HUD National Survey assigned sampling weights to each surveyed housing unit. The sum of all 284 sampling weights equaled the number of pre-1980 privately-owned, occupied units in the national housing stock at the time of the survey. Sampling weights in the HUD National Survey were determined according to four demographic variables associated with the units:

- Age category of unit
- Number of units in the building
- Census region
- Presence of a child under age 7 years.

The method to assigning sampling weights ensured that inferences based on the 284 privately-owned homes sampled in the HUD National Survey would be representative of the pre-1980 national housing stock.

In order to use the environmental-lead levels from the HUD National Survey to characterize environmental-lead levels in the 1997 national housing stock, it was necessary to revise the sampling weights of the HUD National Survey units to represent the 1997 occupied housing stock, both publicly-owned and privately-owned. (While environmental data for only the 284 privately-owned units in the HUD National Survey were used in this risk analysis, the revised 1997 sampling weights for these units represent both privately-owned and publicly-owned units in the national housing stock.) Using data from the U.S. Bureau of the Census, the method for revising the sampling weights is documented in Section 1.1.2 of Appendix C1; Table C1-7 of Appendix C1 lists the revised weights for each unit. The revised weights, therefore, indicate the number of units in the 1997 national housing stock that are represented by the given HUD National Survey unit, and therefore, represented by its environmental-lead levels. The estimated numbers of units in the 1997 national housing stock are presented in Table 3-5, within four age categories.

Table 3-5. Estimated Total Number of Occupied Housing Units in the National Housing Stock in 1997 According to Year-Built Category.

Year In Which the Unit Was Built	Number of National Survey Units	Estimated Numbers of Units in the 1997 National Housing Stock
Pre-1940	77	19,676,000
1940-1959	87	19,718,000
1960-1979	120	34,985,000
Post-1979	28[1]	24,893,000
	Estimated Total:	99,272,000

[1] Units built from 1960-1979 and containing no lead-based paint were placed in this category as well as in the 1960-1979 category.

The HUD National Survey did not consider units built after 1979, as all such units were assumed to be free of lead-based paint. In characterizing the 1997 national housing stock from the HUD National Survey, post-1979 housing was represented by the 28 units built between 1960 and 1979 and containing no lead-based paint (i.e., the predicted maximum amount of lead in paint within the unit was less than 1.0 mg/cm^2). Therefore, the revised sampling weights for these 28 units are the sum of two parts: one part representing 1960-1979 units, and the other representing post-1979 units. This approach assumes that environmental lead levels in post-1979 homes are similar to environmental lead levels in homes built between 1960 and 1979 which do not contain lead-based paint. See Section 1.1.3 of Appendix C1 and Section 3.3.1.5 on the rationale for selecting these 28 units to represent the post-1979 housing stock and on the method for obtaining the portion of the sampling weight representing post-1979 units.

In the HUD National Survey, lead loadings (µg of lead per square-feet of area sampled) and lead concentrations (µg of lead per gram of sample) were measured from dust samples collected on floors, window sills, and window wells. Dust samples were collected using the Blue

Nozzle vacuum method. Lead concentrations in the soil at each unit were measured by collecting soil samples along the foundation, the entryway to the unit, and from remote areas in the yard, using a soil corer with plunger. Lead levels in paint (milligrams of lead per square-centimeter of painted surface) were measured using *in situ* XRF techniques in selected rooms as well as on the exterior of the unit. Detailed protocols for sample collection are available in USEPA, 1995g.

In the HUD National Survey, the dust-lead concentration equaled the amount of lead in the entire dust sample, divided by the tap weight. “Tap weight” is the portion of a dust sample that was tapped out of the sample collection filter. Note that the tap weight could be less than the actual weight of the collected sample. Therefore, the dust-lead concentration measurements used in this risk analysis were adjusted for the effect of underestimated sample weights. Details on the method used to adjust the tap weights is available in USEPA, 1996c. Lead concentrations for dust samples with a tap weight of less than 0.7 mg were omitted from risk analyses.

In this risk analysis, data from the 284 privately-owned units in the HUD National Survey were used to characterize environmental-lead levels in the nation’s occupied housing. Table C1-7 of Appendix C1 contains the following summary of environmental-lead levels for each of these units:

- two weighted arithmetic averages of dust-lead loading: one for floors and one for window sills (where each sample's results were “area-weighted,” or weighted according to area of sample location)

- two weighted arithmetic averages of dust-lead concentration: one for floors and one for window sills (where each sample's results were “mass-weighted,” or weighted according to mass of sample)

- the weighted arithmetic average soil-lead concentration (where remote sample results were weighted twice that of the entryway and dripline results)

- the maximum observed amount of lead in paint, determined for both the interior and the exterior, as measured by *in situ* XRF techniques.

Note that the last bullet indicates the maximum <u>observed</u> (or measured) paint-lead concentration in a unit. To identify whether a unit was suspected of containing any lead-based paint, even in unsampled areas, statistical modeling was performed in the HUD National Survey to obtain a <u>predicted</u> maximum XRF measurement for each unit. If the predicted maximum XRF measurement for a unit was greater than or equal to 1.0 mg/cm^2, the unit was considered to contain lead-based paint (USEPA, 1995a). In this risk analysis, a unit's predicted maximum XRF measurement was used only to identify the presence of lead-based paint within the unit.

Using the environmental-lead measurements and the updated 1997 sampling weights for the HUD National Survey units from Appendix C1, Tables 3-6 and 3-7 summarize the estimated lead loadings and concentrations, respectively, in floor-dust samples across units in the 1997 housing stock. Tables 3-8 and 3-9 summarize lead loadings and concentrations, respectively, in window sill-dust samples. Table 3-10 summarizes lead concentrations in soil. To summarize the results of XRF paint testing across the surveyed units, Table 3-11 presents information on the extent of XRF sampling, the presence of lead-based paint, the presence of deteriorated lead-based paint, and the distribution of maximum XRF measurements in a unit, for specific categories of interior and exterior painted components. Table 3-12 presents summaries of each unit's maximum XRF measurement for paint within three age group categories. The percentages of units in the 1997 housing stock having lead-based paint, as well as the percentages having damaged lead-based paint, are estimated in Table 3-13. The statistics calculated in these tables are summaries of the observed data (using 1997 estimated sampling weights) and do not make any distribution assumptions. Variability in these data may result in unexpected (and likely insignificant) trends across age categories.

Table 3-6. Summary of the Distribution of Lead Loadings in Floor-Dust Samples Within Housing Units in the HUD National Survey, Weighted to Reflect the Predicted 1997 Housing Stock.

Surveyed Units, According to the Year Unit Was Built	Floor Dust-Lead Loadings (µg/ft²)[1]						
	Geometric Mean	Geometric Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile
All Units Built Before 1940	22.6	3.63	2.83	8.47	17.2	46.2	197
All 1940-1959 Units	8.74	3.34	1.25	4.20	8.32	22.5	72.0
All 1960-1979 Units	4.14	2.45	1.20	2.28	4.04	7.63	21.2
1960-1979 units with no LBP[2]	3.14	2.06	1.21	1.76	2.84	5.66	12.2

[1] The statistics presented in this table were calculated on area-weighted (i.e., weighted for area of sample location) arithmetic mean dust-lead loadings from floors for the 284 privately-owned, occupied National Survey units (see Appendix C1). These loadings are converted to represent loadings from dust samples obtained from wipe collection techniques. In the summaries, each unit is weighted by its 1997 weight, which is presented in Appendix C1.

[2] Units with no LBP have a predicted maximum XRF value (interior and exterior) less than 1.0 mg/cm². These units represent post-1979 units in this risk analysis.

Table 3-7. Summary of the Distribution of Lead Concentrations in Floor-Dust Samples Within Housing Units in the HUD National Survey, Weighted to Reflect the Predicted 1997 Housing Stock.

Surveyed Units, According to the Year Unit Was Built	Floor Dust-Lead Concentrations (µg/g)[1]						
	Geometric Mean	Geometric Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile
All Units Built Before 1940	505	4.00	86.6	246	406	813	2260
All 1940-1959 Units	201	2.64	32.2	101	218	330	1240
All 1960-1979 Units	121	3.01	24.5	72.1	137	223	647
1960-1979 units with no LBP[2]	91.9	2.16	21.5	53.5	86.5	165	429

[1] The statistics presented in this table were calculated on mass-weighted (i.e., weighted for mass of sample) arithmetic mean dust-lead concentrations from floors for the 284 privately-owned, occupied National Survey units (see Appendix C1). These concentrations were adjusted to reflect the weight of the entire dust sample, not just the tap weight (USEPA, 1996c). In the summaries, each unit is weighted by its 1997 weight, which is presented in Appendix C1.

[2] Units with no LBP have a predicted maximum XRF value (interior and exterior) less than 1.0 mg/cm². These units represent post-1979 units in this risk analysis.

Table 3-8. Summary of the Distribution of Lead Loadings in Window Sill-Dust Samples Within Housing Units in the HUD National Survey, Weighted to Reflect the Predicted 1997 Housing Stock.

Surveyed Units, According to the Year Unit Was Built	Window Sill Dust-Lead Loadings (µg/ft²)[1]						
	Geometric Mean	Geometric Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile
All Units Built Before 1940	168	16.7	0.797	8.32	96.4	808	6190
All 1940-1959 Units	22.0	10.7	0.659	6.77	27.0	177	1290
All 1960-1979 Units	16.2	14.6	0.250	2.82	18.1	217	575
1960-1979 units with no LBP[2]	8.17	9.94	0.122	2.58	8.11	57.8	127

[1] The statistics presented in this table were calculated on area-weighted (i.e., weighted for area of sample location) arithmetic mean dust-lead loadings from window sills for the 284 privately-owned, occupied National Survey units (see Appendix C1). These loadings are converted to represent loadings from dust samples obtained from wipe collection techniques. In the summaries, each unit is weighted by its 1997 weight, which is presented in Appendix C1.

[2] Units with no LBP have a predicted maximum XRF value (interior and exterior) less than 1.0 mg/cm². These units represent post-1979 units in this risk analysis.

Table 3-9. Summary of the Distribution of Lead Concentrations in Window Sill-Dust Samples Within Housing Units in the HUD National Survey, Weighted to Reflect the Predicted 1997 Housing Stock.

Surveyed Units, According to the Year Unit Was Built	Window Sill Dust-Lead Concentrations (µg/g)[1]						
	Geometric Mean	Geometric Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentil e	95th Percentil e
All Units Built Before 1940	1710	5.24	72.1	500	1690	6680	10200
All 1940-1959 Units	471	4.08	48.1	244	510	1330	4470
All 1960-1979 Units	377	4.91	34.4	148	516	1480	1570
1960-1979 units with no LBP[2]	239	3.26	26.0	124	267	492	1140

[1] The statistics presented in this table were calculated on mass-weighted (i.e., weighted for mass of sample) arithmetic mean dust-lead concentrations from window sills for the 284 privately-owned, occupied National Survey units (see Appendix C1). These concentrations were adjusted to reflect the weight of the entire dust sample, not just the tap weight (USEPA, 1996c). In the summaries, each unit is weighted by its 1997 weight, which is presented in Appendix C1.

[2] Units with no LBP have a predicted maximum XRF value (interior and exterior) less than 1.0 mg/cm². These units represent post-1979 units in this risk analysis.

Table 3-10. Summary of the Distribution of Soil-Lead Concentrations for Housing Units in the HUD National Survey, Weighted to Reflect the Predicted 1997 Housing Stock.

Surveyed Units, According to the Year Unit Was Built	Soil-Lead Concentrations (µg/g)[1]						
	Geometri c Mean	Geometric Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentil e	95th Percentile
All Units Built Before 1940	463	3.09	35.0	138	394	841	2000
All 1940-1959 Units	92.6	3.15	22.0	47.6	81.4	171	485
All 1960-1979 Units	32.8	2.56	6.13	20.4	31.5	62.5	183
1960-1979 units with no LBP[2]	22.4	2.31	5.58	13.6	21.2	45.0	82.5

[1] The statistics presented in this table were calculated on weighted arithmetic mean soil-lead concentrations for the 284 privately-owned, occupied National Survey units (see Appendix C1). Within each unit's average, remote sample results were weighted twice that of the entryway and dripline results. In the summaries, each unit was weighted by its 1997 weight, which is presented in Appendix C1.

[2] Units with no LBP have a predicted maximum XRF value (interior and exterior) less than 1.0 mg/cm². These units represent post-1979 units in this risk analysis.

