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LEAD EXPOSURE ASSOCIATED WITH RENOVATION AND REMODELING ACTIVITIES:

ENVIRONMENTAL FIELD SAMPLING STUDY VOLUME I: TECHNICAL REPORT

Prepared By

Battelle
505 King Avenue
Columbus, OH 43201

for

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

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Contributing Organizations

This study was funded and managed by the U.S. Environmental Protection Agency. The study was conducted collaboratively by two organizations under contract to the Environmental Protection Agency, Battelle, and Midwest Research Institute. Each organization's responsibilities are listed below.

Battelle

Battelle was responsible for designing the study, recruiting participants, creating and maintaining the study data, conducting the statistical analysis, and producing the final report.

Midwest Research Institute (MRI)

MRI was responsible for field data collection, chemical analysis, and reporting of chemical analysis results.

U.S. Environmental Protection Agency

The Environmental Protection Agency was responsible for oversight in the developing the study plan, managing and coordinating the overall study, and reviewing and editing this report. EPA Project Managers included Dan Reinhart, Darlene Watford, Susan Dillman, and Betsy Dutrow. Cindy Stroup was the Branch Chief of the Technical Programs Branch under whose direction the study was conducted.

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Executive Summary

The Residential Lead-Based Paint Hazard Reduction Act (Title X) required the U.S. Environmental Protection Agency (EPA) to conduct a study of lead exposure resulting from renovation and remodeling (R&R) activities (the R&R study). The information obtained from the study is to be used primarily to help determine which groups of people require training, certification, or educational materials because of the potential lead exposure associated with R&R activities they perform. This report presents the results of one of the principal data collection efforts in the R&R study: the Environmental Field Sampling Study (EFSS). The EFSS, through the collection of environmental measurements, assessed the amount of disturbance and potential exposure to lead that resulted from selected R&R activities. The monitored activities included both specific R&R activities, such as carpet removal and window replacement, as well as miscellaneous generic activities such as drilling, sawing, or surface preparation (sanding, paint scraping, etc.). Environmental samples collected in the EFSS included over 90 personal air samples taken within the breathing zone of R&R workers as they performed specific R&R activities, and over 500 samples of dust that settled on building surfaces within a specified period following completion of an activity.

Worker exposure was assessed using the airborne lead levels from each worker's breathing zone, as measured by a task-length average (TLA) exposure. A worker's TLA represents average airborne exposure for the worker <u>during conduct of the activity</u>. The average TLAs were high during the conduct of many of the R&R activities, exceeding the OSHA permissible exposure limit of 50 $\mu g/m^3$ for four of the R&R activities. Average TLAs were greater than 100 $\mu g/m^3$ for paint removal, interior demolition, and sawing, and greater than 49 $\mu g/m^3$ for interior surface preparation and central heating system maintenance/repair. Exposures resulting from drilling, carpet removal, window replacement, and exterior surface preparation were considerably lower (below 20 $\mu g/m^3$). The TLA exposure for each activity (as estimated in the EFSS) can be combined with worker profile information (available from outside sources) to characterize worker exposure.

Potential exposure to building occupants was assessed using the dust samples collected by vacuum techniques from stainless steel dustfall collectors placed at specified distances from the activity. Lead loadings from these samples were measured as indicators of the amount of lead disturbed by an R&R activity and available for exposure to occupants. With the exception of carpet removal and drilling into plaster, all activities monitored in the EFSS deposited significant amounts of lead, ranging from 328 $\mu g/ft^2$ for sawing lead-painted plaster to 42,900 $\mu g/ft^2$ for paint removal. Paint removal, demolition, sawing, and disturbing central heating system ductwork were more likely to cause airborne lead to scatter and settle over a widespread area, while window replacement and drilling confined the disturbed lead to a smaller area. While simple broom and shop-vacuum cleanup substantially reduced the total amount of lead available to occupants, cleanup efficiency declined as the distance from the activity increased. In addition, the average amount of lead following cleanup often remained above 100 µg/ft^2, the current EPA guidance level for floors. The estimates of lead amounts within settled dust presented in this report can be linked with information on types and durations of activities, types of work practices and cleanup activities, and human health effects to provide a more complete characterization of occupant exposure associated with R&R activities.

1.0 INTRODUCTION TO THE OVERALL RENOVATION AND REMODELING (R&R) STUDY

On October 29, 1992, the United States Congress enacted the Residential Lead-Based Paint Hazard Reduction Act (Title X of HR 5334). This includes Title IV of the Toxic Substances Control Act that requires the U.S. Environmental Protection Agency (EPA) Administrator to conduct a study of lead exposure associated with renovation and remodeling activities. In particular, paragraph (2) of Section 402 (c) states:

> *The Administrator shall conduct a study of the extent to which persons engaged in various types of renovation and remodeling activities in target housing, public buildings constructed before 1978, and commercial buildings are exposed to lead in the conduct of such activities or disturb lead and create a lead-based paint hazard on a regular or occasional basis.*

EPA conducted the above study, hereafter referred to as the Renovation and Remodeling (R&R) study, from 1993 through 1995. Results of the R&R study are documented in three separate reports:

- "Lead Exposure Associated With Renovation and Remodeling Activities: Summary Report"
- "Lead Exposure Associated With Renovation and Remodeling Activities: Environmental Field Sampling Study," a technical report on environmental measurements of lead associated with renovation and remodeling; this report also includes the results of the literature review and a summary of data collected from other extant sources; and
- "Lead Exposure Associated With Renovation and Remodeling Activities: Worker Characterization and Blood-Lead Study," a technical report on blood lead levels and work practices of renovation and remodeling workers.

Chapters 1 and 2 of this report include a discussion of the overall design of the R&R study and the complementary roles of its two principal data collection efforts: the Environmental Field Sampling Study (EFSS, or Environmental Study) and the Worker Characterization and Blood-Lead Study (WCBS, or Blood-Lead Study). Subsequent chapters deal with the design, implementation, and results of the EFSS.

1.1 OBJECTIVES OF THE R&R STUDY

The overall or programmatic objective of the R&R study was to determine which groups of people doing R&R work require training, certification, or educational materials because of their potential lead exposure. In direct response to the scope of work outlined in the legislation, the study was designed to satisfy two primary technical objectives:

1. Determine the extent to which persons engaged in various types of R&R activities in target housing (i.e., housing constructed prior to 1978), public buildings constructed before 1978, and commercial buildings are exposed to lead.

2. Determine the extent to which persons engaged in various types of R&R activities disturb lead and create a lead-based paint hazard, on a regular or occasional basis, to building occupants or other exposed individuals.

1.2 SCOPE OF THE R&R STUDY

The broad scope of the study mandated by Title X made it an arduous task to design and implement the R&R study. The study required multiple field studies and decisions concerning priorities, focus, and representativeness. This section presents the final decisions on key definitions and delineation of scope. Chapter 2 provides insight into how these decisions were made.

1.2.1 Definition of Renovation and Remodeling

In accordance with the United States Census Bureau's C-50 report, "Expenditures for Residential Upkeep and Improvement" (U.S. Census Bureau, 1987), remodeling is defined as any construction-related work on an existing property intended to either maintain or improve the property. In addition, the work must be on items permanently attached or firmly affixed to some part of the house or property.

The major components of remodeling include:

- Maintenance (painting, papering, floor sanding, furnace cleaning or adjustment, etc.)
- Repairs (plumbing, heating, electrical work, etc.)
- Additions and alterations (adding a wing, room, porch, deck, shed, basement, fence, driveway, etc.)
- Major replacements (bathroom, kitchen, roof, water pipes, central heating system, siding, etc.).

Renovation is defined as work on an existing property intended to make a major improvement in the property.

1.2.2 Components of the Scope

The scope of the study mandated by the Title X legislation called for an assessment of the lead exposure for different categories of:

- Individuals (specifically R&R workers, building occupants, and other exposed individuals)

- Environments (specifically private housing constructed before 1978, public buildings constructed before 1978, and commercial buildings)

- R&R activities.

Private housing constructed before 1978, known as *target housing*, represented one category in which lead exposure was to be assessed, while public or commercial buildings were placed into one of two additional categories, according to whether or not children regularly inhabited the buildings. The types of activities considered in the R&R activities segment are discussed in the following section.

1.2.3 Specification of R&R Target Activities

The EPA assembled a list of R&R activities associated with lead exposure. This list was developed as a result of more than 200 contacts with other government agencies, lead poisoning prevention experts, industry representatives, labor unions, and other concerned groups. At a final summary meeting on April 16, 1993, in Washington, D.C., with a number of these contacted individuals, the EPA obtained data and subsequently defined eleven categories of R&R activity with potential for lead exposure that could be addressed by this study. These categories, subsequently called ***target activities***, were:

1. Paint removal
2. Surface preparation
3. Removal of large structures
4. Window replacement
5. Enclosure of exterior painted surfaces (i.e., siding)
6. Carpet or other floor covering removal
7. Wallpaper removal
8. HVAC (central heating system) repair or replacement including duct work
9. Repairs or additions resulting in isolated small surface disruptions
10. Exterior soil disruption
11. Major renovation projects involving multiple target activities.

There were several reasons for choosing HVAC repair over plumbing or electrical work as a target activity. First, both plumbing and electrical work were believed to often only disturb small areas of painted surfaces. Second, disturbance of lead in pipes, joints, and soldered connections was considered out of the scope of the study, which was focused on lead-based paint hazards. Finally, there was concern that furnace ductwork could be a significant reservoir for large amounts of lead dust.

1.3 APPROACH

The initial phase of the R&R study involved an extensive literature review and information-gathering process. This process uncovered the currently available information on lead exposure related to R&R activities. It also helped in decision making concerning the focus of the study. The results of this process are presented in Chapter 2. The major conclusion of the literature review and information gathering was that, with the exception of paint removal, insufficient information was available for an exposure assessment of different categories of R&R activities. As a result, new data collection was required to address study objectives. This section discusses the approach to new data collection.

1.3.1 Blood-Lead Measurements Versus Environmental Measurements

The existence and extent of lead exposure created by R&R activities may be assessed either by blood-lead or environmental-lead measurements. Once the need for new data collection was identified, the R&R design team considered the advantages and disadvantages of each approach. A study assessing blood-lead concentrations provides for direct measurement of an internal (absorbed) dose of lead. However, blood-lead concentrations can be explained not only by recent exposure but also by historical exposure and by many secondary factors (such as age, nutrition, and smoking). A study assessing measurements of lead in the environment (dust, air, or soil) makes a direct link between R&R activities and measurements of lead disturbance. However, these measurements serve only as estimates of the amount of lead available for potential inhalation or ingestion, therefore representing only a potential internal dose to humans.

An optimal study design would involve measuring worker and occupant blood-lead concentrations and environmental-lead levels before, during, and after R&R activity. However, measuring blood-lead concentrations before and after an activity was not feasible for ethical and legal reasons. Measuring environmental lead levels before and after an activity was complicated by serious recruitment and liability problems because of the desire to target typical R&R jobs in an unregulated environment.

The approach taken for this study circumvented these problems by defining two principal data collection efforts: one characterizing environmental lead disturbance resulting from R&R activities and the other focusing on the effect of R&R activity on worker blood-lead concentrations through a retrospective study. A third effort, currently in the design stages, will be a retrospective study to evaluate the impact of the conduct of R&R activity on elevated blood-lead concentrations in children. This effort will be conducted jointly with the University of Wisconsin and the State of Wisconsin Public Health Department.

1.3.2 Data Collection

<u>**Environmental Field Sampling Study**</u>

The first principal data collection effort of the R&R study was the Environmental Field Sampling Study (EFSS). In it, environmental measurements were taken to assess the relative disturbance of and exposure to lead associated with selected R&R activities. Activity categories that showed the greatest measured amounts of lead exposure were assumed to be the primary contributors to any potential health effect.

The focus of the EFSS was on monitoring specific R&R ***activities***. An alternative approach was considered, namely to monitor specific R&R ***worker groups*** as they performed their normal duties with whatever mix of activities was encountered. The decision to focus on activities rather than specific worker groups was supported by all representatives who attended the April 16, 1993, study design meeting in Washington, D.C., described in Chapter 2. The primary reasons for focusing on activities were that:

1. A focus on activities provided the best understanding of exactly what was causing the lead exposure.

2. A focus on activities was the most efficient way to assess a wide variety of R&R worker groups. Exposure estimates based on worker groups would be applicable only to the monitored groups. Exposure estimates based on specific activities, on the other hand, could be combined with worker profile information for any given worker group to assess that group's exposure. ***Worker profile*** information includes information on the types of activities workers conduct, the type of work practices and worker protection they use, and the percent of time they work in buildings with lead-based paint.