Table 3-11. Summary of XRF Paint Measurements Taken in the HUD National Survey, Including the Percentage of Housing Units with Lead-Based Paint (LBP) and Deteriorated LBP, by Component Category.[1]

Component Category	# Units with XRF Data	Percent of Units With a Given # of Measurements Reported			Percent of Units with LBP[2]	Percentiles of the Distribution of Maximum XRF Measurement in a Unit (mg/cm^2)			Percent of Units with Deteriorated LBP[3]
		1	2	> 2		25th Percentile	50th Percentile	75th Percentile	
Interior Components									
Cabinets	99	93.9	6.1	0.0	13.1	0.1	0.5	0.6	2.2
Ceiling	247	24.7	75.3	0.0	21.1	0.3	0.6	0.7	3.7
Door components (trim, systems)	219	15.1	27.9	57.1	26.9	0.5	0.6	1.0	3.2
Floors	11	90.9	9.1	0.0	0.0	0.3	0.4	0.6	0.0
Stairs (trim)	14	92.9	7.1	0.0	35.7	0.3	0.6	1.8	7.7
Trim (baseboard, molding)	173	45.1	38.7	16.2	23.7	0.5	0.6	0.9	3.5
Walls	256	0.8	2.3	96.9	21.9	0.3	0.6	0.8	4.4
Window sills	176	54.0	44.9	1.1	29.5	0.5	0.6	1.2	6.3
Other window components (trim, systems)	169	21.3	35.5	43.2	33.7	0.5	0.6	1.3	5.5
Exterior Components									
Door components (trim, systems)	153	33.3	50.3	16.3	40.5	0.5	0.6	2.4	9.0
Porch/stair components (includes columns, rails)	89	59.6	29.2	11.2	33.7	0.4	0.6	1.6	11.1
Trim (soffits, fascia)	153	99.4	0.7	0.0	30.7	0.4	0.6	1.5	10.3
Walls/siding	146	100.0	0.0	0.0	33.6	0.3	0.6	1.6	6.4
Window sills	111	98.2	1.8	0.0	45.9	0.4	0.6	3.7	17.3
Other window components (trim, systems)	132	99.2	0.8	0.0	42.4	0.4	0.6	2.9	16.1

[1] This table is a summary of observed XRF measurements within the 284 privately-owned housing units in the HUD National Survey. Summaries are unweighted (i.e., do not reflect sampling weights associated with the units).

[2] Percentage of units with XRF data whose maximum XRF measurement is at least 1.0 mg/cm^2.

[3] Percentage of units having both XRF data and data on the extent of paint deterioration, whose maximum XRF measurement is at least 1.0 mg/cm^2, and at least one of these measurements is from a component containing some deteriorated paint.

Table 3-12. Summary of the Distribution of Observed Maximum XRF Lead Levels in Paint for Housing Units in the HUD National Survey, Weighted to Reflect the Predicted 1997 Housing Stock.

Year Unit Was Built[2]	# National Survey Units[3]	Observed Maximum XRF Paint-Lead Levels (mg/cm²)[1]						
		Geometric Mean	Geometric Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile
Interior of Unit								
Before 1940	72	1.86	3.78	0.300	0.600	1.45	6.10	11.5
1940-1959	83	1.02	2.42	0.400	0.600	0.800	1.70	7.30
1960-1979	116	0.712	1.79	0.300	0.500	0.600	0.900	2.50
Exterior of Unit								
Before 1940	60	3.14	3.75	0.300	0.700	4.20	7.70	29.0
1940-1959	76	1.45	3.05	0.200	0.600	1.40	2.60	13.0
1960-1979	103	0.719	2.43	0.00	0.500	0.600	0.900	5.10

[1] The statistics presented in this table were calculated on observed maximum XRF paint-lead level for National Survey units across both interior and exterior painted surfaces (see Appendix C1). Each unit's observed maximum XRF paint-lead level was weighted by the 1997 weight for the unit, which is presented in Appendix C1.

[2] No units built after 1979 were included in the HUD National Survey. In this risk analysis, these units are assumed to be free of LBP.

[3] Number of privately-owned units in the HUD National Survey in which an observed maximum XRF paint-lead level was available (for either the interior or exterior).

Table 3-13. Predicted Numbers and Percentages of Units Having Lead-Based Paint in the 1997 Occupied Housing Stock, Based on Information from the HUD National Survey.[1]

Year Unit Was Built	Number (%) of Units with Lead-Based Paint	Number (%) of Units with More Than 5 ft² of Deteriorated Lead-Based Paint
Before 1940	17,248,000 (87.7%)	7,755,000 (39.4%)
1940-1959	18,047,000 (91.5%)	3,065,000 (15.5%)
1960-1979	26,452,000 (75.6%)	2,651,000 (7.6%)
After 1979	0 (0%)	0 (0%)
All Housing	61,747,000 (62.2%)	13,470,000 (13.6%)

[1] A unit in the HUD National Survey is labeled as containing LBP if its predicted maximum XRF value in either the interior or the exterior is greater than or equal to 1.0 mg/cm². Results are weighted using the 1997 weights presented in Appendix C1.

As the §403 dust-lead standards will be defined as lead loadings from dust collected using wipe techniques (Section 1.1), it was necessary to express dust-lead loadings from the HUD National Survey database as loadings based on wipe dust collection, even though a Blue Nozzle vacuum collection technique was used in this survey. As a result, in this section and throughout this document, dust-lead loading data based on Blue Nozzle vacuum techniques were converted to wipe-equivalent dust-lead loadings prior to summarizing these data (e.g., Table C1-7 of Appendix C1, Table 3-6, Table 3-8). Methods used to perform these conversions, specially developed for this risk analysis, are presented in Section 4.3 of Chapter 4.

For some HUD National Survey units, measurements were not reported for either dust-lead loading, dust-lead concentration, or soil-lead concentration. In these situations, it was necessary for modeling purposes to represent these units (and their associated sampling weights) with some type of measurement. As discussed in Section 1.3 of Appendix C1, the value assigned to a unit having a missing value for a particular data parameter equaled the average value across units in the same category of year built and lead-based paint status (i.e., presence or absence of a maximum XRF value in the interior or exterior at or above 1.0 mg/cm^2). Table 3-14 presents these average environmental-lead levels and numbers of National Survey housing units with a missing value. The data summaries in Table C1-7 of Appendix C1 and in Tables 3-6 and 3-7 were calculated after replacing missing values with these imputed values.

Tables 3-6 through 3-9 indicate that the geometric means and medians for dust-lead loadings and dust-lead concentrations decrease with the age of the unit. This finding is consistent with the hypothesis that the potential for dust contamination by lead is higher in older units, due to their propensity to contain greater amounts of lead-based paint and to be located in older neighborhoods with lead-contaminated soil. Window sill dust-lead loadings and concentrations in units built prior to 1940 were considerably higher than those of the other units. These tables also indicate that lead loadings and concentrations tend to be higher on window sills than floors, especially in older units. The same trends were observed in soil-lead concentration (Table 3-10), whose geometric mean and median decreased with the age of the unit, and whose levels were considerably higher in pre-1940 units than in the other units.

The components tested for lead-based paint in the HUD National Survey were selected based on a predetermined sample design. Therefore, the data summarized in Table 3-11 and 3-12 represent both lead-contaminated and lead-free painted surfaces. The primary components sampled included interior doors, windows, walls, and ceilings, and exterior trim, doors, windows, and siding. In general, XRF measurements were low among the tested surfaces (Table 3-11), with those components containing lead-based paint in more than 25% of units limited to exterior components and interior door, window, and stair components. In general, less than 10% of units had deteriorated lead-based paint present on a particular component. One exception was for exterior window surfaces, where from 16% to 17% of units had deteriorated lead-based paint. The relationship between lead levels in paint and age of unit is strongest for the median and upper percentiles (Table 3-12), indicating that while low paint-lead measurements are observed in all housing regardless of age, higher paint-lead measurements are more prevalent in older units.

Table 3-14. Imputed Environmental-Lead Measurements, by Age Category and Presence of Lead-Based Paint[1], and Numbers of Units in the HUD National Survey to Which Imputed Measurements Were Assigned in the Risk Analyses.

Environmental-Lead Measurement	Imputed Measurement[2] (Number of HUD National Survey units in which imputed measurements were assigned)						
	Pre-1940 Units		1940-1959 Units		1960-1979 Units		Post-1979 Units (LBP Not Present)
	LBP Present	LBP Not Present	LBP Present	LBP Not Present	LBP Present	LBP Not Present	
Floor Dust-Lead Loading (µg/ft²) (wipe)[3]	46.2 (1)	--	--	--	7.67 (2)	--	--
Window Sill Dust-Lead Loading (µg/ft²) (wipe)[3]	2300. (6)	--	309. (7)	17.4 (1)	217. (21)	81.5 (4)	83. (4)
Floor Dust-Lead Loading (µg/ft²) (Blue Nozzle vacuum)[4]	17.9 (1)	--	--	--	4.25 (2)	--	--
Window Sill Dust-Lead Loading (µg/ft²) (Blue Nozzle vacuum)[4]	207. (6)	--	34.5 (7)	3.73 (1)	28.3 (21)	12.2 (4)	12.3 (4)
Floor Dust-Lead Concentration (µg/g) (Blue Nozzle Vacuum)[5]	--	--	--	--	740. (2)	--	--
Dripline Soil-Lead Concentration (µg/g)[3,4,5]	1126. (10)	453. (3)	373. (4)	45.8 (1)	84.1 (3)	--	--
Remote Soil-Lead Concentration (µg/g)[3,5]	555. (13)	105. (5)	253. (8)	32.8 (1)	42.7 (4)	--	--

[1] Units with lead-based paint have a predicted maximum XRF measurement (in the interior or the exterior) greater than or equal to 1.0 mg/cm².

[2] For a given measurement type, imputed measurements were the average measurement across housing units within the given category of year-built and presence of lead-based paint. Numbers in parentheses indicate the number of units having no data for the given measurement type (i.e., the imputed measurement in the given cell was used to represent the measurement for the number of units in parentheses). Cells containing dashes had no housing units in the given category needing to have measurements imputed for the given measurement type. The numbers of housing units entering into each imputed value can be determined from Table 3-5 (second column) minus the numbers in parentheses in this table.

[3] This measurement was used to determine whether units exceeded example standards (soil interventions were triggered by the average of dripline and remote soil-lead concentrations).

[4] This measurement was used as input to the empirical model (Section 4.2) to obtain a distribution of predicted blood-lead concentrations from environmental-lead measurements.

[5] This measurement was used as input to the IEUBK model (Section 4.1) to obtain a distribution of predicted blood-lead concentrations from environmental-lead measurements (dripline and remote soil-lead concentrations were averaged prior to input to the IEUBK model).

This risk analysis predicts that approximately 62% of the 1997 occupied housing stock contain lead-based paint (Table 3-13), based on information from the HUD National Survey and under the assumption that no units built after 1979 contain lead-based paint. This percentage is less than 83%, the percentage of pre-1980 occupied housing predicted to contain lead-based paint according to the HUD National Survey (USEPA, 1995a). The estimate of 62% is relative to <u>all</u> occupied housing, even units built after 1979. The percentages of units with lead-based paint within the three pre-1980 year-built categories match those reported in the National Survey report (USEPA, 1995a). Table 3-13 also indicates that approximately 14% of units are predicted to contain more than five square feet of deteriorated lead-based paint, with over half of these units built prior to 1940. Where only housing built prior to 1980 is considered, this percentage increases to 18% (Tables 3-13 and 3-5).

3.3.1.2 The Baltimore Repair and Maintenance (R&M) Study

In the Baltimore R&M Study (Section 3.2.2.1), the BRM vacuum sampler was used to collect dust samples. The BRM dust-lead loadings were converted to wipe equivalent dust-lead loadings using the conversion equations presented in Section 4.3. Tables 3-15 and 3-16 summarize pre-intervention lead loadings and concentrations, respectively, in floor-dust samples across study units that were occupied prior to intervention. Tables 3-17 and 3-18 summarize lead loadings and concentrations, respectively, in window sill-dust samples. Table 3-19 summarizes lead concentrations in soil samples taken at the dripline. Table 3-20 presents summaries of the observed maximum XRF paint-lead measurement within study units slated for R&M interventions, for the interior only and the exterior only, as well as for the entire unit. Recall that XRF measurements were not made in the previously abated and modern urban homes.

Tables 3-15 through 3-18 indicate that geometric mean dust-lead levels are highest for units slated for R&M intervention, while modern urban units have geometric mean levels that are as much as an order of magnitude lower than the other two housing groups. However, units slated for R&M interventions should not be considered representative of occupied inner city homes. As many of these units were in poor condition prior to the interventions, they represent a worst case setting for residential environmental-lead levels. Dust-lead loadings for previously-abated units and units slated for R&M interventions are considerably higher than those reported for pre-1940 housing in the HUD National Survey. Units slated for R&M interventions have very high dust-lead concentrations and window sill dust-lead loadings, due to the deteriorated condition of most of these units. Modern urban units have dust-lead levels that are slightly higher than the HUD National Survey units built from 1960-1979 and containing no LBP.

Soil-lead concentrations summarized in Table 3-19 are based on small numbers of units, due to the lack of available dripline soil to sample at many of the study units. Geometric mean soil-lead concentrations presented in Table 3-19 are high compared to those in the HUD National Survey.

The paint-lead measurements summarized in Table 3-20 are extremely high, as the data represent only units slated for R&M interventions. These units were likely to contain large amounts of lead-based paint, and paint-lead measurements were taken primarily from components suspected of containing LBP to identify and prioritize surfaces requiring LBP intervention. Thus, the data summarized in Table 3-20 reflect a LBP-contaminated environment and are not typical of all painted surfaces in occupied housing.

Table 3-15. Summary of Average Pre-Intervention Floor Dust-Lead Loading for Occupied Housing Units in the Baltimore R&M Study.

Unit Category	# Units	Floor Dust-Lead Loading (µg/ft²)[1]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Study Units	90	40.9	2.3	4.5	266
Previously Abated Units	16	45.6	1.6	23.1	125
Units Slated for R&M Intervention	58	58.6	1.7	22.0	266
Modern Urban Units	16	10.0	1.6	4.5	17.4

[1] The statistics presented in this table were calculated on area-weighted arithmetic mean dust-lead loadings from floors for each unit. These loadings have been converted to represent loadings from dust samples obtained from wipe collection techniques (see Section 4.3).

Table 3-16. Summary of Average Pre-Intervention Floor Dust-Lead Concentrations for Occupied Housing Units in the Baltimore R&M Study.

Unit Category	# Units	Floor Dust-Lead Concentration (µg/g)[1]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Study Units	90	1300	4.1	48.9	60300
Previously Abated Units	16	1210	2.5	332	7360
Units Slated for R&M Intervention	58	2440	2.6	426	60300
Modern Urban Units	16	145	2.2	48.9	704

[1] The statistics presented in this table were calculated on mass-weighted arithmetic mean dust-lead concentrations from floors for each unit, where dust was sampled using the BRM vacuum method.

Table 3-17. Summary of Average Pre-Intervention Window Sill Dust-Lead Loading for Occupied Housing Units in the Baltimore R&M Study.

Unit Category	# Units	Window Sill Dust-Lead Loading (µg/ft²)[1]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Study Units	90	326	3.2	23.0	1880
Previously Abated Units	16	158	2.2	46.6	833
Units Slated for R&M Intervention	58	675	1.6	203	1880
Modern Urban Units	16	48.2	1.6	23.0	86.7

[1] The statistics presented in this table were calculated on area-weighted arithmetic mean dust-lead loadings from window sills for each unit. These loadings have been converted to represent loadings from dust samples obtained from wipe collection techniques (see Section 4.3).

Table 3-18. Summary of Average Pre-Intervention Window Sill Dust-Lead Concentrations for Occupied Housing Units in the Baltimore R&M Study.

Unit Category	# Units	Window Sill Dust-Lead Concentration (μg/g)[1]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Study Units	90	5600	8.5	7.2	141000
Previously Abated Units	16	1880	4.6	255	31500
Units Slated for R&M Intervention	58	20100	2.4	28010	141000
Modern Urban Units	16	161	2.7	7.2	447

[1] The statistics presented in this table were calculated on mass-weighted arithmetic mean dust-lead concentrations from window sills for each unit, where dust was sampled using the BRM vacuum method.

Table 3-19. Summary of Average Pre-Intervention Dripline Soil-Lead Concentrations for Occupied Housing Units in the Baltimore R&M Study.

Unit Category	# Units	Soil-Lead Concentration (μg/g)			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Study Units	28	445	5.1	28.9	3540
Previously Abated Units	2	219	1.6	1570	3060
Units Slated for R&M Intervention	16	1260	2.0	336	354
Modern Urban Units	10	61.1	1.7	28.9	153.7

Table 3-20. Summary of Observed Maximum XRF Paint-Lead Measurement at Pre-Intervention for Occupied Housing Units Slated for R&M Intervention in the Baltimore R&M Study.[1]

Location Within a Unit	# Units	Observed Maximum XRF Paint-Lead Measurement (mg/cm²)			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
Entire Unit	36	38.4	1.7	9.3	98.1
Exterior Only	35	24.8	2.6	0.6	86.3
Interior Only	36	28.2	1.8	7.4	98.1

[1] XRF data were not available for previously-abated units and modern urban units in the study.

3.3.1.3 The Rochester Lead-in-Dust Study

Like the previous studies in this section, the Rochester Lead-in-Dust Study database contains a variable for the year in which the surveyed housing unit was built. As a result, this section presents summaries of environmental-lead levels across all surveyed units, as well as for each of the four age categories considered in the HUD National Survey. However, Rochester study representatives later informed the risk analysis team that the specified year was occasionally determined from public tax assessor records and may not always reflect the actual year of construction. For units experiencing a major renovation effort, the specified year may be the year of the latest such effort, and not the original construction year. Therefore, conclusions on environmental-lead levels for specific age categories should be made cautiously, especially for units categorized as "after 1979," as the actual year of construction for some units may be earlier than that specified.

Across study units, Tables 3-21 and 3-22 summarize lead loadings and concentrations, respectively, in floor-dust samples. Tables 3-23 and 3-24 summarize lead loadings and concentrations, respectively, in window sill-dust samples. In these four tables, dust-lead loadings were summarized for only those samples collected using wipe techniques, while dust-lead concentrations were summarized for only those samples collected using BRM vacuum techniques. Table 3-25 summarizes lead concentrations in soil samples taken at the dripline where bare soil was present, while Table 3-26 summarizes lead concentrations in soil samples taken at the child's principal play area in the yard, where bare soil was present. Table 3-27 presents information on the extent of XRF sampling, the presence of lead-based paint, the presence of deteriorated lead-based paint, and the distribution of maximum XRF measurements in a unit, for specific categories of interior and exterior painted components. Table 3-28 presents summaries of the observed maximum XRF paint-lead measurements within the study units, for the interior only and the exterior only, as well as for the entire unit.

Table 3-21. Summary of Average Floor Dust-Lead Loading for Housing Units in the Rochester Study.

Year Category[1]	# Units	Floor Dust-Lead Loading (µg/ft²)[2]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Units	205	17.7	3.2	1.2	8660
Before 1940	172	19.8	3.2	1.7	8660
1940-1959	19	8.4	2.6	1.2	26.9
1960-1979	4	7.8	2.4	2.1	13.2
After 1979	10	15.0	3.3	3.5	250

[1] Reflects age of housing unit as specified in public tax assessor records.
[2] The statistics presented in this table were calculated on area-weighted arithmetic mean dust-lead loadings from floors for each unit. Results included in the summaries are only for dust samples collected using wipe techniques.

Table 3-22. Summary of Average Floor Dust-Lead Concentrations for Housing Units in the Rochester Study.

Year Category[1]	# Units	Floor Dust-Lead Concentration (µg/g)[2]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Units	204	351	3.7	8.3	40700
Before 1940	172	396	3.6	8.3	40700
1940-1959	18	209	4.6	16.5	7900
1960-1979	4	60.8	2.7	16.9	164
After 1979	10	226	3.0	57.0	1120

[1] Reflects age of housing unit as specified in public tax assessor records.
[2] The statistics presented in this table were calculated on mass-weighted arithmetic mean dust-lead concentrations from floors for each unit. Results included in the summaries are only for dust samples collected using BRM vacuum techniques.

Table 3-23. Summary of Average Window Sill Dust-Lead Loading for Housing Units in the Rochester Study.

Year Category[1]	# Units	Window Sill Dust-Lead Loading (µg/ft²)[2]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Units	196	196	4.0	2.8	14900
Before 1940	164	234	3.7	2.8	14900
1940-1959	18	72.0	6.2	2.8	439
1960-1979	4	52.3	1.4	36.2	70.7
After 1979	10	113	1.9	26.9	320

[1] Reflects age of housing unit as specified in public tax assessor records.
[2] The statistics presented in this table were calculated on area-weighted arithmetic mean dust-lead loadings from window sills for each unit. Results included in the summaries are only for dust samples collected using wipe techniques.

Table 3-24. Summary of Average Window Sill Dust-Lead Concentrations for Housing Units in the Rochester Study.

Year Category[1]	# Units	Window Sill Dust-Lead Concentration (µg/g)[2]			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Units	199	2700	8.4	3.1	368000
Before 1940	166	3860	7.3	15.8	368000
1940-1959	19	497	9.9	5.3	15000
1960-1979	4	473	2.9	160	1900
After 1979	10	674	8.6	3.1	8630

[1] Reflects age of housing unit as specified in public tax assessor records.
[2] The statistics presented in this table were calculated on mass-weighted arithmetic mean dust-lead concentrations from window sills for each unit. Results included in the summaries are only for dust samples collected using BRM vacuum techniques.

Table 3-25. Summary of Average Dripline Soil-Lead Concentrations for Housing Units in the Rochester Study.

Year Category[1]	# Units	Dripline Soil-Lead Concentration (µg/g)			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Units	186	731	3.7	12.3	21000
Before 1940	158	938	3.2	12.3	21000
1940-1959	14	291	3.3	29.7	1790
1960-1979	4	66.4	1.8	29.0	111
After 1979	10	135	3.1	26.0	876

[1] Reflects age of housing unit as specified in public tax assessor records.

Note: Data in this table reflect bare soil areas along the unit's dripline.

Table 3-26. Summary of Average Soil-Lead Concentrations from Play Areas for Housing Units in the Rochester Study.

Year Category[1]	# Units	Play Area Soil-Lead Concentration (µg/g)			
		Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
All Units	87	267	2.8	28.0	7300
Before 1940	79	278	2.8	28.0	7300
1940-1959	6	185	3.1	55.4	767
1960-1979	1	138	.	138	138
After 1979	1	215	.	215	215

[1] Reflects age of housing unit as specified in public tax assessor records.

Note: Data in this table reflect bare soil areas in the child's principal play area in the yard.

Table 3-27. Summary of XRF Paint Measurements Taken in the Rochester Lead-in-Dust Study, Including the Percentage of Housing Units with Lead-Based Paint (LBP) and Deteriorated LBP, by Component Category.

Component Category[1]	# Units with XRF Data	Percent of Units With a Given # of Measurements Reported			Percent of Units with LBP[1]	Percentiles of the Distribution of Maximum XRF Measurement in a Unit (mg/cm^2)			Percent of Units with Deteriorated LBP[2]
		1	2	> 2		25th Percentile	50th Percentile	75th Percentile	
Interior Components									
Baseboards/trim	20	60.0	30.0	10.0	40.0	0.5	0.8	2.4	30.0
Door jambs	196	11.2	88.8	0.0	48.5	0.5	0.9	5.4	13.3
Door surfaces	164	50.6	49.3	0.0	19.5	0.5	0.5	0.7	6.7
Floors	81	76.5	23.5	0.0	19.8	0.5	0.5	0.6	16.0
Walls	14	85.7	7.1	7.1	28.6	0.5	0.5	3.5	28.6
Window sashes	165	30.9	69.1	0.0	70.9	0.7	2.1	6.4	41.8
Window sills	195	21.5	74.4	4.1	66.7	0.7	1.7	4.4	35.4
Window wells	124	40.3	58.9	0.8	91.9	8.3	17.1	25.5	74.2
Exterior Components									
Door jambs	200	100.0	0.0	0.0	63.5	0.5	6.5	26.2	22.0
Door surfaces	193	100.0	0.0	0.0	22.3	0.5	0.5	0.8	7.8
Porch floors	112	92.9	6.3	0.9	58.9	0.5	2.3	8.0	47.3
Trim	39	79.5	7.7	12.8	84.6	1.9	6.9	17.1	79.5
Walls/siding	95	93.7	6.3	0.0	83.2	2.5	10.7	24.6	22.1

[1] Percentage of units with XRF data whose maximum XRF measurement is at least 1.0 mg/cm^2.

[2] Percentage of units having both XRF data, whose maximum XRF measurement is at least 1.0 mg/cm^2, and at least one of these measurements is from a component containing some paint in "average" or "poor" condition.

Table 3-28. Summary of Observed Maximum XRF Paint-Lead Concentration for Housing Units in the Rochester Study.

Year Category[1]	# Units	% of Units with LBP[2]	Observed Maximum XRF Paint-Lead Levels (mg/cm²)			
			Geometric Mean	Geometric Standard Deviation	Minimum	Maximum
Entire Unit (interior and exterior)						
All Units	205	89%	12.8	3.88	0.50	59.8
Before 1940	172	95%	16.6	3.05	0.50	59.8
1940-1959	19	68%	5.50	4.97	0.50	37.6
1960-1979	4	50%	1.04	1.89	0.57	1.93
After 1979	10	40%	1.93	5.92	0.50	39.4
Interior of Unit						
All Units	205	83%	7.58	4.38	0.50	57.6
Before 1940	172	91%	9.90	3.67	0.50	57.6
1940-1959	19	63%	2.86	4.71	0.50	32.9
1960-1979	4	0%	0.61	1.12	0.57	0.73
After 1979	10	20%	1.32	5.72	0.50	39.4
Exterior of Unit						
All Units	204	79%	8.14	4.91	0.50	59.8
Before 1940	171	84%	10.3	4.40	0.50	59.8
1940-1959	19	63%	3.47	5.22	0.50	37.6
1960-1979	4	50%	1.00	1.97	0.50	1.93
After 1979	10	40%	1.63	4.95	0.50	37.4

[1] Reflects age of housing unit as specified in public tax assessor records.
[2] A unit is assumed to contain LBP if its maximum XRF value is greater than or equal to 1.0 mg/cm².

Note from Table 3-21 that at least 84% of the study units were built prior to 1940. Therefore, while the Rochester study considers units in an urban environment and does not attempt to target a particular lead exposure environment in recruiting the units, most of the units are older units. In addition, most units contain families with low income levels.

As was also seen in the HUD National Survey, dust-lead loadings and concentrations are highest among the units in the "before 1940" category (Tables 3-21 through 3-24). For units not in the "after 1979" category, the geometric mean floor dust-lead levels were often lower in the Rochester study than in the HUD National Survey. While the ten units in the "after 1979" category had higher geometric mean dust-lead levels than for the 1940-1959 and 1960-1979 categories, some of these units may have been built prior to 1980 and renovated after 1979.