3. Exposure estimates based on R&R activities provide information useful in the development of subsequent guidelines for the conduct of R&R.

The data collection effort for the EFSS included six of the 11 target activities: removal of large structures (demolition), window replacement, carpet removal, HVAC repair or replacement, surface preparation, and repairs with minimal surface disruption. Paint removal was excluded because exposure associated with paint removal could be assessed from the literature. Exterior siding, wallpaper removal, and exterior soil disruption were excluded by consensus, because the study design team and the individuals consulted in the information-gathering phase considered these target activities to be of secondary importance. It is possible that inferences about exterior siding and exterior soil abatement may be made from professional judgment and comparison with other activities. Wallpaper removal is an activity conducted primarily by painters who were assessed based on other activities they perform — most notably surface preparation and paint removal.

The EFSS was supplemented by an extensive search for extant data that could be used either to fulfill data requirements for a specific activity or to confirm results obtained in the EFSS.

Worker Characterization and Blood-Lead Study

The second principal data collection effort of the R&R study was the WCBS. The WCBS involved collecting questionnaire information and blood-lead measurements from R&R workers to 1) characterize blood-lead concentrations in specific worker groups, 2) determine if specific worker groups or specific R&R activities are associated with increases in blood-lead concentrations, and 3) collect information to be used to develop worker profiles. The WCBS was intended to obtain information independent from the EFSS that would provide a direct measure of effects on worker health and to validate the results of the EFSS. Target R&R activities examined in the WCBS included removal of large structures (demolition), window replacement, carpet removal, HVAC repair or replacement, and paint removal. Post-activity cleanup was also considered.

Figure 1-1 shows the design and coordination of the R&R study. This report presents the technical results of the EFSS (right-hand side of Figure 1-1). As the figure indicates at the bottom, the results of the EFSS and WCBS are integrated in the Summary Report for the R&R study.

1.4 PEER REVIEW

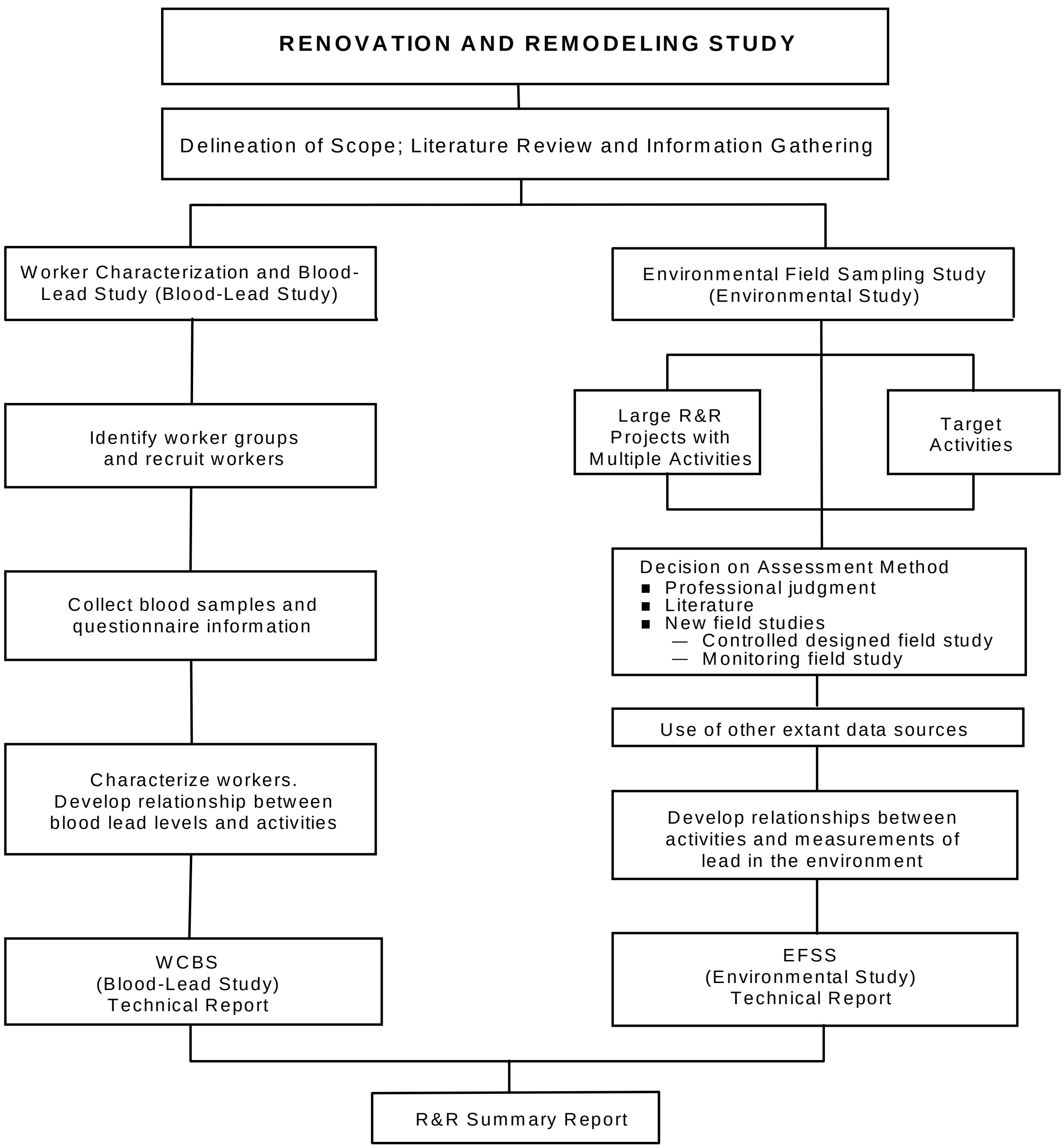


Figure 1-1. Overall Design Structure of the Renovation and Remodeling Study

This report on the Environmental Field Sampling Study (EFSS) was reviewed independently by members of a peer review panel. Comments which are important for interpreting the study results or which resulted in important modifications to the report are discussed below. All peer reviewers recommended publishing the report with minor revisions.

A primary concern for a number of reviewers was the limited sample sizes in the EFSS study. A separate section which discusses data gaps and data limitations is included in the report. In addition, the sample size consideration has been highlighted through characterization of the EFSS independent monitoring jobs as case studies and through judicious use of language such as "potential for disturbing significant amounts of lead during R&R activities" that do not overstate conclusions that can be drawn from this data. Sample sizes are discussed and documented throughout all reports.

Related to the sample size issue was concern over the number of statistical analyses conducted and the exploratory nature of some analyses. Additional cautionary language was added to the reports to warn of exploratory analyses, the effect of multiple statistical comparisons, and the limitation of small sample size on the ability to detect statistical significance.

Another concern expressed by reviewers was the relevance of abatement data to an exposure assessment for R&R workers, and similarly the effect of using trained abatement workers for some of the work conducted in the EFSS. Several sections of the EFSS report address these concerns directly. Section 2.1, Relevance of Information on Abatement, and Section 2.2, Characterization of Renovation and Remodeling, discuss the differences between abatement work and renovation and remodeling. Section 5.0, Overview of Recruitment, addresses the criteria applied in the EFSS for accepting jobs and workers as representative of typical R&R work. Professional abatement workers in the EFSS did wear respirators and follow abatement personal hygiene procedures to protect themselves. However, they did not follow standard abatement procedures, such as use of wet methods, and were instructed to perform the tasks as they are typically conducted in an unregulated environment. For example, demolition was conducted dry with hammers and crow bars, and sawing was conducted dry with a circular saw and no HEPA attachment. Since no dust minimization procedures were used, the work was considered representative of typical renovation and remodeling work. On the other hand, available data sources from professional abatement work that did involve dust minimization were not included in any data summaries.

Several comments related to clarification of the terms "surface preparation" and "paint removal." Although there is certainly overlap between the two activities, there was general concurrence among all parties consulted during the design of the study that it was important to distinguish between the two activities. These terms are defined throughout the report to make as clear as possible the exact type and duration of activity that took place.

Concern was also expressed over the inability to collect both blood-lead and environmental lead measurements from the same group of workers and/or occupants. Human subjects review, for both ethical and legal reasons, would not allow measuring blood-lead concentrations for occupants (young children) before and after conduct of an activity that was suspected of causing a hazard. For workers, the difficulty in this study was *recruiting* typical R&R workers operating in an unregulated environment. For this group of workers, employers were very reluctant to participate even as the study was conducted. Contractors were concerned over lawsuits by workers in the event that the study revealed a worker's blood-lead increased as a result of a specific job they were assigned to. We had very few contractors participating in either phase of the study. Employees participated in the WCBS largely because of either their own interest or the interest and encouragement of their national and local union. Gaining access to work sites for environmental and biological sampling would have required participation of the contractors, homeowners, and workers. If such sampling was conducted under forced cooperation, then the results may have been biased. If the study had focused on lead abatement workers this may not have been a problem, but with a focus on typical R&R workers who were not, at the time of this study, using worker protection practices, there were many problems recruiting contractors to participate. In short, the difficulty in recruiting contractors was in getting at the population of interest: unregulated R&R workers not specializing in lead abatement.

One reviewer requested more information to show that the QC data are consistent with the statistical analysis applications and results. As a result of this comment, more documentation was added to the reports, including references to appendices and quality assurance project plans.

EPA has established a public record for the peer review under administrative record AR152, “Lead Exposure Associated with Renovation and Remodeling Activities Peer Review.” The record is available in the TSCA Nonconfidential Information Center, which is open from noon to 4 PM Monday through Friday, except legal holidays. The TSCA Nonconfidential Information Center is located in Room NE-B607, Northeast Mall, 401 M Street SW, Washington, D.C.

2.0 LITERATURE SEARCH AND INFORMATION GATHERING

The initial phase of the R&R study involved an extensive literature review and information-gathering process. This phase, conducted in concert with the development of EPA guidelines for R&R ("Reducing Lead Hazard When Remodeling Your Home"), had three primary objectives:

1. Define and characterize R&R and its component activities.

2. Collect the available information concerning human lead exposure and environmental lead hazards resulting from R&R activities.

3. Identify any data sources that could be used in this study's assessment of lead exposure and hazards related to R&R.

The goal of the information-gathering process was to identify and thoroughly examine the sources of information regarding lead exposure during R&R activities. This chapter presents the methodology, findings, and the conclusions of the literature search and information gathering phase.

2.1 RELEVANCE OF INFORMATION ON ABATEMENT

Early in the process of gathering information about R&R activities, it was decided to exclude information developed during lead-based paint abatement. This exclusion was a difficult decision. A number of R&R activities are conducted during abatement (e.g., paint removal and window replacement), and comparable worker populations perform both abatement and the R&R activities. Moreover, considerable information is available in the scientific literature on the human lead exposure and environmental lead contamination resulting from implementation of various abatement strategies. However, there were some important differences between R&R and abatement that impact the relevance of abatement results.

The work practices associated with abatement are likely to be considerably different from those associated with R&R activities. It is recommended that abatement workers wear protective equipment (e.g., respirators) during the activities that disturb lead, and that the disturbed lead be contained by spreading and taping into place polyurethane sheeting. The procedures employed in abatement were developed to either minimize the lead dust generated (e.g., misting) or restrict its spread outside the immediate area (e.g., via vacuum attachments). Abatement often includes extensive cleanup procedures, such as wet-mopping the area with a detergent solution of 5% trisodium phosphate (TSP), then vacuuming with a high-efficiency particle accumulator (HEPA) vacuum. In addition, abatement workers, by definition, operate more frequently and knowledgably in a lead-contaminated environment than do R&R workers. Both their training and awareness of the hazards of lead are usually more advanced than that of workers performing strictly R&R activities. Therefore, their blood-lead concentrations and the environmental lead generated by their activities are not representative of general R&R workers and their activities in a non-abatement environment.

2.2 CHARACTERIZATION OF RENOVATION AND REMODELING

The first objective of the information gathering phase was to characterize R&R, thereby defining the scope of the study and the activities to be examined. The questions to be addressed included:

- What is renovation and remodeling?
- Who performs it and what procedures do they employ?
- Is there a recognized lead hazard from such activities?
- If so, what activities have been identified as producing a hazard?