Geometric mean soil-lead concentrations were higher than those observed in the HUD National Survey. Less than half of the units had soil samples taken from play areas (Table 3-26), where geometric mean concentrations were generally lower than at the dripline for older units.

The paint testing protocol for the Rochester study indicated that 10 to 15 surfaces were tested in each housing unit and that the selected surfaces either contained paint in the greatest state of deterioration or were most accessible to children. As indicated in Table 3-27, the tested surfaces were primarily door and window components, as well as painted floors, trim, and exterior siding. Typically, no more than two measurements were taken of each type of component within each unit. As seen in Table 3-27, the majority of units had some lead-based paint on exterior surfaces and interior window components. Interior door components and trim also had high incidences of lead-based paint. Window wells and exterior trim contained deteriorated lead-based paint in at least three-fourths of the units, while at least 40% of the units had deteriorated lead-based paint on window sashes and exterior porch floors.

Table 3-28 indicates that units built prior to 1940 had the highest geometric mean paint-lead measurements and the highest percentage of units with lead-based paint in the study. While at least 40% of the units within each year category had XRF lead measurements at or above 1.0 mg/cm^2 (i.e., the criterion for determining the presence of lead-based paint), caution must be taken when interpreting this result. One should consider the following when making any conclusion from the XRF paint-lead measurement summary in Table 3-28:

- As described above, the year category may not represent the actual construction year for some housing units, especially units with recent specified years.

- The Microlead I XRF instrument was used in this study without substrate correction. A study of *in situ* XRF instrument performance (USEPA, 1995j) found that measurements by this instrument tend to be positively biased, especially when not corrected for type of substrate.

3.3.1.4 Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program ("HUD Grantees")

The Department of Environmental Health at the University of Cincinnati (UCDEH) provided pre-intervention data collected in the HUD Grantees evaluation program from February, 1994, to September, 1997. These data are considered preliminary, as data continue to be collected in this program.

An area-weighted arithmetic average dust-lead loading (under wipe collection techniques) was calculated for floors and window sills within each housing unit. Only dust-lead loadings from targeted rooms were considered (entryways, play rooms, kitchens, and up to two bedrooms). Tables 3-29 and 3-30 summarize these area-weighted averages across housing units, for floors and window sills, respectively. Results are summarized across all housing units, for units in each of four age categories, and by grantee. Note that observed differences across grantees are not simply due to geographical variation, but also to other differences among the grantees, such as differences in the recruitment process and in dust sampling and analysis procedures.

For both Tables 3-29 and 3-30, the geometric mean dust-lead loading in pre-1940 housing units was higher than that for units built from 1940-1959 and from 1960-1977. (As seen in Table 3-3a, nearly 90% of housing units in the program were built prior to 1940, so considerably more data are available to characterize lead levels in this category of units). For pre-1978 units, geometric means were generally higher than in the Rochester study and the HUD National Survey, but lower than in the Baltimore R&M study. Primarily the result of the different grantees, the geometric standard deviations associated with the data for a given age category of housing units are higher than observed in the Baltimore R&M and the Rochester Lead-in-Dust studies.

In Tables 3-29 and 3-30, it is uncertain why average dust-lead loadings are so high in the few units built after 1977. One likely reason is cross-contamination from other lead-contaminated housing units in the same neighborhood. In addition, these units were likely targeted for lead abatement activities, which contributed to the magnitude of their dust-lead loadings. Three of the four post-1977 units were recruited by the Rhode Island grantee, and the other by the Minnesota grantee.

Tables 3-31 and 3-32 summarize soil-lead concentrations measured in the HUD Grantees program at play areas and at the dripline, respectively. Results are presented in the same manner as in Tables 3-29 and 3-30. Note that since soil sampling was considered optional in the HUD Grantees program, soil-lead concentration data were available for less than 15% of the enrolled housing units, and for only eight of the 14 grantees. Only one unit with soil data was specified as being built after 1959, although some units had no age information specified. While each housing unit represented in Tables 3-31 and 3-32 had a single soil-lead concentration measurement for the specified yard location, the analyzed soil sample was a composite of 5-10 subsamples.

Play area soil-lead concentrations had a geometric mean of 415 µg/g across 330 units (Table 3-31), while dripline soil-lead concentrations had a geometric mean of 1180 µg/g across 557 units (Table 3-32). These geometric means were somewhat higher than those reported in the HUD National Survey, the Baltimore R&M study, and the Rochester study. While the geometric means for play area soil were similar between pre-1940 units and units built from 1940-1959, the geometric mean dripline soil-lead concentration for pre-1940 units was over twice that of units built from 1940-1959 (Table 3-32).

Table 3-33 presents information on the extent of XRF sampling, presence of lead-based paint, presence of deteriorated lead-based paint, and distribution of maximum XRF measurements in a unit, for the components most commonly tested. A variety of components were tested, with interior component testing occurring for more housing units than exterior component testing, and with greater than two measurements taken within each component classification in most housing units. The XRF measurements were higher than those observed in the HUD National Survey and the Rochester study, with over 70% of units having lead-based paint on all component types except interior cabinets, ceilings, floors, and stairs. In a majority of housing units, the lead-based paint on these components was in a deteriorated state. For specific door and window components, as well as exterior porch and stair components, the maximum XRF measurement exceeded 19 mg/cm^2 in at least 25% of the housing units. Thus, lead-based paint was quite prevalent, and lead in the paint was at high levels, among the HUD Grantee units.

Table 3-29. Summary of Area-Weighted Average Floor Dust-Lead Loadings (Pre-Intervention, Using Wipe Collection Techniques) for Housing Units In the HUD Grantee Program, According to Age of Unit and Grantee.[1]

	# of Units with Data	Area-Weighted Average Floor Dust-Lead Loadings (µg/ft^2)						
		Geometric Mean	Geometric Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
All Units	2826	55.4	5.3	0.088	17.7	40.5	160	26400
Units Built Prior to 1940	2260	52.3	5.1	0.088	17.7	38.1	145	19600
Units Built 1940-1959	211	31.9	5.2	2.12	8.43	22.3	75.8	26400
Units Built 1960-1977	35	15.5	2.1	4.03	14.1	14.1	17.2	247
Units Built After 1977	4	372	5.6	32.5	120	580	1160	1750
Alameda County Grantee	177	24.6	4.0	3.54	7.52	18.0	65.8	1230
Baltimore Grantee	405	164	4.1	17.7	50.1	166	456	7470
Boston Grantee	99	68.9	4.2	5.00	21.2	57.5	170	2490
California Grantee	86	22.1	4.6	3.54	7.01	13.1	47.9	2220
Cleveland Grantee	105	91.2	5.6	3.54	25.4	84.0	280	10900
Massachusetts Grantee	221	70.0	5.5	1.64	19.2	64.5	210	16600
Minnesota Grantee	208	38.2	3.2	14.1	17.7	22.8	61.5	5060
New Jersey Grantee	57	54.8	5.4	3.54	14.1	29.0	247	4250
Rhode Island Grantee	199	59.5	4.6	5.22	17.8	53.6	157	2260
Wisconsin Grantee	221	26.9	5.8	1.77	6.49	16.5	78.1	2780
Milwaukee Grantee	294	31.3	4.2	2.06	11.0	26.5	73.8	5810
Chicago Grantee	119	28.8	3.5	3.54	10.5	28.9	62.8	26400
New York City Grantee	277	49.4	6.4	0.088	18.8	34.3	95.3	19600
Vermont Grantee	358	86.5	4.7	7.07	22.5	51.6	195	15600

[1] Summaries include data collected through September, 1997. Only data for wipe dust samples collected in entryways, play rooms, kitchens, and two targeted bedrooms were considered. Eleven sample results labeled as statistical outliers were not included in calculating area-weighted averages at the housing unit level.

Table 3-30. Summary of Area-Weighted Average Window Sill Dust-Lead Loadings (Pre-Intervention, Using Wipe Collection Techniques) for Housing Units In the HUD Grantee Program, According to Age of Unit and Grantee.[1]

	# of Units with Data	Area-Weighted Average Window Sill Dust-Lead Loadings (µg/ft^2)						
		Geometric Mean	Geometric Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
All Units	2669	475	6.7	0.32	115	403	1730	132000
Units Built Prior to 1940	2220	505	6.7	0.32	126	428	1810	132000
Units Built 1940-1959	201	260	6.1	2.79	63.6	208	1000	29400
Units Built 1960-1977	35	61.0	2.2	22.9	33.7	45.6	105	289
Units Built After 1977	2	2380	4.5	816	816	2380	6940	6940
Alameda County Grantee	177	150	4.7	7.41	42.1	131	440	19100
Baltimore Grantee	404	1910	5.1	36.3	597	2130	5850	130000
Boston Grantee	87	474	6.5	12.0	138	419	1650	47200
California Grantee	77	333	4.9	19.8	93.4	268	1040	10200
Cleveland Grantee	97	757	5.0	45.8	261	677	1610	54400
Massachusetts Grantee	198	407	6.0	2.60	133	368	1260	76100
Minnesota Grantee	189	396	5.6	23.5	88.3	339	1230	100000
New Jersey Grantee	57	142	5.2	10.3	39.4	84.4	425	8130
Rhode Island Grantee	189	740	6.4	8.75	201	655	2120	132000
Wisconsin Grantee	218	341	6.2	3.54	93.7	294	1250	73900
Milwaukee Grantee	273	546	6.6	19.1	127	413	2110	53600
Chicago Grantee	117	456	6.0	11.3	127	475	1200	36500
New York City Grantee	263	278	5.7	0.32	97.6	184	708	57100
Vermont Grantee	323	306	7.5	10.6	63.6	214	1050	98100

[1] Summaries include data collected through September, 1997. Only data for wipe dust samples collected in entryways, play rooms, kitchens, and two targeted bedrooms were considered. Two sample results labeled as statistical outliers were not included in calculating area-weighted averages at the housing unit level.

Table 3-31. Summary of Play Area Soil-Lead Concentrations (Pre-Intervention) for Housing Units In the HUD Grantee Program, According to Age of Unit and Grantee.[1]

	# of Units with Data	Play Area Soil-Lead Concentrations (µg/g)						
		Geometric Mean	Geometric Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
All Units	330	415	4.5	0.005	259	480	870	12000
Units Built Prior to 1940	190	357	4.9	0.005	210	456	800	12000
Units Built 1940-1959	12	223	5.5	5.00	80.6	402	723	2630
Units Built 1960-1977	0	.	.	.	.	.	.	.
Units Built After 1977	1	481	.	481	481	481	481	481
Alameda County Grantee	69	483	2.7	41.0	241	501	1010	4170
California Grantee	8	271	3.5	22.0	148	462	585	830
Cleveland Grantee	99	633	2.6	43.0	390	589	1010	12000
Minnesota Grantee	44	469	2.4	54.0	284	464	687	4100
Rhode Island Grantee	41	457	4.8	5.00	370	621	1060	5210
Wisconsin Grantee	38	132	16.3	0.005	100	300	572	2100
Milwaukee Grantee	11	690	1.8	407	442	538	1300	2050
Vermont Grantee	20	151	5.1	3.80	49.5	140	547	3730
All Other Grantees	0	.	.	.	.	.	.	.

[1] Summaries include data collected through September, 1997. One play area soil-lead concentration was reported for each housing unit represented in this table.

Table 3-32. Summary of Dripline Soil-Lead Concentrations (Pre-Intervention) for Housing Units In the HUD Grantee Program, According to Age of Unit and Grantee.[1]

	# of Units with Data	Dripline Soil-Lead Concentrations (µg/g)						
		Geometric Mean	Geometric Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
All Units	557	1180	3.7	0.07	557	1250	2580	52700
Units Built Prior to 1940	266	1030	3.9	0.07	534	1080	2150	50600
Units Built 1940-1959	17	478	3.2	66.0	174	530	925	5390
Units Built 1960-1977	0	.	.	.	.	.	.	.
Units Built After 1977	1	330	.	330	330	330	330	330
Alameda County Grantee	97	776	2.7	30.0	395	710	1390	21100
California Grantee	8	331	1.9	94.0	269	360	456	780
Cleveland Grantee	99	2380	2.3	420	1350	2140	4520	16400
Minnesota Grantee	44	593	2.7	45.0	280	559	1150	8120
Rhode Island Grantee	60	1390	3.3	66.0	638	1500	2780	26200
Wisconsin Grantee	66	564	7.3	0.007	400	859	1500	5730
Milwaukee Grantee	12	1970	2.5	327	1160	1690	3490	10300
Vermont Grantee	171	1540	3.3	25.0	692	1500	3380	52700
All Other Grantees	0	.	.	.	.	.	.	.

[1] Summaries include data collected through September, 1997. One dripline soil-lead concentration was reported for each housing unit represented in this table.

Table 3-33. Summary of XRF Paint Measurements Taken in the HUD Grantee Program, Including the Percentage of Housing Units with Lead-Based Paint (LBP) and Deteriorated LBP, by Component Category.[1]

Component Category	# Units with XRF Data	Percent of Units With a Given # of Measurements Reported			Percent of Units with LBP[2]	Percentiles of the Distribution of Maximum XRF Measurement in a Unit (mg/cm^2)			Percent of Units with Deteriorated LBP[3]
		1	2	> 2		25th Percentile	50th Percentile	75th Percentile	
Interior Components									
Cabinets	2139	22.3	28.6	49.0	39.6	0.100	0.500	3.60	19.2
Ceiling	2841	7.50	5.17	87.3	55.0	0.300	1.60	9.90	36.6
Doors/transoms -- friction surfaces (jamb, threshold)	2953	12.7	9.11	78.2	80.9	1.70	9.90	16.4	63.4
Doors/transoms -- other surfaces (door surface, casing, transom sash)	3348	1.76	2.78	95.5	84.5	2.20	10.0	19.3	65.0
Floor	2195	29.5	15.8	54.7	35.6	0.100	0.300	2.40	28.5
Stairs	439	42.6	27.3	30.1	55.1	0.200	1.70	10.0	40.3
Trim (baseboards, chair rails, crown molding)	3152	4.79	6.00	89.2	75.1	1.00	6.60	14.2	47.1
Walls	3371	2.46	2.52	95.0	77.7	1.20	7.60	15.1	52.3
Window sills	3085	5.80	6.13	88.1	79.2	1.40	6.40	12.8	64.0
Window wells	1958	15.7	12.3	72.0	94.5	6.10	10.0	24.3	88.9
Other window components (casing/apron, jamb/track, sash)	3208	2.37	3.58	94.0	91.9	5.30	10.0	22.0	79.3
Exterior Components									
Ceiling	640	74.5	18.1	7.34	76.7	1.65	9.90	18.5	61.7
Doors/transoms -- friction surfaces (jamb, threshold)	1308	23.2	25.5	51.3	89.8	6.35	12.4	25.6	81.3
Door surfaces	1602	13.0	17.4	69.5	87.7	4.60	10.0	22.4	78.3
Porch/stair components	1282	18.1	14.9	67.0	70.7	0.500	7.10	15.9	63.8
Trim (including gutters, downspouts, soffits, fascias)	1021	46.7	31.1	22.1	77.6	1.70	9.60	14.3	66.9
Walls/siding	1417	36.6	33.0	30.5	75.9	1.10	7.80	14.9	63.8
Window wells	631	53.1	28.5	18.4	89.4	3.10	9.90	15.2	76.4
Other window components (sashes, casing)	980	40.9	28.6	30.5	95.3	6.15	10.0	21.3	83.3

[1] Summaries include data collected through September, 1997.
[2] Percentage of units with XRF data whose maximum XRF measurement is at least 1.0 mg/cm^2.
[3] Percentage of units having both XRF data, whose maximum XRF measurement is at least 1.0 mg/cm^2, and at least one of these measurements is from a component containing some paint in "fair" or "poor" condition.

3.3.1.5 Evaluating the Approach to Representing the Post-1979 Housing Stock

Recall from Section 3.3.1.1 that the HUD National Survey did not include housing units built after 1979. As a result, this risk analysis used the 28 surveyed housing units built from 1960 to 1979 and not containing lead-based paint to represent the national housing stock built after 1979 (these units also were included among those housing units representing the national housing stock built from 1960-1979). Under this approach, results in Tables 3-6 through 3-10 and Table 3-13 represent a summary of environmental-lead levels for the entire 1997 occupied national housing stock. In order to evaluate the assumption that using HUD National Survey units constructed between 1960 and 1979 with no lead-based paint accurately represents post-1979 housing units, Table 3-34 presents geometric means of environmental lead levels for modern urban units in the Baltimore R&M study, which were built after 1979, along with environmental lead levels for HUD National Survey units with no lead-based paint and constructed between 1960 and 1979. Geometric means presented in this table suggest that the environmental-lead levels used to represent the post-1979 housing stock in this risk analysis are similar to or lower than estimates for post-1979 housing from the Baltimore R&M study. When interpreting the results in Table 3-34, one must consider the different dust sampling methods used in the two studies, along with the different conversion factors used to obtain wipe-equivalent dust-lead loadings.

Table 3-34. Estimates of Geometric Mean Environmental-Lead Levels for HUD National Survey Units Representing Post-1979 Housing in this Risk Assessment and for Modern Urban Units in the Baltimore R&M Study.

Study (Subset of housing units considered)	# of Housing Units	Lead Concentrations[1] (µg/g)			Lead Loadings (µg/ft²) assuming wipe techniques[2]	
		Floor Dust	Window Sill Dust	Dripline Soil	Floor Dust	Window Sill Dust
HUD National Survey (1960-1979 units with no lead-based paint)[3]	28	91.9	239	27.4	3.14	8.17
Baltimore R&M Study (Modern urban units)	16[4]	145	161	61.1	10.0	48.2

[1] Dust-lead concentrations in this table are geometric means (across housing units) of the mass-weighted mean concentrations for each housing unit. Concentrations for HUD National Survey units reflect Blue Nozzle vacuum methods, while concentrations for the Baltimore R&M Study reflect BRM vacuum methods. Soil-lead concentrations are geometric means (across housing units) of mean dripline soil-lead concentrations for each housing unit.

[2] Dust-lead loadings in the HUD National Survey and the Baltimore R&M Study were converted to wipe-equivalent dust-lead loadings according to type of surface and dust collection method. Table entries are geometric means (across housing units) of the area-weighted mean dust-lead loadings for each housing unit.

[3] Environmental-lead levels in these units also represent levels in post-1979 housing in this risk assessment.

[4] Only 10 housing units had data for dripline soil-lead concentration.

3.3.2 Characterizing the Population of Children in the Nation's Housing Stock

Tables 3-6 through 3-10 in Section 3.3.1.1 characterize measured lead levels in dust and soil in the 1997 occupied housing stock, prior to implementing interventions that would occur under the proposed §403 rule. These summaries were based on data from the HUD National Survey with sampling weights revised to represent the 1997 national occupied housing stock. To characterize the extent to which these environmental-lead levels provide exposures to children and to characterize the benefits associated with performing interventions under §403 rules, it was necessary to estimate numbers of children of specific age groups who reside within the 1997 national housing stock depicted in Table 3-5 of Section 3.3.1.1.

Methods used to obtain numbers of children in the national housing stock are presented in Section 1.2 of Appendix C1. These methods used estimates developed by the U.S. Bureau of the Census of the 1997 birth rate, the average number of children per 1,000 people, and the average number of residents per housing unit. While this risk analysis focused on characterizing the blood-lead concentrations and associated health effects for children aged 1-2 years (i.e., 12-35 months), the sensitivity analysis within the risk characterization (Section 5.4) also considered children aged 1-5 years (i.e., 12-71 months). Therefore, the methods in Appendix C1 were applied to both age groups.

Table 3-35 provides the estimated number of children residing in the 1997 housing stock according to age of housing unit and age of child. Numbers of children associated with the 1997 sampling weights for each HUD National Survey unit are displayed in Table C1-7 of Appendix C1.

Table 3-35. Estimated Number of Children in the 1997 National Housing Stock, by Age of Child and Year-Built Category.

Years in Which Housing Units Were Built	Age of Child Within These Housing Units	
	1-2 Years	1-5 Years
Prior to 1940	1,578,000	4,043,000
1940-1959	1,581,000	4,051,000
1960-1979	2,805,000	7,188,000
After 1979	1,996,000	5,115,000
All Housing[1]	7,961,000	20,397,000

[1] Values in this row may differ from sum of previous rows due to rounding.

3.4 DISTRIBUTION OF CHILDHOOD BLOOD-LEAD

As described in Section 2.4, the population of interest in this risk analysis is children aged 1-2 years (i.e., 12-35 months). To characterize the national distribution of blood-lead concentration for these children, this risk analysis uses data from Phase 2 of the Third National Health and Nutrition Examination Survey (NHANES III). Information on NHANES III and a summary of the blood-lead concentrations from Phase 2 of this survey are presented in Section 3.4.1. These data are used in Section 5.1 to establish a baseline distribution of blood-lead concentration for this risk analysis to measure health effects in children aged 1-2 years. In Section 5.1, three factors were used to establish this baseline distribution: the geometric mean blood-lead concentration for this age group as presented in Section 3.4.1, the corresponding geometric standard deviation of these data, and an assumption that blood-lead concentrations for this group of children follow a lognormal distribution.

Additional information on blood-lead concentrations to support the NHANES III data is provided in Sections 3.4.2 through 3.4.4 through summary statistics from the Baltimore R&M study, the Rochester Lead-in-Dust study, and the HUD Grantees program. While blood-lead concentrations in these latter three studies are not representative of lead exposure on a national scale, they provide supporting information on the prevalence of elevated blood-lead concentrations in children living in inner-city locations, in children living in primarily older housing in an urbanized setting, or in children living in housing units likely to contain lead-based paint.

3.4.1 Distribution of Blood-lead Concentration, as Measured by NHANES III

The National Health and Nutrition Examination Surveys, conducted by the CDC's National Center for Health Statistics (NCHS), trace the health and nutritional status of the noninstitutionalized, civilian U. S. population. The surveys consist of adult, youth, and family questionnaires, followed by standardized physical examinations.

NHANES III, conducted from 1988 to 1994, was the seventh in a series of national examination studies conducted by NCHS since 1960. The target population for NHANES III included the civilian noninstitutionalized population 2 months of age and older. The primary objectives of NHANES III were the following (CDC, 1992):

> *"To produce national population health parameters; to estimate the national prevalence of selected diseases and disease risk factors; to investigate secular trends in selected diseases and risk factors; to contribute to the understanding of disease etiology; and to investigate the natural history of selected diseases."*

Approximately 40,000 persons were sampled in NHANES III, including approximately 3,000 children aged 1-2 years. Phase 1 of NHANES III was conducted from 1988-1991, while Phase 2 was conducted from 1991-1994. Phase 2 provided the most recently-collected data on blood-lead concentrations available to this risk analysis. These data included 987 children aged 1-2 years, and 2,392 children aged 1-5 years. Results from Phase 2 presented in this section were calculated from datasets obtained from CDC's National Center for Health Statistics.

Study participants in NHANES III were subjected to a physical examination conducted by a physician, a dentist, and health technicians. For participants aged 12 months and older, these examinations included taking a blood sample via venipuncture. This sample was analyzed for lead content by graphite furnace atomic absorption spectrophotometry.

To provide for a nationally representative sample, a complex survey design was employed in NHANES III (CDC, 1992; CDC, 1994). Although estimates of national population health and nutrition parameters were the primary objectives of the survey, suitably precise estimates for certain age and race groups were obtained through oversampling. As part of the survey design, each subject was assigned a sampling weight indicating the total number in the U.S. population represented by the given subject in the survey. This weight was determined from 1993 Current Population Survey (CPS) data on demographic groups associated with the subject. As a result, the NHANES III provides national and subpopulation estimates of the distribution of childhood blood-lead concentrations.

Table 3-36 contains descriptive summaries of the blood-lead concentration data collected in Phase 2 of NHANES III for three age groups: 1-2 years, 3-5 years, and 1-5 years. As seen in this table, the geometric mean blood-lead concentration for children aged 1-2 years is 3.14 µg/dL, with a geometric standard deviation of 2.09. Lower geometric means, and slightly lower geometric standard deviations, were observed in the other two age groups, supporting the hypothesis that blood-lead concentration tends to peak at some age between 1 and 2 years. The geometric mean of 3.14 µg/dL is a decline from 4.03 µg/dL observed for children aged 1-2 years in Phase 1 of NHANES III. The geometric mean and geometric standard deviation blood-lead concentration for children aged 1-2 years form the basis for the baseline risk characterization in Section 5.1.1.

Table 3-36. Summary of Blood-Lead Concentration Data for Children Aged 1-2 Years, 3-5 Years, and 1-5 Years, Based on NHANES III (Phase 2) Data.

Age Range (years)	# Children with Blood-Lead Conc. Reported	Sum of NHANES Sample Weights[1]	Blood-Lead Concentration (µg/dL)[2]				
			Minimum	Maximum	Geometric Mean	Geometric Standard Deviation	95% Confidence Interval on the Geometric Mean
1-2	987	8,262,537	0.70	32.6	3.14	2.09	(2.82, 3.49)
3-5	1,405	11,916,489	0.70	56.6	2.51	2.05	(2.31, 2.73)
1-5	2,392	20,179,026	0.70	56.6	2.74	2.08	(2.52, 2.99)

[1] Weights assigned at the time of the physical examination. Included in this sum are the weights for all children who were examined, including those who did not have a blood-lead concentration reported.
[2] Summaries are calculated using sample weights to reflect the entire nation in this age group.

Table 3-36 also presents approximate 95% confidence intervals on the geometric mean blood-lead concentration for the three age groups. These intervals indicate the level of variability that is associated with the geometric mean estimates. This variability was estimated using statistical software that takes into account the correlation in the data resulting from the complex survey design. As seen in Table 3-36, the confidence interval for the 1-2 year age group does not overlap the confidence interval for the 3-5 year age group, providing some evidence that the two geometric means differ from a statistical perspective. Methods for calculating these confidence intervals are documented in Appendix C2.

For these same three age groups, Table 3-37 displays estimates of the probability that U.S. children have blood-lead concentrations at or above a given threshold: 10, 15, 20, and 25 µg/dL. These probabilities were estimated by determining the numbers of children in Phase 2 of NHANES III whose blood-lead concentrations were at or above the given threshold, with the results for each child weighted by his/her sampling weight. This approach differs from that taken in the risk analysis to estimate these probabilities (Chapter 5). The estimated probabilities in Table 3-37 are accompanied by approximate 95% confidence intervals, calculated using the methods documented in Section 2.0 of Appendix C2.