To answer these questions, the available literature was examined and prominent individuals in the field of lead exposure (both residential and occupational) and within the R&R industry were consulted. The primary goal was to obtain data on lead exposure to workers and occupants (as measured by body-lead burden) resulting from R&R activities. If such data were unavailable, information on environmental lead contamination was sought.

A comprehensive list of individuals or groups currently involved in lead research and policy making from national committees, major trade industries, published authors, federal and state agencies, academia, and medical institutions was compiled. People on the list were contacted by telephone or personal interview. Target activities and worker classifications associated with R&R were drafted by sorting through the literature and the information and perspectives offered in the many phone calls and interviews. After more than 200 interviews were completed, a final summary meeting was held on April 16, 1993, in Washington, D.C. with a number of the contacted individuals. From this meeting, a general concurrence on the scope of R&R and its component target activities and worker classifications was reached. The resulting characterization and definition of R&R target activities to be considered was presented in Section 1.2.3.

In addition to defining R&R and its component target activities and classifying the workers who perform these activities, the actual work practices involved in R&R needed to be identified. Many of the contacts from national trade unions and government agencies stressed the need to focus on "typical" R&R practices. They also stressed their belief that abatement practices would not be representative of typical R&R practices. Although no information was identified that directly described actual R&R work practices, some information concerning guidelines for performing R&R work was uncovered. The National Association of Home Builders (NAHB) has produced guidelines entitled, "What Remodelers Need to Know and Do About Lead — An Interim Guide" (NAHB, December 1992). These guidelines parallel the HUD Guidelines for Evaluation and Control of Lead-Based Paint Hazards in Housing (U.S. Department of Housing and Urban Development, July 1995). Information concerning typical work practices was targeted for collection in the WCBS component of the R&R study.

Finally, the parties attending the Washington meeting prioritized the identified R&R target activities according to the need for data collection efforts to assess the lead exposure or environmental lead hazard generated. As a result, the following activities (listed in no particular order) were chosen for new data collection as part of this study:

- Carpet removal
- Window replacement
- Removal of large structures (demolition)
- HVAC work
- Isolated surface disruptions.

2.3 REVIEW OF THE AVAILABLE LITERATURE

The second objective of the information gathering phase was to thoroughly explore and understand the existing body of information concerning the relationship between renovation and remodeling and lead exposure, and to identify any data that could be used to assess this relationship. Beginning with the individuals asked to define R&R, a search was performed to identify published reports, papers, data, or other individuals or organizations that would provide information on lead exposure or hazards associated with R&R activities. This method of information gathering was pursued until no previously unidentified sources were uncovered.

In addition to soliciting opinions and information from interested parties, an extensive literature search was undertaken. The search covered all information published in the last 15 years pertaining to the lead exposure of occupants, R&R workers, activities, R&R methods within an activity, R&R in industry, and R&R in the military. Using the on-line library search system, DIALOG, journals available through MEDLINE, NTIS, Engineering Information, Enviroline, Pollution Abstracts, Occupational Safety and Health, and other sources were examined for information relating to lead exposure and renovation and remodeling. More than 500 potentially relevant articles were identified.

From this search, it was confirmed that literature directly discussing lead hazards or exposure created by R&R activities was limited. Only 12 articles focused on renovation and remodeling. Moreover, there appeared to be no definitive lead exposure study examining R&R activities. In fact, all references to R&R activities were either secondary or anecdotal. For example, four articles described case studies of individuals suffering from elevated blood-lead levels during renovation of their homes. Overall, however, these twelve articles did provide evidence of lead elevations in both body burden (blood) and environmental media (dust, air, and soil) resulting from R&R activities.

On the other hand, there was a significant body of literature discussing R&R-related activities, such as lead abatement. Approximately 20 such articles and reports were identified, providing detailed information about the association between disturbances to an existing lead reservoir (e.g., lead-contaminated soil or lead-based paint) and environmental or body-burden lead levels. As was indicated in Section 2.1, the activity performed and the actual work practice in an abatement are likely to be different from that of R&R. In fact, an argument could be made that exposures measured during an abatement activity represent either a best- or worst-case scenario when applied to the same renovation and remodeling activity. They could represent a best-case scenario because of the extensive precautions taken during abatement work. They could represent a worst-case scenario because of the amount of lead disturbed during an abatement. Therefore, only to the degree that an abatement activity is considered "similar" to a typical R&R activity would the abatement literature prove useful in evaluating the lead hazard associated with an R&R activity.

Despite the scarcity of directly relevant literature, there did appear to be a consensus that R&R activities can produce both body-lead burden and environmental lead contamination. In a longitudinal study of blood-lead levels in neonates, Rabinowitz and Needleman note that "infants residing where lead paint is being resurfaced (as typically performed) may be at special risk of increased lead exposure" (Rabinowitz et al., 1985). The Center for Disease Control and Prevention's (CDC's) publication, "Preventing Lead Poisoning in Young Children," reports that "many cases of childhood lead poisoning that result from renovation and remodeling of homes have been reported" (Centers for Disease Control and Prevention, 1991). The Department of Health and Human Services' (HHS') "Strategic Plan for the Elimination of Childhood Lead Poisoning," cites as priorities for lead abatement "homes with lead-based paint that are being renovated and remodeled for other reasons" (U.S. Dept. of HHS, February 1991). Dr. Julian Chisolm, a respected doctor involved in childhood lead research, and other contacts, expressed their personal opinion that R&R activities are responsible for elevated blood-lead levels in many middle-class children. Renovation and remodeling activities, by their very nature, have the potential to disturb existing reservoirs of lead (e.g., intact lead-based paint, lead dust-contaminated carpet). Once the disruption occurs, the lead is available for contamination of workers and residents. This fact, along with the acknowledged link between environmental lead levels (especially dust-lead levels) and blood-lead concentrations, leads to a recognition that R&R activities are a possible source of lead exposure to both children and adults.

A debate arises, however, when assessing which R&R activities produce a lead hazard. Upon closer examination of the literature, the activity cited most often as responsible for lead exposure and hazards is lead-based paint removal. Even industry sources (e.g., the National Association of Home Builders) concede the hazard of paint removal. However, some literature sources claim that other activities such as surface enclosure or component removal generate a non-significant lead hazard. In fact, this dichotomy is fairly complete: lead-based paint removal is widely recognized as generating a lead hazard, but other R&R activities are only sparsely addressed. For example, the NAHB suggests that "while remodeling and lead abatement tasks other than paint removal may generate small amounts of airborne lead dust and paint debris, with proper cleanup they represent a minimal hazard to workers and occupants" (NAHB, December 1992). Within the literature, R&R activities have been effectively characterized into two groups: paint removal and everything else.

Chemical stripping, surface sanding, and heat gun stripping are procedures usually used for paint removal. All are widely acknowledged to generate a lead hazard in the presence of lead-based paint. There are numerous studies of lead poisoning of construction workers employed at removing lead-based paint. The HUD Abatement Demonstration Study found unacceptably elevated levels of personal exposure to airborne lead for workers removing lead-based paint with heat guns, despite temperature controls to prevent vaporization of the paint (U.S. Dept. of HUD, 1991). Industry also concedes the problem as reported in the NAHB guidelines entitled, "What Remodelers Need to Know About Lead" (NAHB, December 1992). The evidence from the literature and the broad consensus suggests that additional studies of paint removal will yield little new information on this activity's potential lead exposure to workers and occupants.

Few references address lead hazards or exposure associated with the other renovation and remodeling activities, and the information is insufficient for assessing the hazards presented in R&R activities other than paint removal. A National Institute of Safety and Occupational Safety and Health (NIOSH) evaluation of the lead hazard produced during the HUD Abatement Demonstration Study found that "less than 5% of the personal exposures to lead measured for ... enclosure and replacement methods, and none of the exposures for encapsulation, ... exceeded the OSHA PEL* of 50 $\mu g/m^3$" (NIOSH, February 1992). These figures were for abatement methods, however, not for typical R&R methods. Conversely, an abatement study conducted by NIOSH evaluating the hazards associated with cleaning up lead-based paint found that short-term personal exposure levels met or exceeded the OSHA PEL limit in 16 of 36 workers. NIOSH reports that "... the results of the study are of interest because many construction workers potentially perform similar activities during renovation ..." (NIOSH, Ohio University, May 1993). Additionally, the Comprehensive Abatement Performance (CAP) Pilot Study reported elevated dust-lead levels resulting from extensive renovation (including large surface demolition and plumbing installation) of a formerly abated housing unit (Battelle Report to USEPA, September 1994). A two-year monitoring study of lead exposure in infants found "home refinishing" as a contributor to dust and blood-lead levels (Rabinowitz et al., 1985). The specific activities that constituted home refinishing were not thoroughly discussed, but activities other than exclusively paint removal were considered. Therein lies much of the reason for the scarcity of information about other R&R activities. Discussions of R&R activities in the literature focus on the source of the lead hazard, not the activities that contribute to that hazard. Since many R&R activities occur within the residence, lead-based paint is usually identified as that source. Any information about the activities is anecdotal. The lead hazard or poisoning documented in case studies may be caused by activities other than paint removal, but details are not available. It was concluded, as a result, that the lead hazard or exposure from renovation and remodeling activities other than paint removal cannot be assessed from the literature alone.

2.4 REVIEW OF AVAILABLE DATA SOURCES

Since the literature search yielded little information concerning the lead hazard associated with R&R activities other than paint removal, a comprehensive search was undertaken to uncover any existing sources of data that might relate a specific R&R activity to the lead exposure presented by that activity. Starting with the contact list compiled earlier and likely resources identified in the literature, a list of potential data sources was created. This list included individuals from special interest groups in the construction industry, independent researchers, the U. S. military, public housing authorities (PHAs), and other government agencies. To ensure a comprehensive search, individuals who were contacted were asked to identify possible data

* Permissible exposure limit.

sources or individuals who might lead to a data source. If a potential new source was identified, then the individual or organization was added to the list. This was continued until no new individuals were identified.

Telephone calls were made to each individual on the list. During the course of the conversation, the scope of the project was conveyed, emphasizing strongly the need to find data that could directly relate lead exposure or contamination to a specific R&R activity. During the phone interview, a determination was made whether the recommended data source was representative of a renovation and remodeling activity. Generally, data collected when abatement techniques were employed was not considered representative of the exposure that may occur during "typical" R&R activity. [It is recognized that what constitutes "typical" R&R is currently under revision, owing primarily to the issuance of OSHA's Interim Final Rule for Lead Exposure in Construction (29 CFR 1926.62), which became effective during the term of this study.] Exceptions were allowed for some abatement activities, such as exterior work and encapsulation, since these activities are very similar to R&R activities. If there was any doubt as to the applicability of the data, the person was asked to send the data with some documentation if possible. A determination was made whether to include the data after the data collection methods were more closely reviewed. This ensured that a potential data source was not missed because of miscommunication or misunderstanding. Those individuals with data that fit well into the scope of the study were asked to send the data in whatever format was convenient, with documentation whenever possible. All data were compiled into a common data set so that summaries could be made.

More than 40 individuals and organizations were contacted. However, very few *renovation and remodeling* data sources were uncovered. A large body of information covers specific activities and the lead exposure associated with these activities when abatement techniques are employed, but very few sources collected information during activities that resemble or actually are R&R settings. For instance, abatement data from several PHAs were available, but because many of the abatement projects were sponsored by HUD grants, HUD’s guidelines on abatement (which include extensive worker and occupant protection measures and cleanup) were followed. Some of the activities that very closely resemble renovation and remodeling activities, even when abatement guidelines are followed, include interior and exterior encapsulation, component replacement, and some surface preparation. Whenever possible, these activities were extracted from the abatement studies and included in the data base.

Several potential data sources reported monitoring data that could not be related to specific activities or to R&R activities that were conducted on surfaces coated with lead-based paint. As a result, these data could not be placed in an appropriate context in this study and therefore were not included in the data base. Other contacts have confirmed the lack of lead exposure data related to renovation and remodeling. One military official, representing a data source included in Table 2-1, stated that before their study in 1992, they could not find any data related specifically to R&R.

Table 2-1 lists several characteristics of the potential data sources identified. Of the 18 identified sources, the results from 10 studies were received. Of those 10, eight had information that related exposure to a particular R&R activity. These eight data sources are discussed in Section 8E of Chapter 8.

Table 2-1. Potential Sources of Existing Data Associating Lead Exposure With a Particular Renovation and Remodeling Activity

Identified Data Sources	Activities	Number of Sources Identified
National Association of Home Builders (NAHB)	▪ Demolition ▪ Window Replacement	2
Private Environmental/ Abatement Contractors	▪ Component Removal ▪ Window Replacement ▪ Carpet Removal ▪ Demolition ▪ Surface Preparation	4
Public Housing Authorities (PHAs)	▪ Surface Preparation ▪ Kitchen Remodeling ▪ Exterior work	5
National Institute of Occupational Safety and Health (NIOSH)	▪ Various R&R activities ▪ Cleanup	2
California Department of Health; New York State Department of Health; Massachusetts Department of Environmental Health	▪ Surface Preparation: Sanding and Scraping ▪ Window Replacement	3
U. S. Military	▪ Surface Preparation: Sanding, Scraping, Power Sanding ▪ Cleanup ▪ Exterior Component Installation ▪ Interior Component Removal ▪ Painting	2

In general, data provided by the PHAs were not representative of typical R&R or were not available to the study. Much of the PHA data were collected in an abatement setting that was not representative of typical R&R. Because much of the abatement work was contracted out, the data did not reside with the PHAs. The need to obtain data from contractors greatly diminished the potential for collecting PHA data. Only one PHA contractor provided data to this study.

The data identified and obtained from sources other than a PHA tended to be more closely related to R&R activities. The individuals contacted were very much aware of the potential problems of lead exposure to R&R workers and were sensitive to the issues involved in locating data specific to R&R. Several good prospects were developed through these individuals, and potentially informative data sets were obtained.

2.5 SUMMARY

Available information on the lead hazards associated with R&R activities other than paint removal is very limited. Despite a comprehensive literature search and hundreds of phone calls to individuals very familiar with lead issues and policies, little information was uncovered. Only eight sources were found to contain data on lead exposure related specifically to R&R activities. The data collected from these other sources are summarized and discussed in Section 8E of Chapter 8.

Two additional studies were identified that were in the planning stages at the time the EFSS was conducted: 1) a study sponsored by a state government agency (with support of a HUD grant) of surface preparation using dry scraping, heat guns, and torches, and 2) a study sponsored by the NIOSH of the renovation and remodeling of post offices and General Accounting offices throughout the U.S. These studies have the potential to provide additional useful data for investigating the relationship between lead exposure and R&R.

3.0 QUALITY ASSURANCE

In the EFSS, as in any environmental sampling program, a variety of sources of error exists that could potentially affect the quality of the study results. A careful assessment of these sources of error was made, and quality control measures were implemented to help minimize their effects. The most important quality control measure was the Quality Assurance Project Plan (QAPjP). The QAPjP is intended to document the entire process involved in executing the field program, along with appropriate quality assurance measures. QAPjPs were prepared for the carpet removal and window replacement phases, and an addendum was prepared for the CED phase. The entire project team contributed to the QAPjPs, which were reviewed and approved by the EPA/OPPT technical staff and Quality Assurance Officer. Subjects covered in the QAPjP include:

- Project overview.
- Project organization and management structure, including organization and personnel responsibilities, and personnel qualifications.
- Study objectives including chemical data quality objectives.
- Method selection and analytical method performance including objectives and specifications for precision, accuracy, and verification and validation.
- Sampling plan including sampling frame construction, screening protocols, unit selection criteria, field QC samples, and sample size determination.
- Analysis plan including data review and transfer procedures, data quality assessment, and statistical analysis procedures.
- Sample collection procedures, including specification of the field sampling team, determination of sampling locations, and sampling schedule, transfer and storage procedures.
- Sample identification, tracking, and handling.
- Sampling equipment, including equipment performance requirements, preventive maintenance, corrective actions, contamination avoidance, and equipment calibration.
- Sample preparation procedures.
- Data processing procedures, including storage, transfer, tracking, and outlier detection procedures.
- Specification of all data collection forms.

- Health and safety procedures, including Human Subjects Review.

- Audit requirements, including system, performance evaluation, and data audits, and audit reporting and corrective action.

- Reporting requirements.

The QAPjPs may be referenced for additional details on any of the above subjects.

Appendix B in Volume II of this report documents data processing procedures followed in this study and presents results of the outlier detection analyses and decisions. Only one outlier in the three phases of the EFSS study was deleted from the statistical analysis as documented in Appendix B.

Appendix D in Volume II presents the results of analysis of quality control samples collected in the study including field blanks and field side-by-side samples. In all three phases of the EFSS, the results of analyzing initial calibration verification and continuing calibration verification samples in each instrumental analysis batch were within the protocol criteria of $\pm 10\%$. This indicates that the analytical instrument was properly calibrated for all of the sample analyses. Tables D-3a through D-3c in Appendix D report the status of meeting data quality objectives within batches in the carpet removal, window replacement, and CED phases, respectively.

4.0 STUDY DESIGN FOR THE ENVIRONMENTAL FIELD SAMPLING STUDY (EFSS)

The purpose of the EFSS was to assess the lead exposure and lead disturbance associated with various types of R&R activities through environmental measurements of lead in air and dust.

The EFSS consisted of four phases of data collection that either addressed a specific type of R&R activity or a group of activities. These phases were:

1. ***An information-gathering phase,*** to uncover the current body of information concerning lead exposure associated with renovation and remodeling and to analyze environmental lead exposure data collected in other studies that investigated exposures associated with specific R&R target activities, or with large R&R projects

2. ***A carpet removal phase,*** to investigate lead exposure associated with carpet removal activities

3. ***A window replacement phase,*** to investigate lead exposure associated with window replacement activities

4. ***A controlled, experimentally designed (CED) phase,*** to investigate lead exposure associated with several R&R activities (large structure removal, small surface disruption, HVAC repair, generic R&R activities) that are difficult to isolate in an actual R&R job or are components of larger R&R activities.

The first phase was described in Chapter 2. In the other three phases, the same sampling and laboratory analysis protocols were applied to environmental samples from various media. This chapter presents common elements of the study design for these three phases. Chapter 8 presents details on the specific implementation of the general study design.

4.1 OBJECTIVES OF THE EFSS

Technical objectives for the R&R study were presented in Section 1.1 of Chapter 1. The primary technical objectives of the EFSS were to characterize the:

1. Personal exposure to airborne lead for workers during the performance of different R&R target activities and combinations of activities, and determine if worker exposure to airborne lead during those activities exceeds 50 $\mu g/m^3$ [the OSHA permissible exposure limit (PEL)].

2. Airborne lead levels in areas adjacent to the activity area (the area -- room, floor, etc. -- in which the R&R activity took place) for selected R&R activities.

3. Amount of lead disturbed that settles on building surfaces within a specified period following completion of the R&R activity.

4. Extent that lead disturbance and exposure are affected by various factors such as distance from the activity and pre-activity measures of lead contamination in the building.

Some secondary objectives of interest related to sampling methodology were incorporated into selected phases of the EFSS to aid in refining the design of this study. The secondary objectives are discussed in Section 4.3 and in greater detail in Chapter 7.

4.2 ENVIRONMENTAL SAMPLING

Although the activities, buildings, and, in some instances, types of samples differed for each category of activities, the design and protocol for all environmental sampling were similar.

In general, for each monitored R&R activity, buildings containing lead-based paint suitable for typical application of the activity were selected. Buildings were selected based on predetermined screening criteria, as discussed in Chapter 5, that included taking X-ray fluorescence (XRF) and/or inductively coupled plasma (ICP) samples on painted surfaces in selected rooms of the unit.

Environmental measurements of lead were taken before, during, and after conducting the target activity. The measurements taken in the EFSS included:

1. ***Personal Air Samples.*** Measures of airborne lead concentrations at a fixed flow rate within each worker's personal breathing zone were collected by taking air samples through a cassette filter mounted to the worker's lapel. An air sampler pump was used to take the sample. The activity period was defined for each specific R&R activity, but generally included immediate preparation for the activity, activity conduct, and cleanup. For each worker, average exposure over the duration of the activity period was calculated in $\mu g/m^3$.

2. ***Room (Ambient) Air Samples.*** Ambient air samples were collected for selected activities in areas adjacent to the activity. Adjacent areas were used to address the levels at which occupants might be exposed to airborne lead in other parts of the building while conducting the activity.

3. ***Settled Dust Samples.*** Settled dust samples were taken either from stainless steel dustfall collectors (see Section 4.3) or from selected areas such as floors, window sills, window wells, and carpets. Samples were collected at varying distances from the surfaces disturbed by the activity. Lead loadings from settled dust samples were measured as indicators of the amount of lead disturbed by the activity and made available as a potential exposure to occupants. Further discussion on the sampling methodology for settled dust samples is provided in Section 4.6 below.

It was not possible to obtain a statistically based, representative sample of the exposed populations or the defined jobs, because of recruitment difficulties in obtaining "real-world" R&R

jobs as they are currently being conducted, cost constraints, and the wide variety of work practices and building characteristics. Consequently, the EFSS focused on characterizing "case studies" that were deemed "reasonably representative" (i.e., not atypical) of general R&R work as it is currently conducted. Two different approaches were taken to characterize these case studies:

1. Monitoring "real-world" R&R jobs as they occurred in the field

2. Monitoring controlled, experimentally designed simulations of specified renovation and remodeling activities in vacant buildings.

In the first approach, an attempt was made to select R&R jobs (case studies) that did not appear atypical of general R&R work currently being conducted. These jobs needed to have high potential for lead contamination because of the age of the building, presence of lead-based paint, and types of activities being conducted.

In the second approach, the design team specified the type, quantity, and characteristics of activities to be conducted in dwellings in the field. Experienced R&R workers, contracted to perform the work, simulated target activities and generic R&R tasks (e.g., cutting and drilling) so that measurements could be taken of lead disturbance associated with these tasks. The generic tasks are often components of any number of R&R target activities and provide an indication of potential hazards associated with many different R&R jobs.

Details of the sampling plan and design for each R&R activity or task monitored are presented in Chapter 8 with the discussion of each phase of the EFSS.

4.3 EVALUATION OF SAMPLING METHODOLOGY

The EFSS was designed to measure lead disturbance and lead exposures associated with specific short-term R&R activities. Sampling methodologies commonly used in occupational studies, clearance testing, risk assessment, and previous abatement studies were employed whenever possible in this study. In the case of settled dust, however, a different method of characterizing the amount of lead disturbed by a specific activity was employed. Post-activity and pre-activity measurements on building surfaces are commonly compared in lead contamination studies in buildings. The alternative method involves placing one-square-foot stainless steel plates on the floor immediately before the start of an activity at varying distances from the activity area. These plates are referred to as stainless steel dustfall collectors (SSDCs). Settled dust samples are collected from these plates at a specified period of time after completion of the activity.

Interest in evaluating the sampling methodology introduced additional objectives into the early phases of the study. Those objectives were to:

- Compare results from the sampling methodology using SSDCs to results from the sampling methodology employing pre- and post-activity floor samples

- Compare results from settled dust samples collected one hour following completion of an activity with results from settled dust samples collected two hours after completion of an activity

- Compare results from settled dust samples collected using vacuum techniques with results from samples collected using wipe techniques.

To assess the first objective, SSDCs were placed next to the post- and pre-activity floor samples at all locations in the carpet removal phase, and at two out of three sampling locations in each unit in the window replacement phase. The second objective was assessed by placing two SSDCs side by side at all locations in the carpet removal phase, and at one out of three locations in each unit in the window replacement phase. One side-by-side sample was collected approximately one hour after completion of the activity and the other approximately two hours after completion of the activity. The third objective was assessed by additional side-by-side samples at two out of three sampling locations in each unit in the carpet removal phase and at a total of 12 sampling locations during interior demolition work in the controlled, experimentally designed (CED) phase. Results pertaining to sampling methodology evaluation are discussed in Chapter 7.

4.4 HUMAN SUBJECTS REVIEW

All aspects of the field work involved in the EFSS were documented and submitted to both the contractors' and EPA's Human Subjects Review Committees for review and approval. All procedures complied with the requirements of the human subjects committees.

4.5 DATA GAPS AND LIMITATIONS OF THE R&R STUDY

Due to the broad scope of the EFSS and the R&R study as defined by Title X legislation, combined with time and budget constraints, recruitment difficulties, and human subjects concerns, insufficient information was available to make inferences on certain areas of interest to the study.