Table 3-37. Estimated Probabilities of Elevated Blood-Lead Concentrations in Children Aged 1-2 Years, 3-5 Years, and 1-5 Years, Based on NHANES III (Phase 2) Data.

Age Range (years)	# Children with Blood-Lead Conc. Reported	Sum of NHANES Sample Weights[1]	Percentages with Elevated Blood-Lead Concentration[2] (95% Confidence Interval)			
			≥10 µg/dL	≥15 µg/dL	≥20 µg/dL	≥25 µg/dL
1-2	987	8,262,537	5.88% (3.75, 9.22)	1.96% (0.980, 3.90)	0.431% (0.191, 0.977)	0.148% (0.021, 1.04)
3-5	1,405	11,916,489	3.45% (2.20, 5.41)	0.943% (0.662, 1.34)	0.315% (0.153, 0.648)	0.285% (0.125, 0.648)
1-5	2,392	20,179,026	4.41% (2.93, 6.65)	1.34% (0.804, 2.25)	0.361% (0.173, 0.756)	0.231% (0.080, 0.667)

[1] Weights assigned at the time of the physical examination. Included in this sum are the weights for all children who were examined, including those who did not have a blood-lead concentration reported.
[2] The methods for estimating these percentages differ from those used in the risk characterization (Section 5.1.1).

According to the methods used in Table 3-37, approximately 5.88% of the nation's children aged 1-2 years have blood-lead concentrations of 10 µg/dL or above, the current action level established by the CDC. The estimated probability of children aged 1-2 years having blood-lead concentrations of 20 µg/dL or above is only 0.431%.

For children aged 1-2 years, Table 3-38 presents geometric mean blood-lead concentration and percentage of children with a blood-lead concentration at or above 10 µg/dL for selected subgroups of the U.S. population (family income level, urban status, and selected race groups). Also included in Table 3-38 are approximate 95% confidence intervals associated with these estimates, calculated using the procedures in Appendix C2. These results illustrate that socioeconomic status is an important factor in the incidence rate of elevated lead exposure. Across all children, low-income families and children in urban centers have the highest percentages of children with blood-lead concentration at 10 µg/dL or above, with income level having more of an effect on this percentage. Urban centers are usually associated with high environmental-lead exposure due to the high density of older buildings containing lead-based paint and remaining fallout of leaded gasoline emissions from urban traffic. While Table 3-38 also presents results by race group, sample sizes are typically too small to warrant adequate comparison, as indicated by the large widths of the 95% confidence intervals. However, there is clearly a trend of high blood-lead concentration among certain race groups, such as non-Hispanic African-Americans.

Table 3-38. Estimated Percentage of Children Aged 1-2 Years (Within Selected Subgroups) With Blood-Lead Concentrations At or Above 10 µg/dL, and the Geometric Mean and Geometric Standard Deviation of Blood-Lead Concentration, Based on NHANES III (Phase 2) Data.

		All Children Aged 1-2 Years	Selected Race Groups of Children 1-2 Years: Non-Hispanic White	Non-Hispanic African American	Mexican American	Other
FAMILY INCOME LEVEL[1]						
Low	% ≥10 µg/dL (95% conf. int.)	10.1% (7.4, 13.7)	10.8% (6.2, 18.9)	14.2% (8.8, 22.8)	5.3% (2.3, 12.1)	6.2% (1.3, 29.4)
	Geometric Mean (95% conf. int.)	4.27 (3.86, 4.73)	3.74 (3.03, 4.60)	5.38 (4.68, 6.19)	3.69 (3.05, 4.45)	4.56 (3.37, 6.17)
	Sample size	501	75	183	212	31
Mid	% ≥10 µg/dL (95% conf. int.)	3.7% (1.8, 7.8)	4.0% (1.5, 10.7)	1.6% (0.2, 11.7)	8.3% (4.5, 15.4)	0% observed in these data
	Geometric Mean (95% conf. int.)	2.79 (2.49, 3.13)	2.71 (2.31, 3.17)	3.81 (3.12, 4.67)	2.98 (2.50, 3.56)	1.92 (1.25, 2.93)
	Sample size	271	114	75	71	11
High	% ≥10 µg/dL (95% conf. int.)	3.1% (1.1, 8.9)	0.6% (0.1, 5.0)	11.4% (3.4, 38.2)	3.7% (0.7, 18.0)	13.0% (3.0, 56.1)
	Geometric Mean (95% conf. int.)	2.46 (2.19, 2.76)	2.28 (2.00, 2.60)	4.21 (3.06, 5.78)	2.43 (1.68, 3.49)	2.92 (1.62, 5.25)
	Sample size	215	113	35	47	20
URBAN STATUS[2]						
Population ≥1,000,000	% ≥10 µg/dL (95% conf. int.)	6.7% (3.8, 11.7)	3.3% (1.2, 9.4)	12.3% (5.4, 27.8)	5.8% (2.9, 11.7)	10.3% (3.5, 30.3)
	Geometric Mean (95% conf. int.)	3.29 (2.84, 3.81)	2.79 (2.29, 3.40)	4.92 (3.99, 6.07)	3.29 (2.74, 3.95)	3.25 (2.31, 4.58)
	Sample size	543	111	168	218	46
Population < 1,000,000	% ≥10 µg/dL (95% conf. int.)	5.0% (2.0, 12.4)	5.0% (1.6, 15.0)	7.9% (3.8, 16.3)	5.3% (0.9, 32.1)	0% observed in these data
	Geometric Mean (95% conf. int.)	2.98 (2.48, 3.57)	2.68 (2.20, 3.26)	4.56 (3.55, 5.86)	3.21 (2.67, 3.86)	3.47 (2.35, 5.12)
	Sample size	444	191	125	112	16

[1] Income level was defined by poverty income ratio (PIR) categorized as low (0 < PIR < 1.30), mid (1.30 PIR < 3.0), and high (PIR ≥ 3.0). Persons with missing information on income level are not included in summaries by income level.

[2] Persons with missing information on urban status are not included in summaries by urban status.

As age of housing unit has historically been recognized as an important factor associated with the presence and magnitude of lead-based paint hazards, the blood-lead concentration data collected in Phase 2 of NHANES III were also summarized according to age of housing unit. Table 3-39 presents the geometric mean blood-lead concentration (and geometric standard deviation) and the percentages of children at or above specified concentration thresholds for each category of age of house considered in NHANES III. The geometric mean blood-lead concentration and the percentage of children at or above 10 µg/dL are presented according to combinations of age of house and either family income level or urban status in Table 3-40. Approximate 95% confidence intervals are provided in both tables.

Table 3-39. Estimated Geometric Mean Blood-Lead Concentration and Probabilities of Elevated Blood-Lead Concentration in Children Aged 1-2 Years, 3-5 Years, and 1-5 Years, by Age of Housing Unit, Based on NHANES III (Phase 2) Data.

Year Housing Unit Was Built	# Children[1]	Geometric Mean Blood-Lead Conc. (µg/dL) (95% conf. int.)	Percentages with Elevated Blood-Lead Concentration (95% confidence interval)			
			≥10 µg/dL	≥15 µg/dL	≥20 µg/dL	≥25 µg/dL
Children Aged 1-2 Years						
Pre-1946	153	4.46 (3.77, 5.27)	12.2% (6.26, 23.9)	6.01% (2.54, 14.2)	0.139% (0.018, 1.07)	0% observed in these data
1946-1973	361	3.27 (2.94, 3.64)	6.54% (3.59, 11.9)	1.05% (0.438, 2.50)	0.323% (0.045, 2.31)	0% observed in these data
Post-1973	315	2.37 (2.12, 2.65)	2.17% (0.93, 5.05)	0.255% (0.069, 0.937)	0% observed in these data	0% observed in these data
Children Aged 3-5 Years						
Pre-1946	215	3.40 (2.69, 4.29)	6.16% (3.27, 11.6)	1.89% (0.947, 3.75)	0.465% (0.156, 1.39)	0.303% (0.079, 1.16)
1946-1973	528	2.55 (2.30, 2.83)	3.43% (1.72, 6.83)	0.432% (0.164, 1.14)	0.171% (0.039, 0.752)	0.171% (0.039, 0.752)
Post-1973	429	1.83 (1.68, 2.00)	1.23% (0.32, 4.72)	0.551% (0.120, 2.52)	0.141% (0.020, 0.985)	0.141% (0.020, 0.985)
Children Aged 1-5 Years						
Pre-1946	368	3.79 (3.12, 4.60)	8.60% (5.22, 14.2)	3.54% (1.97, 6.37)	0.334% (0.103, 1.08)	0.181% (0.046, 0.716)
1946-1973	889	2.81 (2.58, 3.06)	4.64% (2.88, 7.46)	0.670% (0.349, 1.29)	0.230% (0.130, 0.406)	0.105% (0.024, 0.465)

Post-1973	744	2.04 (1.86, 2.24)	1.62% (0.60, 4.40)	0.427% (0.134, 1.36)	0.082% (0.012, 0.579)	0.082% (0.012, 0.579)

[1] Number of children with blood-lead concentration reported and for which the age category of his/her housing unit was known.

Table 3-40. Estimated Percentage of Children With Blood-Lead Concentrations Exceeding 10 µg/dL, and the Geometric Mean and Geometric Standard Deviation of Blood-Lead Concentration, for Children Aged 1-2 Years According to Age of Child's Residence and Either Family Income Level or Urban Status.

		Year Housing Unit Was Built		
		Pre-1946	**1946-1973**	**Post-1973**
FAMILY INCOME LEVEL[1]				
Low	% ≥10 µg/dL (95% conf. int.)	19.7% (11.5, 33.9)	9.01% (5.52, 14.7)	7.81% (3.65, 16.7)
	Geometric Mean (µg/dL) (95% conf. int.)	6.18 (5.20, 7.33)	4.11 (3.49, 4.83)	3.60 (3.14, 4.13)
	Sample size	73	201	126
Mid	% ≥10 µg/dL (95% conf. int.)	10.2% (2.32, 44.6)	3.73% (1.42, 9.82)	0.59% (0.11, 3.26)
	Geometric Mean (µg/dL) (95% conf. int.)	3.73 (2.76, 5.04)	2.82 (2.37, 3.36)	2.33 (2.01, 2.71)
	Sample size	39	97	99
High	% ≥10 µg/dL (95% conf. int.)	6.52% (1.22, 35.0)	5.76% (1.49, 22.2)	0% observed in these data
	Geometric Mean (µg/dL) (95% conf. int.)	3.78 (2.84, 5.02)	2.65 (2.07, 3.41)	1.87 (1.68, 2.08)
	Sample size	41	63	90
URBAN STATUS[2]				
Population ≥1,000,000	% ≥10 µg/dL (95% conf. int.)	16.5% (8.89, 30.7)	6.67% (3.60, 12.4)	1.22% (0.53, 2.78)
	Geometric Mean (µg/dL) (95% conf. int.)	4.87 (3.70, 6.43)	3.47 (3.05, 3.94)	2.44 (2.20, 2.70)
	Sample size	85	224	158
Population <1,000,000	% ≥10 µg/dL (95% conf. int.)	7.79% (1.61, 37.8)	6.38% (1.97, 20.7)	3.16% (0.92, 10.9)

	Geometric Mean (µg/dL) (95% conf. int.)	4.06 (3.31, 4.99)	3.05 (2.55, 3.64)	2.30 (1.84, 2.88)
	Sample size	68	137	157

[1] Income level was defined by poverty income ratio (PIR) categorized as low (0 < PIR < 1.30), mid (1.30 PIR < 3.0), and high (PIR ≥ 3.0). Persons with missing information on income level are not included in summaries by income level.
[2] Persons with missing information on urban status are not included in summaries by urban status.

The overall conclusion made by Phase 2 of NHANES III is that blood-lead concentrations in U.S. children continued to decline in the early 1990s. However, the percentage of children with elevated blood-lead concentration remains disproportionately high in certain subpopulations (e.g., low-income households, urban area households) that have a greater likelihood of encountering lead hazards.

3.4.2 Baltimore Repair and Maintenance (R&M) Study

Childhood blood-lead concentrations collected prior to any interventions performed in the Baltimore R&M Study (Section 3.2.2.1) provide evidence of elevated blood-lead concentrations for children in inner-city, high-exposure environments. Units slated for R&M interventions were documented to contain lead-based paint and elevated lead levels in household dust. Modern urban units, assumed to be free of lead-based paint, acted as negative controls. Previously-abated units were abated for lead-based paint previous to this study, and therefore reflect a post-abatement environment.

Table 3-41 summarizes blood-lead concentrations measured in the initial round of sampling (i.e., at study enrollment, prior to any interventions that may have occurred in the study, or when a child moves into a vacant unit following R&M intervention). In the initial sampling of blood among 93 children aged 1-2 years in this study (collected from 1993-1994), the overall geometric mean blood-lead concentration is 9.94 µg/dL, which is over three times the value of 3.1 µg/dL obtained from Phase 2 of NHANES III (Table 3-36). In particular, geometric mean blood-lead concentrations for children aged 1-2 years in previously-abated units and units slated for R&M intervention (11.9 µg/dL and 10.6 µg/dL, respectively) are high, while for 1-2 year old children residing among the modern urban units, where potential for lead exposure was reduced, the geometric mean was 2.82 µg/dL. Thus, it is possible that previously-abated units continue to have lead exposures that affect children's blood lead concentration.