Data gaps that remain include:

1. ***Information on the relationship between R&R and occupants' (children's) blood-lead concentrations.*** The combination of environmental measurements and worker blood-lead concentrations was expected to provide sufficient exposure information to address regulatory needs. However, the blood-lead concentrations of R&R workers were very low, while the amount of lead released to the environment was very high. These conflicting outcomes imply that measuring environmental lead levels might be an inadequate surrogate for measuring human blood-lead levels. This, combined with difficulties in determining a health-based standard for acceptable environmental lead levels, places more importance on the relationship between R&R and occupant exposure as measured by blood-lead concentrations. Therefore a follow-on study will be conducted to evaluate the impact of the conduct of R&R activities on elevated blood-lead concentrations in children. This study will

be conducted jointly with the University of Wisconsin and the State of Wisconsin Public Health Department.

2. ***Exposure of people other than occupants and workers was not assessed.*** Other potentially exposed populations include workers' families and residents of neighboring buildings.

It is important to note the limitations of the data collected in the EFSS:

1. ***The EFSS field monitoring work represents a series of case studies that were not selected by a random sampling scheme***. Generalizing the results of the EFSS to a broader population must be based on a qualitative assessment of how representative the case studies are of that population. However, no reason was uncovered to believe that the case studies were atypical of general R&R work as it is conducted in an unregulated environment containing high levels of lead-based paint.

2. ***Measurements of lead distributed into the occupants' environments were collected before cleanup.*** The effect of different cleanup methods was measured for two target activities in the EFSS, and data were collected in the WCBS on typical cleanup methods employed by R&R workers. However, additional information on the extent of typical cleanup would be useful.

3. ***The focus of the data collected in the EFSS was on target housing.*** Exposure differences between building environments from a lead abatement perspective are discussed in EPA's proposed rule 40 CFR Part 745, "Requirements for Lead-Based Paint Activities," where an argument is made that public buildings and target housing represent similar exposure environments. However, there are no data at this time to assess whether environmental exposures monitored in target housing are representative of environmental exposures encountered in public or commercial buildings.

Further discussion of limitations on inferences drawn from the results of the EFSS are presented in the discussion of overall results in Chapter 9.

4.6 SAMPLING AND ANALYTICAL METHODS

During the course of the EFSS, field sampling activities were conducted to monitor a variety of renovation and remodeling activities. The following categories of field samples were collected during the study:

- Wipe sampling of settled dust
- Vacuum sampling of settled dust
- Personal exposure samples
- Area airborne dust samples
- Paint chip samples

- Plaster samples.

The following two sections discuss the sampling and analytical methods applied to the above categories of samples. Further details on sampling and analytical methods can be found in the QAPjP.

4.6.1 Sampling Methods

Wipe Samples of Settled Dust

Wipe samples of settled dust were collected from the SSDCs, as well as directly from other horizontal sampling surfaces (e.g., HVAC ducts). All wipe samples were collected using commercially available, premoistened disposable wipes (Wash-a-bye Baby™). The protocol for collecting a wipe sample is as follows:

- Don a clean pair of powderless vinyl gloves.

- Open the lid of the wipes container and remove several wipes. Discard the initial wipes removed, and use the next wipe from the container to collect the sample.

- Place the wipe flat on the sample surface. (Note that in some cases the sample surface was a 1-ft^2 steel template; in other cases, the surface was a ventilation duct, etc.)

- Using an open flat hand with the fingers together, wipe the marked surface in an overlapping "S" pattern. The initial pattern should be from side to side and then from front to back so that the entire sample collection area is covered.

- When sampling small areas (i.e., less than 1-ft^2), the wipe should be folded in half with the sample side folded in. Repeat the wiping procedure within the defined surface area.

Vacuum Sampling of Settled Dust

Special equipment is employed for collecting vacuumed settled dust. The vacuum sampling equipment included a modified HVS3 cyclone dust collector and a Red-Devil® portable vacuum (Figure 4-1). The cyclone dust collector has an output nozzle on the top, which is connected to the portable vacuum, and an inlet on the side, which is connected to a tygon "collection" tube. The bottom segment of the cyclone dust collector is conical in shape, with internal threads at the narrow end of the case to accommodate the sample collection bottle. A Teflon sealing ring forms the joint between the cyclone top and bottom segments. A cyclone

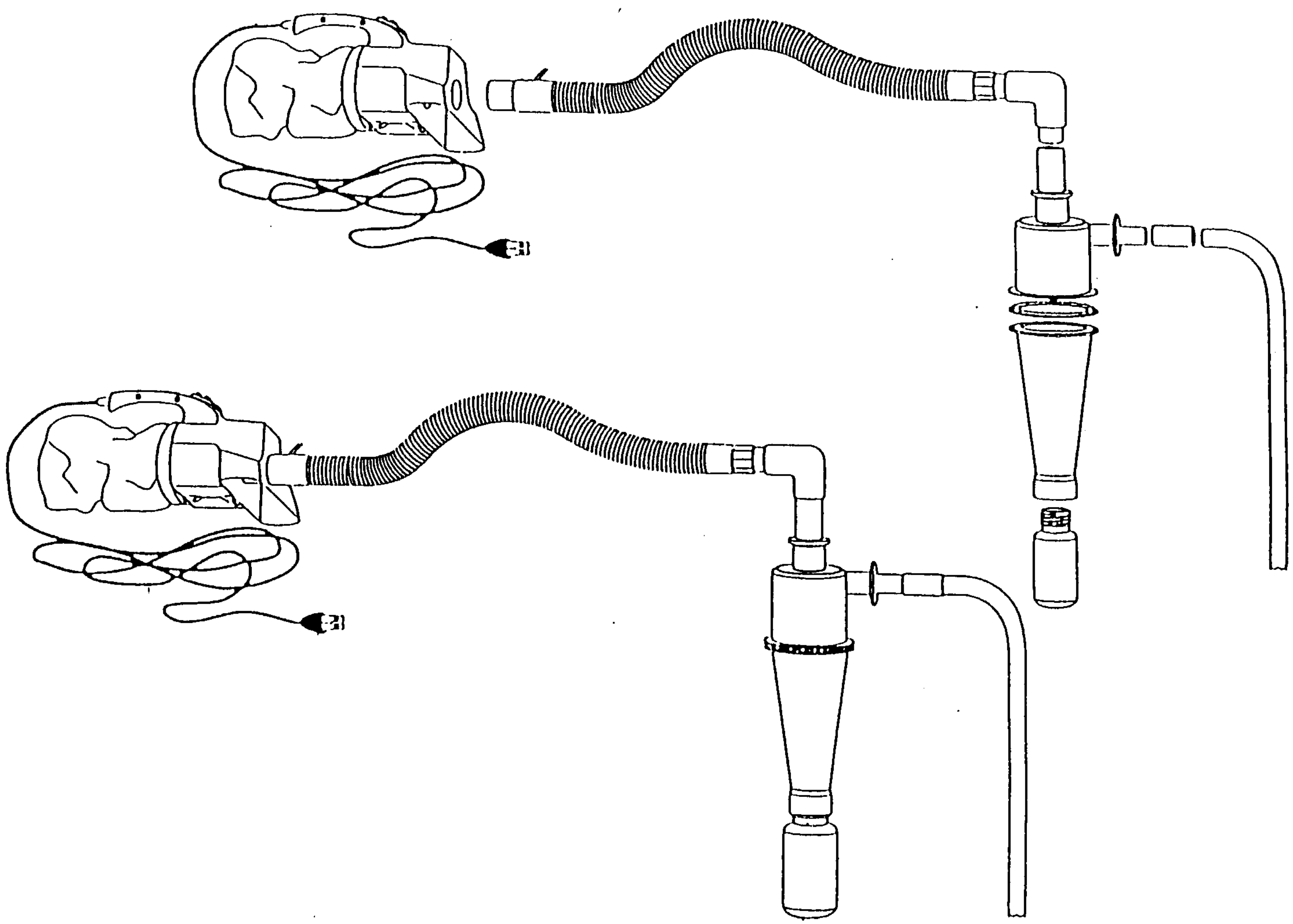


Figure 4-1. Cyclone Dust Collector

dust collector has advantages over a dust collector that uses a filter. The collection bottle eliminates the need for pre- and post-weighing and conditioning of the filter, and has a larger capacity. The protocol for collecting a vacuumed settled dust sample is as follows:

- Place a clean grey PVC transition piece onto the tangential inlet of the cyclone head.

- Position the cyclone in a vertical position and securely screw the sampling collection bottle into the lower threaded end of the cyclone.

- Insert the proper end of the collection tube into the grey transition piece. Attach the vinyl tubing to the sampler case's 3/4-inch inlet.

- Run an extension cord from the nearest 110-V AC outlet (or generator) to the designated sampling location and plug in the portable vacuum.

- Turn on the pump and vacuum the sample area in overlapping passes (i.e., at least 50% overlap), initially left to right, then front to back over the entire designated area. Repeat vacuuming pattern for two minutes.

- When vacuuming is complete, turn off the vacuum and keep cyclone vertical. Raise the humidity within the cyclone by slowly blowing three breaths into the grey transition piece. Tap the cyclone case three times to dislodge any remaining debris.

- While keeping the cyclone vertical, unscrew the dust collection bottle from the cyclone and recap the dust collection bottle.

Exposure Samples

Personal exposure monitoring to airborne lead was conducted using NIOSH method 7300. The personal sampler, illustrated in Figure 4-2, pulls air across sample media at a known sample flow rate. The flow rate of the sampling pumps is set between 1 and 4 liters per minute, with a preference for 4 liters per minute. The exact flow rate is determined during calibration procedures that are performed before and after each sampling period. The protocol for collecting personal exposure samples is as follows:

- Samples are collected by using a battery operated pump (Gilian HFS 113 and 513) attached to a tygon tubing with the sample media attached to the opposite end of the tubing.

- Don clean vinyl gloves. Remove inlet and outlet plugs from an unused 0.8 μ, 37 mm mixed cellulose ester filter cassette. Attach the tygon tubing to the sample media by inserting a nipple into the open end of the tubing (i.e., the end opposite of that attached to the sampling pump) and inserting the nipple into the outlet opening of the cassette.

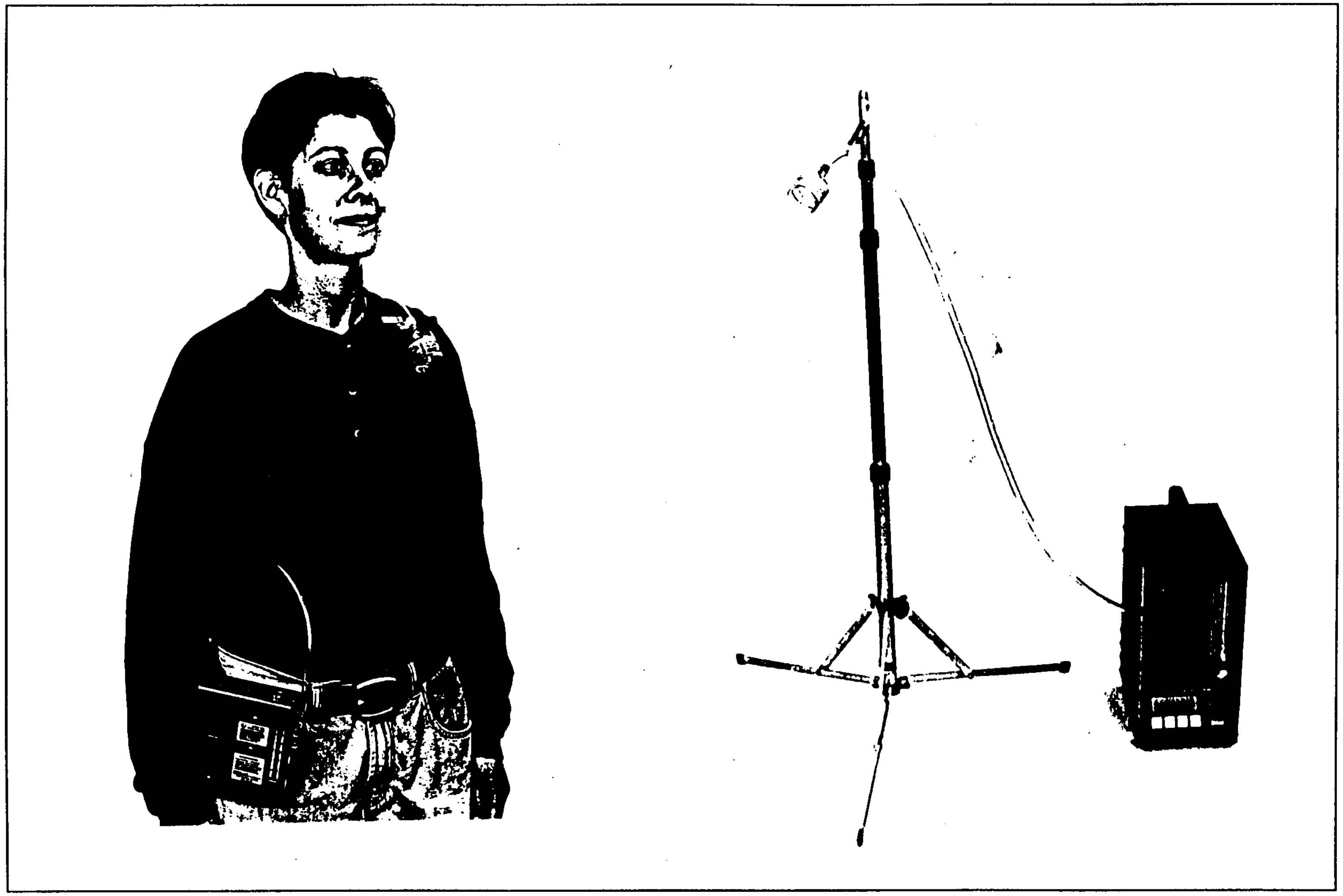


Figure 4-2. Personal Air Monitoring Sampler (Left) and Ambient Air Monitoring Sampler (Right)

- Mount the sampler at the waist using the belt clip attached to the sampler. Clip the filter cassette to the worker's lapel (make sure that the cassette remains in the worker's breathing zone), making sure to secure the tubing to the worker in a manner such that is does not interfere (e.g., tape the tubing to the worker's back). The inlet of the filter cassette should be positioned slightly downward to avoid dust from passively falling into the cassette.

- Turn the sampling pump on and record time.

- When sampling is complete, turn the sampling pump off and record time. Cap the inlet and outlet plugs of the cassette.

Area Airborne Dust Samples

Area exposure monitoring to airborne lead was conducted using Gilian AirCon High Volume samplers. The ambient air sampler, illustrated in Figure 4-2, has a flow rate set at rates up to 12.5 liters per minute. The exact flow rate is determined during calibration procedures that are performed before and after each sampling period. The protocol for collecting area airborne dust samples is as follows:

- Set up tripod at sample location and set pump on floor under tripod.

- Don clean vinyl gloves. Remove inlet and outlet plugs from an unused 0.8 µ, 37 mm mixed cellulose ester filter cassette. Mount the filter cassette to the tripod mast at breathing-zone height (approximately five feet above the floor). Attach the tygon tubing to the sample media by inserting a nipple into the open end of the tubing (i.e., the end opposite of that attached to the sampling pump) and inserting the nipple into the outlet opening of the cassette.

- Turn the sampling pump on and record the time.

- When sampling is complete, turn the sampling pump off and record the time. Cap the inlet and outlet plugs of the cassette.

Paint Chip Samples

The protocol for collecting a paint chip at a sampling location is as follows:

- Don a clean pair of disposable leather gloves.

- Using a cutting tool, score the perimeter of the area to be removed.

- Affix a tray, paper funnel, or equivalent collection device directly below the sampling location. Begin removing the paint from the substrate. If possible, peel the paint off of the substrate by sliding the blade along the score and underneath the paint. Remove all paint down to the bare substrate and transfer to the collection container.

Plaster Samples

Samples are collected from painted surfaces to characterize lead levels in surfaces about to be demolished or disturbed during renovation and remodeling activities. When collecting plaster samples, the selection of the surface to be sampled is important. Deteriorated plaster can become crumbly, increasing the potential for sample contamination. For example, when chipping into a wall the plaster can easily become pulverized and fall to the floor. It is best to select a firm, rigid surface and collect the plaster sample in accordance with the following steps:

- Don a clean pair of disposable vinyl gloves.

- Select the surface and area to be sampled (do not outline the sample area with any type of marker, pen, pencil, etc.).

- Affix a tray, paper funnel, or equivalent collection device directly below the sampling location. Note that because of the relative mass of the plaster compared to the collection device, the person collecting the sample or an assistant may need to support the device.

- Using a chisel and hammer, carefully break through the surface of the sample area.

- Begin removing the plaster by gently prying it away from the surface being sampled.

- Allow the plaster sample to drop into the collection device. As mentioned previously, the collection device may need to be supported at this time.

- Carefully transfer the plaster sample from the collection device into a sample bottle. Cap the sample bottle.

4.6.2 Analytical Methods

Analysis procedures used in the EFSS study were as follows:

- Settled dust, vacuum samples: Digested using a modified version of EPA SW-846 Method 3050. Analyzed using a modified version of EPA SW-846 Method 6010A, Inductively Coupled Plasma (ICP).

- Settled dust, wipe samples: Digested using a modified version of EPA SW-846 Method 3050. Analyzed using a modified version of EPA SW-846 Method 6010A, Inductively Coupled Plasma (ICP).

- Air, personal exposure samples: Digested and analyzed using a modified version of EPA SW-846 Method 3050.

- Air, area airborne samples: Digested and analyzed using a modified version of EPA SW-846 Method 3050.

- Paint chip samples: Digested using a modified version of NIOSH Method 7082. Analyzed using a modified version of EPA SW-846 Method 6010A.

Primary instrumentation for the analysis of vacuumed dust and dust wipe samples was an Inductively Coupled Plasma—Atomic Emission Spectrometer (ICP-AES). A Thermo-Jarrell Ash simultaneous ICP was utilized for this analysis effort. Primary instrumentation for the analysis of personal exposure and area airborne samples was a Varian SpectrAA 300Z graphite furnace atomic absorption spectrometer (GFAAS).

More details on the analytical method, including protocols, are provided in the study's QAPjP.

5.0 OVERVIEW OF RECRUITMENT IN THE EFSS

The study objectives and design, discussed in the preceding chapters, defined three basic criteria for the recruitment process:

1. The workers monitored and the R&R activities performed must be typical of general R&R work as it is currently being conducted.

2. The buildings undergoing R&R must be representative of typical target housing or public and commercial buildings and must contain interior lead-based paint.

3. Recruitment and subsequent study procedures must meet all requirements specified by EPA, Battelle, and MRI's Human Subjects Committees.

Reasons for the first criterion, including reasons for the decision not to monitor abatement work, were presented in Chapter 2. The decision to monitor R&R workers conducting activities typical of general unregulated R&R work was reinforced during the recruitment process; contractors repeatedly expressed the opinion that R&R work being conducted by government contractors who take extensive precautions against lead exposure is not representative of much of the R&R work being conducted by R&R contractors focused on the private sector. Our definition of "typical unregulated R&R work" did allow inclusion of a worker who takes personal precautions during the R&R activity, such as wearing a respirator or protective clothing. However, we did not include dust reduction measures normally encountered in abatement work, such as:

- Misting surfaces that will be disturbed
- Using plastic to enclose surfaces to be removed
- Using negative air or tools with HEPA vacuum attachments.

The second recruitment criterion was chosen to help focus the study on the most likely environments for a lead exposure problem, while ensuring that buildings selected were not atypical of the environments defined by the scope of the study. The screening of candidate buildings included testing for lead-based paint using XRF methods and/or ICP analysis on paint chip samples to measure lead concentrations (mg/cm^2) on painted surfaces. The XRF testing was intended for screening purposes only. Details on the minimum levels of lead-based paint required for including a building in the study are presented in the QAPjP. In general, all sites included in the study had extensive lead-based paint, and the XRF results were used along with other criteria (such as the size and overall condition of the building) to choose between candidate sites. XRF results were not used in any subsequent statistical analysis. Where measurement of the paint in the substrate being disturbed was required, paint chip samples were collected at the time of the R&R activity.

The third criterion, compliance with Human Subjects Committee guidance, affected separate phases of the study differently. In the carpet removal and window replacement phases, where R&R jobs already planned in the marketplace were being recruited, the primary Human

Subjects requirements were that the study not alter any of the work that was to be monitored and that workers and residents sign approved informed consent forms. In the CED phase, on the other hand, Human Subjects guidance required that the work be conducted by contractors with experience in worker protection practices, an OSHA-certified respirator program in place, and who agreed to follow the OSHA lead standard for the construction industry (29 CFR 1926.62). In addition, for the CED phase, buildings where the work was to be conducted were required to be scheduled for subsequent demolition, gutting and complete restoration, or complete abatement and clearance testing before reoccupancy.

Multiple approaches were taken in the attempt to recruit the "real-world" R&R contractors and workers. These included newspaper ads, telephone solicitation, letters, flyers, contact with unions, trade organizations, government agencies, and ongoing R&R programs, and targeting schools and other institutions that were suspected to have reason to be interested in the lead problem. A telephone script was composed that attempted to:

- allow R&R workers to understand the benefit of the study
- reduce their liability concerns
- stress that their participation would not disrupt the job or their normal work practice in any way.

Attempts were made to recruit contractors directly as well as indirectly through the individuals hiring the job or through union participation. Workers and contractors were offered compensation for any inconvenience resulting from participation in the study.

Overall, recruitment of "real-world" non-abatement R&R jobs for participation in this study was time consuming, cost intensive, and very problematic. The primary reasons for this difficulty were:

1. ***Liability concerns***. The fear of being held liable by workers, homeowners, the public, EPA, OSHA, or NIOSH was the single biggest disincentive to participation in the study. Very early in the recruitment process, one carpet removal contractor told us "one lawsuit could put me out of business." This concern was repeated often. Larger institutions often appeared reluctant to lose the protection that was perceived to come with ignorance. The attempt to recruit the maintenance staffs of several institutions was unsuccessful for this reason.

2. ***Negative reactions to EPA and OSHA.*** Many contractors expressed concerns that their participation would result in either a fine from OSHA for working incorrectly, or concerns about newly mandated requirements that they did not want or did not feel were justified. The president of a window replacement firm with offices in Wisconsin wrote,

"A concern I have with the methodology of your study, is that new Federal rules will be formulated based upon your study. Your study as presently designed is not representative of the type of window replacements we do. In fact, the vast majority of window replacements are done without disturbing the original window frame."

3. ***Contractors, agencies and individuals too busy to participate.*** Many individuals we spoke with would not even take the time to fully listen to the description of the study before stating, *"I'm too busy and don't have time for this now."* Contractors who seemed receptive but too busy to talk at the time of the first call were sent a letter describing the study and then called back at a later date. In general, first refusals were seldom converted by a letter or a follow-up phone call.

4. ***Difficulty in recruiting a "contracted job."*** A unique challenge to this recruitment effort was that it was not single individuals or organizations being recruited ultimately but rather contracted R&R jobs. This required coordination and recruitment of two parties and the ability to firmly determine schedules so sampling could be arranged. The inconvenience involved was often perceived by those recruited to outweigh any advantages to participation including the compensation offered.

5. ***No match for the unit or work requirements.*** Many contractors did not work in the older buildings (>50 years old) we required or did not meet phase-specific requirements such as full replacement of wood windows.

6. ***Failure to find lead-based paint after a building was recruited.*** In the recruitment of large R&R projects and potential CED sites, a high ratio of buildings screened did not contain appreciable amounts of lead-based paint. Six units that were eventually used in the CED phase had sufficient interior lead-based paint, but seven other units that were more than 50 years old did not contain sufficient lead-based paint anywhere in the interior of the building.

The recruitment difficulties led to more emphasis on the CED phase of the study where the recruitment effort became one of locating vacant buildings and cooperative owners rather than willing contractors. Details of the recruitment process, results obtained, and lessons learned are presented below.

5.1 DETAILS AND RESULTS OF THE RECRUITMENT PROCESS

The details and results of the recruitment process are presented below for each of four study phases, in chronological order. Results of one phase were used to formulate the strategy and effort for subsequent phases.

5.1.1 Carpet Removal

The first four homes in the carpet removal phase were located in the Oakland, California, area. They were selected through cooperation of the Alameda County, California, Planning Department, Housing and Community Development Program. The four dwelling units were already scheduled for lead-paint abatement with removal of the carpets planned as the first activity in the abatement process. The Alameda County agency also provided floor plans and existing XRF sampling results for these units. Representatives of the study field team visited each unit to perform a visual survey and found them adequate for study participation.