The percentages of children with blood-lead concentrations at or above 10, 15, 20, or 25 µg/dL are high for all but the modern urban units (Table 3-41). When measured at enrollment or prior to interventions performed in the study, blood-lead concentrations were at or above 10 µg/dL for approximately 47% of 1-2 year olds compared to the Phase 2 NHANES III estimate of 5.88% (Table 3-37). Again, this large difference is likely due to the increased lead exposure associated with these children compared to the national population. Of the different groups of study units in the study, the highest percentage of children with blood-lead concentrations above 10 µg/dL occurred for previously-abated units (67%). Recall from Section 3.3.1.2 that environmental-lead levels were high in these units as well, suggesting that not all environmental-lead exposures were removed as a result of the abatements performed previous to this study. In contrast, no children aged 1-2 years who resided in modern urban units had elevated blood-lead concentrations.

Table 3-41. Summary Statistics on Blood-Lead Concentration Measured in the Initial Round of Sampling in the Baltimore Repair and Maintenance Study.

Age Range of Children (years)	Number of Children	Blood-Lead Concentration (μg/dL)				Percentages with Elevated Blood-Lead Concentration (%)			
		Minimum	Maximum	Geometric Mean	Geometric Standard Deviation	≥10 μg/dL	≥15 μg/dL	≥20 μg/dL	≥25 μg/dL
All Initial Round Blood-Lead Concentrations[1]									
All	163	0.9	65.5	10.4	2.12	58.3	35.0	14.7	10.4
1-2	93	0.9	65.5	9.94	2.29	53.8	33.3	16.1	12.9
Children Living in Study Units at the Time of Enrollment (Pre-Intervention)									
All[2]	115	0.9	65.5	8.78	2.14	47.0	26.1	9.6	5.2
1-2	68	0.9	65.5	8.38	2.34	44.1	26.5	11.8	7.4
Children in Previously-Abated Units									
All[3]	23	3.65	28.8	12.7	1.60	73.9	43.5	13.0	4.3
1-2	12	3.65	24.2	11.9	1.71	66.7	50.0	8.3	0.0
Children in Units Slated for Repair and Maintenance (Pre-Intervention)									
All[2]	69	1.75	65.5	10.2	1.87	49.3	27.5	10.1	5.8
1-2	41	1.75	65.5	10.6	1.99	51.2	26.8	14.6	9.8
Children in Modern Urban (control) Units									
All[4]	19	0.9	10.2	3.04	1.74	5.3	0.0	0.0	0.0
1-2	14	0.9	5.8	2.82	1.67	0.0	0.0	0.0	0.0

[1] Includes children moving into vacant study units following R&M interventions (blood sampling performed prior to moving into these units).
[2] Children aged 6-57 months.
[3] Children aged 10-57 months.
[4] Children aged 16-43 months.

3.4.3 Rochester Lead-in-Dust Study

Blood-lead concentration data were collected in 1993 in the Rochester study (Section 3.2.2.2) for 205 children aged 12-30 months of age. While units having recent major renovations or the potential for lead contamination from exterior sources were not considered in this study, no attempt was made to include units based on environmental-lead levels or the presence of lead-based paint. Therefore, this study characterizes lead exposure conditions in a particular urban setting, but not the inner-city setting portrayed in the Baltimore R&M Study.

Table 3-42 summarizes the blood-lead concentrations from the Rochester study (as stored in the study's public use database). The geometric mean blood-lead concentration was 6.38 µg/dL (geometric standard deviation, 1.85), twice the geometric mean reported in Phase 2 of NHANES III for children aged 1-2 years. Twenty-three percent of the children had blood-lead concentrations at or above 10 µg/dL, 8% at or above 15 µg/dL, and 3% at or above 20 µg/dL. Therefore, blood-lead concentrations in the Rochester study are generally higher than those for Phase 2 of NHANES III, but lower than those for the Baltimore R&M study.

Table 3-42. Summary Statistics on Blood-Lead Concentration Measured in the Rochester Lead-in-Dust Study.

Number of Children	Blood-Lead Concentration (µg/dL)				Percentages with Elevated Blood-Lead Concentration			
	Minimum	Maximum	Geometric Mean	Geometric Standard Deviation	≥10 µg/dL	≥15 µg/dL	≥20 µg/dL	≥25 µg/dL
205	1.4	31.7	6.38	1.85	23.4	7.8	2.9	1.5

3.4.4 Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program ("HUD Grantees")

Blood-lead concentrations of children residing in households participating in the evaluation phase of the HUD Grantees program (Section 3.2.2.3) were measured, along with environmental-lead levels in various media. The population of children targeted for participation in the program differed among the fourteen grantee recipients, due to the different enrollment criteria among the grantees (see Table 3-4). These criteria included targeting high-risk neighborhoods, enrolling only homes with a lead-poisoned child, and considering unsolicited applications. Pre-intervention data collected through September 1997 are presented in this exposure assessment; these data provide some of the most recent information on the relationship between children's blood-lead concentration and environmental-lead levels.

Across all grantees, blood-lead concentration data were collected for 471 children aged 1-2 years and for 657 children aged 3-5 years. Either venipuncture or fingerstick blood collection methods were used. Table 3-43 summarizes blood-lead concentrations by blood collection type, by age, and by grantee. The geometric mean blood-lead concentration via venipuncture collection method is 9.2 µg/dL for children aged 1-2 years, and 7.6 µg/dL for children aged 3-5 years. These geometric mean values are from two to three times higher than those obtained for children at the same age group from Phase 2 of NHANES III (Table 3-36), reflecting the procedure of selecting higher-risk children for the HUD Grantees program. The differing enrollment criteria across grantees also contributed to considerable differences in the geometric mean blood-lead concentration among the grantees. Under venipuncture, the geometric means for individual grantees reporting more than one blood-lead result ranged from 4.0 µg/dL (California, which only targeted older units) to 18.9 µg/dL (Cleveland, which targeted units with lead-poisoned children). The geometric mean blood-lead concentration via fingerstick method is 9.5 µg/dL for children aged 1-2 years and 8.9 µg/dL for children aged 3-5 years. When data were available for more than one child under fingerstick collection methods, the geometric means ranged from 5.5 µg/dL (Wisconsin) to 13.2 µg/dL (Milwaukee).

Table 3-43. Summary of Children's Blood-Lead Concentration in the HUD Grantees Program, According to Blood Collection Method, Age of Child, and Grantee.

	Number of Children	Blood-Lead Concentration (µg/dL)						
		Geometric Mean	Geometric Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
Age Range	**Blood Collection Method = Venipuncture**							
1-2 Years	313	9.2	2.3	0.7	5.0	10.0	17.0	53.0
3-5 Years	442	7.6	2.2	0.7	4.0	8.0	15.0	48.0
1-5 Years	755	8.2	2.2	0.7	4.9	9.0	16.0	53.0
Grantee	**(Children Aged 1-2 Years only)**							
Alameda County	26	4.8	2.3	1.4	3.0	4.8	6.6	24.8
Baltimore	23	8.0	1.9	2.0	6.0	7.0	10.0	26.0
Boston	19	9.9	2.0	3.0	6.0	14.0	19.0	24.0
California	19	4.0	2.0	1.4	2.6	3.5	7.2	15.0
Cleveland	46	18.9	1.7	4.0	14.0	18.0	28.0	53.0
Massachusetts	45	8.7	1.9	3.0	5.0	9.0	15.0	40.0
Minnesota	75	10.7	2.4	0.7	6.0	11.0	22.0	43.0
New Jersey	1	3.0	.	3.0	3.0	3.0	3.0	3.0
Rhode Island	13	8.2	2.0	2.0	6.0	9.0	14.0	21.0
Wisconsin	8	7.6	1.7	4.0	4.9	7.5	11.5	16.0
Chicago	15	13.5	1.7	4.0	11.0	14.0	19.0	28.0
New York City	15	4.6	1.6	2.0	4.0	5.0	5.0	12.0
Vermont	8	12.4	1.6	6.0	8.5	14.4	17.0	22.0
Age Range	**Blood Collection Method = Fingerstick**							
1-2 Years	158	9.5	2.0	2.0	6.0	9.0	16.0	62.0
3-5 Years	215	8.9	2.0	2.0	5.0	9.0	15.0	49.0
1-5 Years	373	9.1	2.0	2.0	5.0	9.0	15.0	62.0
Grantee	**(Children Aged 1-2 Years only)**							
Baltimore	1	9.0	.	9.0	9.0	9.0	9.0	9.0
Cleveland	1	13.0	.	13.0	13.0	13.0	13.0	13.0
Massachusetts	3	7.1	1.7	4.0	4.0	9.0	10.0	10.0
Minnesota	1	33.0	.	33.0	33.0	33.0	33.0	33.0
Rhode Island	9	8.2	1.5	5.0	7.0	7.0	11.0	15.0
Wisconsin	36	5.5	1.4	3.5	4.0	5.0	7.0	14.0
Milwaukee	83	13.2	2.0	2.0	9.0	15.0	20.0	62.0
Vermont	24	7.0	1.6	3.5	5.0	6.5	11.0	16.0

The percentages of children with blood-lead concentrations at or above 10, 15, 20 or 25 µg/dL are summarized in Table 3-44. Fifty two percent of children aged 1-2 years had blood-lead concentrations (venipuncture) at or above 10 µg/dL, compared to the estimates of 5.88% for Phase 2 of NHANES III (Table 3-37), 53.8% for the Baltimore R&M study (Table 3-41), and 23.4% for the Rochester Lead-In-Dust study (Table 3-42). For individual grantees, the percentage of children aged 1-2 years with blood-lead concentrations (venipuncture) at or above 10 µg/dL varies from 16% (California) to 91% (Cleveland). Percentages under the fingerstick method are similar to that under venipuncture, but less data were available to estimate them.

Table 3-44. Percentage of Children with Elevated Blood-Lead Concentration in the HUD Grantees Program, According to Blood Collection Method, Age of Child, and Grantee.

	Number of Children	Percentage of Children with Elevated Blood-Lead Concentration (%)			
		≥ 10 µg/dL	≥ 15 µg/dL	≥ 20 µg/dL	≥ 25 µg/dL
Age Range	**Blood Collection Method = Venipuncture**				
1-2 Years	313	52	35	19	12
3-5 Years	442	41	26	10	5
1-5 Years	755	45	30	14	8
Grantee	**(Children Aged 1-2 Years only)**				
Alameda County	26	23	12	4	0
Baltimore	23	39	22	9	4
Boston	19	53	47	11	0
California	19	16	5	0	0
Cleveland	46	91	70	48	37
Massachusetts	45	44	29	9	7
Minnesota	75	61	44	31	21
New Jersey	1	0	0	0	0
Rhode Island	13	38	23	8	0
Wisconsin	8	38	13	0	0
Chicago	15	80	47	20	7
New York City	15	7	0	0	0
Vermont	8	63	50	13	0
Age Range	**Blood Collection Method = Fingerstick**				
1-2 Years	158	45	30	14	11
3-5 Years	215	46	26	14	7
1-5 Years	373	45	28	14	9
Grantee	**(Children Aged 1-2 Years only)**				
Baltimore	1	0	0	0	0
Cleveland	1	100	0	0	0
Massachusetts	3	33	0	0	0
Minnesota	1	100	100	100	100
Rhode Island	9	33	11	0	0
Wisconsin	36	3	0	0	0
Milwaukee	83	69	51	25	19

	Number of Children	Percentage of Children with Elevated Blood-Lead Concentration (%)			
		≥ 10 µg/dL	≥ 15 µg/dL	≥ 20 µg/dL	≥ 25 µg/dL
Vermont	24	29	13	0	0

Figures 3-4 and 3-5 illustrate the nature of the linear relationship observed in the HUD Grantees program between (log-transformed) children's blood-lead concentration and the household's (log-transformed) area-weighted arithmetic average dust-lead loading for floors and window sills, respectively. Also included in these figures are the linear relationship associated with the data from Rochester Lead-In-Dust study and, in Figure 3-5, the Baltimore R&M study. The regression lines span the ranges of the observed dust-lead loadings. Note that the slopes of these lines are relatively parallel across the grantees and the two other studies. This indicates that the relationships between blood-lead concentration and dust-lead loading are relatively consistent across grantees. In particular, blood-lead concentration and dust-lead loading data from the Rochester study (used in developing the empirical model in Chapter 4) have similar relationships to what is observed in the HUD Grantees program, which considers data from a much larger geographical area and under various exposure conditions.