The Alameda County agency also recruited the R&R contractor who performed all carpet removal activities for the four units. The contractor was subject to regulations imposed by Alameda County in such areas as waste disposal, worker safety, and contamination control of residential belongings. There was no requrirement specifically to minimize dust generation (e.g., misting the carpet).

The attempt to select four additional homes in another city proved much more problematic. Initially, contractors advertising in St. Louis and Kansas City, Missouri, were contacted by phone. They all declined to participate in the study, primarily due to liability concerns. Next, fliers were placed in home-improvement stores and government agencies and trade union representatives were contacted. Finally, newspaper advertisements were placed in St. Louis newspapers offering an incentive to homeowners replacing their own carpet, and providing a toll-free number to call.

This last recruitment step provided additional candidate homes rather easily. The homeowners did not express anything in the way of liability concerns, fear of EPA, NIOSH, or OSHA, or conflicting business interests. Also, the homeowners considered the monetary incentive as a positive motivating factor, while the contractors considered it insignificant. Recruitment of resident-workers enabled the study to include data on carpet removal performed by nonprofessionals. The candidate homes were classified according to the following criteria:

- Age of dwelling unit (priority given to homes built before 1940)
- Availability of dwelling unit to the study
- Length of time since carpet was installed (priority given to carpet in place for at least 8 years)
- Lead-based paint in the dwelling unit (unit has not recently undergone lead abatement).

Study recruiters narrowed the field to eight promising candidates, and the field team and an XRF contractor performed XRF and visual surveys during scheduled screening visits. Based on the findings of the screenings, study statisticians then selected four units for the study.

5.1.2 Window Replacement

The initial approach to identify and recruit individuals performing window replacement work or having this type of work done in their homes was to place advertisements in newspapers in Baltimore, Maryland, and St. Louis, Missouri. The EPA-approved ads described the study, solicited participants (homeowners or contractors), offered an incentive, and listed a toll-free number to call. This method of recruiting was abandoned rather quickly because there was virtually no response. In contrast to the carpet removal phase, no homeowners performing the work themselves were uncovered.

The next step was telephone soliciation by trained recruiters using an EPA-approved script. They solicited window installation companies and contractors in thirteen selected U.S. cities. The cities were Baltimore, Hartford, Boston, Columbus, St. Louis, Youngstown, New Haven, Washington D.C., Newark, Cincinnati, Chicago, Milwaukee, and Cleveland. Most companies and contractors contacted were listed in municipal telephone directories. Additional contacts included trade organizations, unions, large and small licensed window installation firms, independent contractors, business owners, and home owners. Although this recruitment technique yielded the largest number of contacts (more than 800), it was largely unsuccessful.

Only five individuals were willing to participate in the study: three contractors and two building owners. All five were located in Columbus, OH; our assessment is that all five were influenced to participate in the study because of Battelle's involvement in the study and their reputation in the Columbus area. In fact, one of the window installation companies, which located two of the four homes eventually enrolled, wanted to participate so that it could advertise its participation in a study with Battelle as a way to enhance business.

The four homes eventually selected for the study were identified by three professional contractors as candidate study units. Two contractors were general building contractors, and one was a specialized window removal/installation contractor. Representatives of the field sampling team visited each eligible unit to conduct a visual survey and to supervise an XRF screening of painted window components. Information from this screening visit was used to determine whether the unit would be selected for the study, and if so, which of three windows would be considered for environmental sampling. The four study units were located in the Ohio cities of Piketon, Columbus, Richwood, and Plain City.

5.1.3 Large Projects

From a design perspective, there was significant interest in obtaining a large R&R project involving multiple activities conducted simultaneously. A sampling plan was developed for monitoring such a project. However, this project could not be accomplished in the time frame available to the study.

The recruitment effort for finding a large R&R project was extended to the following potential candidate sources:

1. Large public facilities such as hospitals, universities, and schools

2. Military bases and state and federal agencies controlling government buildings

3. Solicitation of help from national trade unions.

In general, individuals contacted for the large R&R project were more receptive than those contacted in the window replacement recruitment effort. Most quickly understood the study and were in agreement with its purpose. However, a major problem for almost all large R&R projects was that final approval for participation did not rest with a single individual or department. Typically, several levels of approval were required including that of the legal, health and safety, and facilities departments.

For example, one month-long solicitation of a large university had resulted in approvals from the Environmental Safety and Health Department, university lawyers, and Board of Trustees, but a lack of final approval because of the concerns and narrower interests of the Facilities Department. In large institutions, including universities, there appears to be concern about disclosing a lead problem.

Trade unions cooperated in recruitment efforts to identify eligible jobs and contractors. The United Brotherhood of Carpenters (UBC) alone sent over 2,000 letters to its local chapters and district councils soliciting their help in locating jobs. The only solid prospect from this effort was a seminary in Ohio. Although the seminary was more than 60 years old, no lead paint was found in the interior.

Failure to locate a suitable large project led the project team to abandon the effort in favor of the use of hired contractors performing simulated R&R work in the CED phase.

5.1.4 CED Phase

Recruitment for the CED phase was more successful than recruitment of "real-world" jobs. The fact that contractors would be hired to do the work meant that basically only vacant buildings needed to be found. Public housing authorities, government and private agencies were willing to offer candidate buildings. Although many buildings were not suitable because they were too deteriorated, sufficient numbers of vacant, but habitable buildings were located for the CED phase. This phase of the study was conducted in Baltimore, Maryland, and Denver, Colorado.

In Baltimore, a number of row houses scheduled for "gut rehab" were recruited from a private developer. During initial site visits, some of the dwellings were determined to be in such poor condition that they could be excluded from the study. Three buildings were in habitable condition, but one was found to contain an insufficient amount of lead-based paint during the XRF screening. The other two were enrolled in the study. The contractor employed in Baltimore met all study requirements and had many years of general construction and R&R experience before concentrating on lead abatement work.

Buildings in Denver were recruited through the cooperation of Denver Housing Authority (DHA). This agency identified eligible vacant buildings scheduled for subsequent abatement or "gut rehab." CED activities were conducted in four different buildings. All activities were conducted by DHA maintenance staff with experience in general R&R tasks as well as in lead abatement.

A summary of the recruitment effort and results for each phase of the EFSS is presented in Table 5-1.

5.2 GENERAL CHARACTERISTICS OF THE WORKERS AND UNITS RECRUITED

This section presents a general description of the workers and buildings (units) included in the three phases of the EFSS. Further details on specific unit characteristics for a given study phase are included in Chapter 8.

5.2.1 Worker Characteristics

The workers performing R&R activity in the EFSS differed in many aspects, including experience in performing the activity, awareness of potential lead hazards associated with the activity, and the level of protection from exposure. Following the R&R activity at each study unit in the carpet removal and window replacement phases, field team representatives interviewed the R&R workers to characterize the type of worker participating in this phase. The worker survey collected information on such items as experience level, familiarity with the hazards associated with lead exposure, and opinion on how typical the activity has been at a site compared to similar jobs. Results of this survey were used only to characterize the workers participating in this study. They cannot be used to make inferences on the general population of R&R workers.

Carpet Removal

In the carpet removal phase, the four Alameda County, CA, units had professional carpet removal workers who were employees of an R&R contractor with experience in dealing with environmental hazards such as lead contamination. Approximately 25% of the R&R jobs performed by this contractor involved carpet removal, and approximately 30% of the jobs consisted of lead-based paint abatement. In this study, the contractor's employees wore Tyvek suits and respirators when performing carpet removal in each unit. The workers were aware of various precautionary measures to reduce dust generation, although the only such measure taken in this study was using plastic sheeting to cover occupant belongings and seal off nonactivity areas.

The owner of the contracting company in Alameda County, who had more than 35 years of R&R experience, participated in carpet removal in one unit and was monitored for personal exposure. The four other workers for this contractor had from 3 months to 15 years of experience in R&R and in carpet removal specifically.

Table 5-1. Summary of Recruitment Efforts and Results in the EFSS

Target for Recruitment	Method	No. of Contacts	Results
Carpet Removal Phase			
Government agencies and contractors	Personal and inter-organizational contacts; telephone calls	>10	4 units
Contractors	Telephone calls with predetermined script	>100	No success
Contractors	Fliers posted in retail outlets frequented by R&R contractors	N/A	No success
Homeowners	Newspaper advertisements with cash incentive	Ads placed in two cities	4 units
Window Replacement Phase			
Government agencies	Personal and inter-organizational contacts; telephone calls	>10	No success for non-abatement work
Contractors or homeowners	Newspaper advertisements with cash incentive	Ads placed in two cities	No success
Contractors	Telephone calls with guided script and follow-up letters	>800	4 units
CED Phase			
Government agencies and special interest groups	Personal and inter-organizational contacts; telephone calls	>10	All required units obtained
Universities, hospitals, government agencies	Telephone calls with guided script	>50	Several leads
Large R&R Projects[1]			
Government agencies and trade unions	Personal and inter-organizational contacts	>20	No success for non-abatement work
Universities, hospitals, contractors	Telephone calls with guided script and follow-up letters	>400	No success
Workers/contractors	Letters sent to locals of United Brotherhood of Carpenters	>2000 letters	No success

[1] This study phase could not be accomplished in the time frame of this study.

In contrast, the carpet removal workers in the four St. Louis, MO, area units were all nonprofessional residents or helpers. The residents usually had no previous awareness of potential lead exposure in performing carpet removal, and they only had informal previous experience in performing R&R activities. Only two resident-workers in one unit identified themselves as ex-R&R professionals or self-employed professionals, with less than 15% of their experience in carpet removal and no experience in lead decontamination areas. Therefore, the St. Louis workers were less experienced in performing carpet removal activity and in handling potential lead contamination resulting from the activity.

Window Replacement

Workers participating in the window replacement phase were professional contractors experienced in window replacement. The workers in three of the four study units claimed that window replacement was the only R&R activity they performed, while the workers in the fourth unit claimed that window replacement activities constituted 50% of their R&R work. The R&R experience of the workers ranged from 1.5 to 27 years. Window replacement experience ranged from 1.5 to 16 years.

None of the workers in the window replacement phase had any experience in abatement work. Only two workers at one unit claimed to be aware of any potential risk for lead exposures during window replacement; none of the workers took any precautions to reduce lead exposure.

CED Phase

Unlike the carpet removal and window replacement phases, contractors in the CED phase were hired by the EFSS study team to perform the specified activities at a study unit. All workers in the CED phase were professional lead abatement workers. Full worker precautions were taken, but no effort was made to reduce dust generated by the activity. The contractors were instructed to do the assigned jobs in a manner typical of general R&R work in an unregulated environment.

5.2.2 Unit Characteristics

All eight study units in the carpet removal phase were occupied, single-family residences. Carpet removal was performed in a portion of a given unit. Two of the four units in the window replacement phase were occupied single-family residences. The other two units were occupied, but the floors on which the window replacement activity took place had been vacant and neglected for some time. The CED phase included two vacant row houses in Baltimore, Maryland, and four single-family homes in Denver, Colorado. All units in the CED phase were scheduled for demolition, abatement, or gutting/restoration in the near future.

The study units had varying degrees of lead paint contamination and differed in their overall observed levels of cleanliness. In addition, the amount and type of dust generated during a specific R&R activity often differed from one unit to another. For example, workers in one unit of the carpet removal phase reported excessive dust generation from disintegrated carpet padding, while carpet in another unit contained considerable surface debris. The discussion of results for each phase in Chapter 8 presents additional details and demographic information on the study units.

5.2.2.1 Comparability with Units from Previous Studies

This section compares the pre-activity lead levels of the recruited study units in the carpet removal and window replacement phases to the pre-activity lead levels in other studies. Table 5-2 contains summaries of dust-lead loadings across EFSS units as well as for units from other studies. Lead loadings are from dust samples collected from floors, window sills, and window wells. Besides the carpet removal and window replacement phases, the following studies are represented in Table 5-2:

- The HUD Abatement Demonstration Study (U.S. Dept. of HUD; 1990)
- The HUD National Survey of Lead-Based Paint in Housing (U.S. EPA, 1995)
- Two Kennedy-Krieger studies on abatement/maintenance methods (Farfel and Chisolm, 1990; Farfel and Chisolm, 1991).