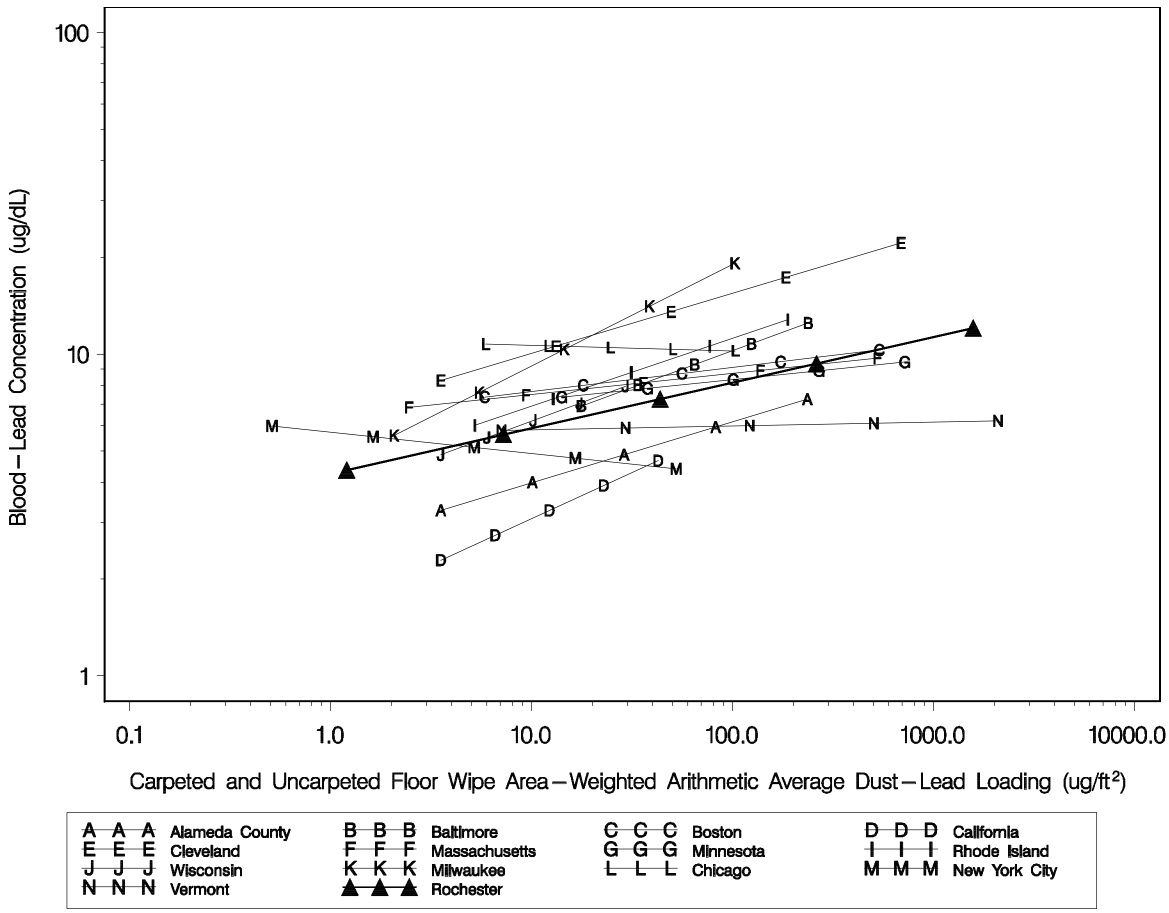

Figure 3-4. Blood-Lead Concentration Versus Area-Weighted Arithmetic Average Floor Dust-Lead Loading (Wipe Collection Method), for HUD Grantee and Rochester Lead-in Dust Study Data.

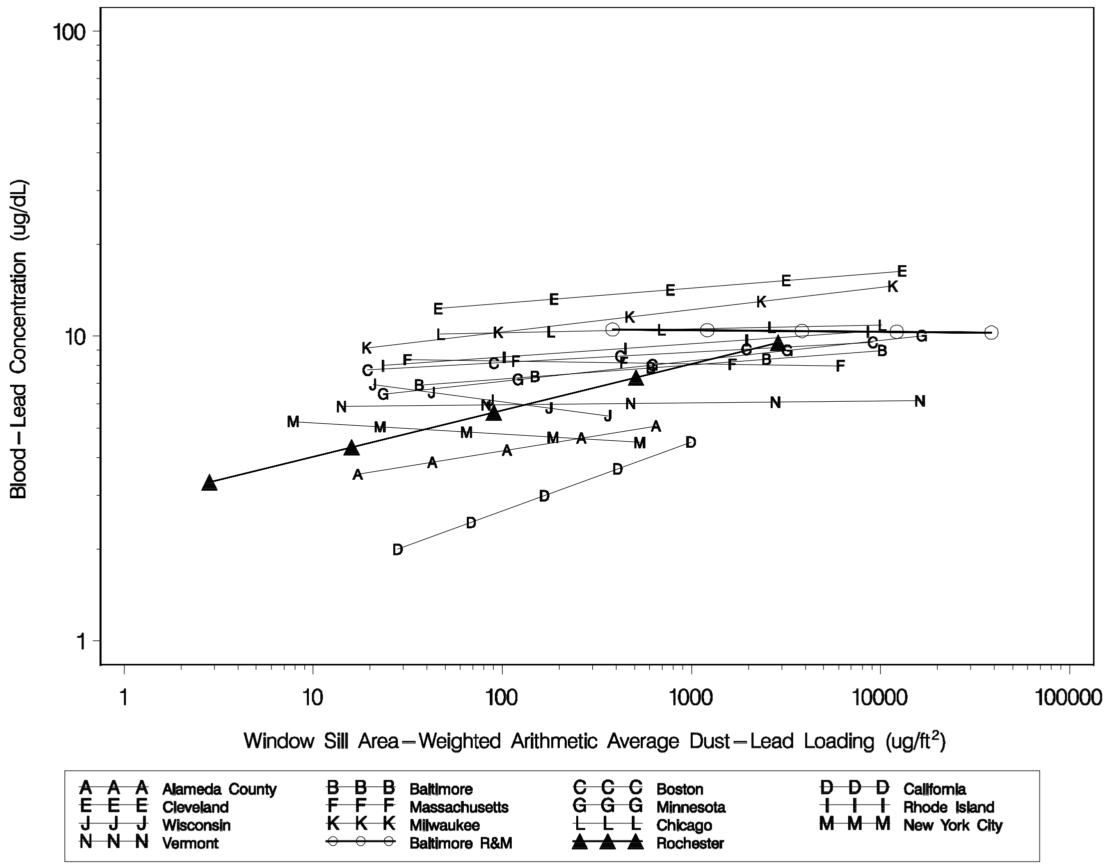

Figure 3-5. Blood-Lead Concentration Versus Area-Weighted Arithmetic Average Window Sill Dust-Lead Loading, for the HUD Grantee, Rochester Lead-in-Dust, and Baltimore R&M Studies.

3.5 EXPOSURE ASSESSMENT CHARACTERIZATION

Conclusions across multiple studies have indicated that lead-based paint hazards, including lead-contaminated soil and lead-contaminated dust, are primary contributors to overall lead exposure in young children. Lead-based paint, especially when in a deteriorated state or when found on accessible, chewable, impact, or friction surfaces, is a significant high-dose source of lead exposure in pre-school children. In turn, several lead exposure studies have concluded that the pathway of lead-contaminated soil and dust to children's blood is an important means by which young children are exposed to lead from lead-based paint hazards.

For this risk analysis, the exposure media associated with lead-based paint hazards within the nation's housing are segmented into three categories: 1) deteriorated lead-based paint; 2) yard soil contaminated from exterior sources such as deteriorated lead-based paint on the exterior of the residence; and 3) household dust contaminated from sources such as deteriorated lead-based paint on interior surfaces and lead-containing soil tracked in from the exterior of the residence.

This risk analysis selected the HUD National Survey of Lead-Based Paint in Housing as the primary data source for characterizing the distribution of environmental-lead levels in dust and soil in the nation's housing stock. The HUD National Survey is considered the most complete and representative characterization of lead levels in dust and soil in the nation's housing built prior to 1980. As part of the survey, each surveyed unit was assigned a sampling weight corresponding to the number of units in the national housing stock whose environmental conditions were represented by the given unit. Data from the American Housing Survey (sponsored by the Bureau of the Census and the U.S. Department of HUD) were used to revise these sampling weights to reflect the 1997 national housing stock.

Using HUD National Survey data with revised sampling weights, this risk analysis has estimated that the 1997 national housing stock contains over 99 million occupied housing units, of which 62% are expected to contain lead-based paint and 14% to contain more than five square feet of deteriorated lead-based paint. When considering only occupied units built prior to 1980, 83% are expected to contain lead-based paint, and 18% are expected to contain more than five square feet of deteriorated lead-based paint. Geometric mean environmental-lead levels in paint, dust, and soil tend to increase with age of unit. This finding is consistent with several studies that provide evidence of a link between the presence of lead-based paint (especially in a deteriorated state) and age of housing unit.

The design and findings of the HUD National Survey have been peer reviewed and published in several government reports. However, among the limitations associated with using data from this survey (with revised sampling weights) in this risk analysis are the following:

- The survey did not collect blood samples from children within the sampled units, thereby preventing this data source from being used to characterize the relationship between lead-based paint hazards and blood-lead concentration.

- The survey did not take more than three dust samples from within a housing unit; these samples were not necessarily taken from areas experiencing high levels of activity among resident children.

- Considerable measurement error may be present in the measured dust-lead concentrations due to small amounts of dust collected in some samples. (Adjusting dust-lead concentrations for small dust mass required a laboratory study to be conducted as part of this risk assessment as discussed in USEPA, 1996c.) Measurement error and its impact on the relationship between dust-lead and blood-lead concentration, as characterized by data from the Rochester study, is investigated in Emond et al., 1997.

- Dust samples were collected using the Blue Nozzle vacuum method, which differs from the wipe sampling method assumed in the §403 rulemaking when determining whether dust-lead loadings in a housing unit exceed pre-specified standards. (This situation required a dust-lead loading conversion procedure as discussed in Section 4.3 of Chapter 4.)

- The HUD National Survey did not attempt to sample lead levels in paint on all painted surfaces in a surveyed housing unit, creating considerable uncertainty in how housing units are characterized as containing lead-based paint.

- The survey did not sample housing built after 1979. (To represent such housing, this risk assessment had to employ inference procedures.)

- It is uncertain how environmental-lead levels in housing have changed since the survey was performed in 1989-1990.

- The need to update the sampling weights to represent the 1997 national housing stock introduced additional uncertainty to these weights. While the updating procedure was based on data from the nationally-representative American Housing Survey, these data were collected in 1993 and required additional procedures to be developed in this risk assessment to update the results to 1997.

- The sample size of 284 housing units may be considered too small to adequately represent the nation's housing stock.

- The field sampling occurred in winter months, which can influence the values of environmental-lead and blood-lead measurements.

A collection of human characterization studies and intervention studies were identified in which <u>significant positive relationships were consistently observed between lead-based paint exposures in residential environments and children's blood-lead concentration</u>. Three recent studies, the pre-intervention phases of the Baltimore (MD) Repair & Maintenance Study (conducted in a variety of housing types in an inner-city setting) and the Evaluation of the HUD Lead-Based Paint Hazard Control Grant program, as well as the Rochester (NY) Lead-in-Dust study (conducted in an urban/suburban setting), provided extensive information on environmental-lead levels and blood-lead concentrations in children exposed to such levels in their respective cities. Data from these three studies were summarized as part of this exposure assessment, to supplement the information on baseline distributions of environmental-lead levels in housing and blood-lead concentrations in young children. Conclusions from these studies indicate that elevated lead levels in paint, dust, and soil continue to exist in residential environments, particularly in older housing units. <u>Even at low to moderate lead levels, lead-contaminated dust can affect children's blood-lead concentration</u>.

Despite the general agreement across studies that blood-lead concentration is positively associated with environmental-lead levels, it is difficult to combine these findings into a single, quantitative measure of association. One reason is the presence of qualitative dissimilarities among the studies. These dissimilarities include differences in study design, sampling and analysis protocols, study objectives, target populations, and study locations. Another reason is that each study collects different types of supporting data, some of which may reduce the influence of some environmental-lead variables on blood-lead concentration when they are represented in statistical modeling procedures.

The extent to which a particular child is exposed to lead-based paint hazards is determined not only by environmental factors, but also by the child's activity patterns and by household characteristics. Examples include the number of hours the child is inside/outside the residence, the amount of time the child is away from the residence (including any exposures he/she may encounter there), the presence of pets, the occupation of adults in the household, cleaning habits of the residence, the presence of air conditioning, and the frequency that windows are opened. Therefore, lead exposures pose a health hazard to a child only to the extent that the child encounters the exposures and they become bioavailable to the child.

<u>The baseline distribution of blood-lead concentration in the target population (children aged 1-2 years) was derived in this risk analysis from data collected in Phase 2 of NHANES III</u>. These data, the latest available on the national distribution of blood-lead concentration (representing the period 1991-1994), verify the hypothesis that blood-lead concentration tends to peak in children at ages 1-2 years. Phase 2 of NHANES III estimates that <u>the geometric mean blood-lead concentration for this age group is 3.14 µg/dL; approximately 5.88% of these children have blood-lead concentrations at 10 µg/dL or higher.</u> While these statistics have declined from earlier years, they continue to be unacceptably high, especially for children in urban centers or within low income households due to their higher likelihood of encountering lead-based paint hazards. While the national representation of NHANES III results is widely accepted, some possible limitations in using these data include ignoring any seasonality effects on blood-lead concentration and any further decline in concentrations that may have occurred since 1994.

Information on average family sizes (as measured in the American Housing Survey) and numbers of children per person in the U.S. population (as projected by the U.S. Census Bureau) was used to determine numbers of children exposed to each environmental-lead condition as represented by housing units within the HUD National Survey. Possible limitations associated with using this information include assumptions that these numbers remain consistent across the entire national housing stock.