The HUD Abatement Demonstration ("HUD Demo") Study assessed the costs and short-term efficacy of alternative methods of lead-based paint abatement. A total of 172 dwelling units in seven metropolitan areas were abated in the FHA portion of the HUD Demo study. The HUD Demo statistics in Table 5-2 represent loadings from wipe samples taken in these units as part of post-abatement clearance procedures.

The HUD National Survey estimated the incidence of lead-based paint in U.S. public and privately-owned housing. Table 5-2 includes statistics on lead loadings from 182 privately-owned units from the National Survey, partitioned into two groups according to lead levels from XRF testing.

The Kennedy-Krieger Institute studies examined the effect of different types of abatement/maintenance methods on dust and blood lead levels. In the first study, 53 units were earmarked for traditional abatement practices and 18 for modified abatement practices. These units had multiple interior surfaces with lead-based paint and at least one child with elevated blood lead levels. The second study considered experimental abatement practices in six older row homes with multiple lead-based paint hazards. In Table 5-2, the geometric means of pre-abatement lead loadings for the Kennedy-Krieger studies are summarized for three groups of units in the following order: traditional practice units, modified practice units, and experimental practice units.

Table 5-2. Descriptive Statistics for Pre-Activity Lead Loadings on Floors, Window Sills, and Window Wells in the EFSS, with Comparison to Levels Observed in Previous Abatement Studies

Study[(1)]		# Samples	Log Std. Dev.	25th Percentile ($\mu g/ft^2$)	Geometric Mean ($\mu g/ft^2$)	75th Percentile ($\mu g/ft^2$)
Floor Dust Lead Loadings						
EFSS Carpet Removal Phase		32	1.91	2.61	14.7	49.0
EFSS Window Replacement Phase		39	3.26	28.4	637	9,120
HUD Demonstration		1026	1.53	23.6	66.0	185
National Survey[(2)]	High XRF	234	1.82	0.70	2.40	8.23
	Low XRF	304	1.61	0.22	0.64	1.91
Kennedy-Krieger studies[(3)]		280 82 70			251 288 520	
Window Sill Lead Loadings						
EFSS Carpet Removal Phase		16	2.32	88.8	418.0	2740
HUD Demonstration		783	1.79	26.7	89.10	297
National Survey[(2)]	High XRF	123	2.64	1.42	8.40	49.7
	Low XRF	126	2.13	0.37	1.57	6.59
Kennedy-Krieger studies[(3)]		249 95 34			1,340 1,800 4,610	
Window Well Lead Loadings						
EFSS Window Replacement Phase		11	0.94	54,700	135,000	296,000
HUD Demonstration		756	1.93	138	506	1,860
National Survey[(2)]	High XRF	56	2.28	47.4	220	1,020
	Low XRF	38	2.46	3.27	17.2	90.4
Kennedy-Krieger studies[(3)]		150 37 28			15,500 18,300 29,400	

(1) Data for the EFSS phases reflect all regular and QC side-by-side samples collected prior to R&R activity. HUD Demonstration data represent post-activity clearance results for units in the FHA portion of the study.

(2) "High XRF" entries reflect readings for units with at least one interior and one exterior XRF reading exceeding 10 mg/cm^2. "Low XRF" entries reflect readings for units where all XRF readings were below 1.0 g/cm^2.

(3) The first two entries in each cell reflect pre-abatement readings from homes where traditional and modified abatement procedures, respectively, were to be employed (Farfel and Chisolm, 1990). The third entry in each cell reflects pre-abatement readings in units from Farfel and Chisolm, 1991.

Compared to units in the HUD Demo study, the units in the carpet removal phase had generally lower lead loadings in floor dust, but higher lead loadings in window sills. The units in the window replacement phase had higher lead loadings in floor dust, and much higher lead loadings in window wells. It should be noted, however, that all floor samples collected in the window replacement phase were within 6 feet of a window, possibly accounting for the high lead loadings from floors. Also, the data for the HUD Demo study primarily represented post-activity sampling after cleanup procedures.

The two EFSS study phases had considerably higher lead loadings than National Survey units. However, the "blue nozzle" vacuum sampler used to collect dust samples in the National Survey was shown to be approximately five times less efficient than the wipe and vacuum sampling techniques used in the HUD Demo and the EFSS. Consequently, reported results may be lower than what would have been observed using more efficient sampling techniques.

The Kennedy-Krieger results are higher than all other study results except those from the window replacement phase.

In general, the variability observed was similar across all studies. From Table 5-2 one can conclude that the observed lead levels in carpet removal units were not atypical of inhabited units with lead contamination. Units included in the window replacement phase, on the other hand, had relatively high levels of pre-activity lead contamination, especially in the window wells. These levels were high in both the vacant and occupied activity areas.

6.0 DATA ANALYSIS OVERVIEW

As introduced in Chapter 1, the technical objectives of the R&R study were to characterize lead exposure to workers conducting R&R activities in contaminated housing, investigate how these workers disturb lead and create a lead-based paint hazard to occupants or other exposed individuals, and provide technical input and recommendations for developing guidelines and regulations on lead exposures resulting from R&R activities. This chapter presents an overview of those data analysis objectives and approaches that were consistent across the EFSS phases and that addressed these technical objectives.

6.1 DATA ANALYSIS OBJECTIVES

Data summaries and statistical analyses were centered around data analysis objectives established for the EFSS. The data analysis objectives address the overall objectives of the EFSS (presented in Chapter 1). The study phases shared many of the same data analysis objectives. These objectives are categorized below according to the goal which they satisfy.

A. Characterize Lead Disturbance and Potential Lead Exposure

- Characterize average personal exposure levels of airborne lead for workers over the duration of a given R&R activity and determine if these levels exceed 50 $\mu g/m^3$ (the OSHA Permissible Exposure Limit (PEL))

- Characterize lead loadings and concentrations within samples of dust that settles on flat surfaces (e.g., floors, window sills) within a specified period during and following completion of R&R activities.

Carpet removal and window replacement phases only:

- Characterize airborne dust lead levels in rooms adjacent to "activity rooms" (rooms in which the R&R activity occurs) while the activity is in progress.

In a separate evaluation:

- Determine the effect that typical cleanup procedures have on lead loadings in settled dust that remains following the activity as a lead exposure to occupants.

B. Assess Factors or Measurements Related to Lead Disturbance

- Characterize the extent to which lead disturbance and exposure are affected by indicators of lead contamination in the dwelling unit, extent of exposure to the activity, and building characteristics. (Depending on the study phase, indicators include lead loadings in settled dust existing prior to the start of activity, available lead loadings on painted surfaces disrupted by the activity, distance of sample location from the activity, type of substrate disturbed, and elapsed time in which the activity took place.)

- Quantify the components of total variability in lead measurements taken within samples of various media. (Variance components could constitute variability attributable to sampling across different dwelling units, sampling from different locations or workers within the same unit, or sampling from different areas within the same location.)

The following data analysis objectives, grouped as a third category, were devised to provide information to aid in the design and development of future lead exposure studies:

C. Evaluate Different Media and Methods as Indicators of Lead Exposure

Carpet removal and window replacement phases only:

- Compare settled dust lead loadings on stainless steel dustfall collectors (SSDCs) introduced prior to the start of activity with baseline-adjusted settled dust lead loadings directly from the floor surface

- Compare lead loadings from settled dust samples collected one hour following completion of activity with loadings from samples collected at two hours following completion of activity

- Compare lead loadings from settled dust samples collected using vacuum techniques with loadings for samples collected using wipe techniques

- Examine correlations between lead measurements among different collection media.

CED phase only:

- Investigate the potential for cross-contamination between activities.

Data analyses addressing the first three objectives within Category C provide information to evaluate competing sampling methodologies as presented and analyzed in Chapter 7. The remaining objectives are addressed by the analyses presented in Chapter 8 for each R&R activity.

6.2 APPROACH TO DATA ANALYSIS

Most of the data analysis objectives and the approaches taken to analyzing the data were consistent across the study phases. Data analysis in the EFSS was centered on characterizing the distributions of lead levels in various media affected by each of the target R&R activities. Variability in lead measurements was characterized as a function of sampling from different units, from different locations/workers with a unit, and from different areas within the same location. The extent of correlation present between lead loadings in settled dust and personal/ambient air lead levels, and between lead exposure and building and activity characteristics, was investigated. All statistical analyses and data summaries were performed using Versions 6.03 and 6.08 of the SAS® System.

Lead levels as determined from analytical methods performed on the environmental field samples were expressed in terms of loadings and/or concentrations. For personal air and ambient air cassette samples, lead levels were expressed as concentration of lead per cubic meter of air sampled ($\mu g/m^3$). For each settled dust sample, lead loadings expressed the amount of lead (μg) per unit area (square foot) sampled. For the purposes of this study, dust lead loading provides a measure of the total amount of lead disturbed in a specified area by the studied R&R activity. For vacuum dust samples, lead concentration was also reported, representing lead amounts (μg) per unit weight (g) of dust. However, while lead concentration in dust provides information to characterize the nature of the exposure and to provide insight into appropriate avoidance or cleanup practices, concentration data provide no indication of the total amount of lead disturbed by the activity. Because the primary objective of the study was to characterize the amount of lead disturbed and the potential human exposure associated with an activity, loadings were emphasized in the statistical evaluation of lead disturbance in each phase of the EFSS. For settled dust samples, statistical comparisons and modeling were performed on loadings, while only data summaries were performed on concentrations and physical sample weights. For personal and ambient air samples, statistical analysis was performed on the reported lead concentrations.

Personal exposure monitoring during R&R activity provides data on the amount of lead per volume of air sampled within the breathing zone of a monitored worker. These data represent average exposures over the duration of an activity period and are referred to in this document as *task-length averages (TLA)* (in μg lead per cubic meter of air). Exposure data are calculated from the amount of lead collected within the sample cassette(s), the duration of monitoring, and the air pump flow rate. The TLA for a worker performing a given R&R activity at a study unit is calculated as follows:

$$TLA = \frac{\text{total lead across all cassettes at a unit for a worker}}{(\text{duration of task})\cdot(\text{flow rate})}$$

This approach to calculating the TLA for personal exposure monitoring was followed in each study phase of the EFSS.

6.2.1 Common Approaches Taken Within Each Study Phase

Log Transformations

Throughout the EFSS, analysis of lead loading or concentration data was performed after taking a natural-logarithm (or "log") transformation of the data. In many standard statistical inference procedures, the assumption of normally distributed data is necessary to make accurate inferences on the central tendency and variability within the data distribution. In this setting, lead loadings and concentrations appeared to originate from skewed distributions. The arithmetic mean is heavily influenced by large data values in the upper tail of the distribution, and therefore may not be an appropriate representation of the central tendency of the data. However, distributions of the log-transformed data more closely resembled a normal distribution (as determined through normal probability plots and results of the Shapiro-Wilk test for normality).

In such a situation, if the arithmetic mean of the log-transformed data is calculated and then exponentiated, the result (called the "geometric mean") is an estimate of the median of the distribution of untransformed data. Thus, due to lognormality, the geometric mean is an estimate of the central tendency of the distribution and is more robust to outliers than the arithmetic mean. As a result, summaries of lead loadings and concentrations within each phase are based on geometric means and on variability associated with log-transformed data. These summaries, which also include minimum and maximum observed data values, are presented in tabular form within Appendix A.

Pearson Correlation Coefficients

The Pearson correlation coefficient was calculated to quantify the extent to which linear relationships were present between a pair of measurements. Values of the correlation coefficient close to one indicates a positive correlation, while values near -1 represent negative correlation. Statistical tests for nonzero correlation were executed to determine whether the coefficient differs significantly from zero at the 0.05 level.

Statistical Modeling

Statistical models were fitted to lead levels in various media to evaluate the effects of external factors (called *covariates*) on these data. For example, models within the carpet removal phase included the effects of pre-activity lead loadings in the carpet and on the floors. F-tests were performed to determine whether specific covariates had statistically significant effects on the modeled data at the 0.05 level. Statistical models were also fit that included exclusively random effects, such as a dwelling unit effect, to determine the contribution to overall variability in the study data which could be explained by these effects. Further detail on the approach to statistical modeling is presented in Appendix C. In some instances, small numbers of data points restricted the extent to which model effects could be characterized within statistical models.

Fitting linear statistical models to log-transformed data affects how the modeling results are interpreted relative to the untransformed data. In this study, the modeled data (i.e., log-transformed data) are expressed as a linear combination of fixed and random factors. Therefore, the models are considered "additive" models relative to the log-transformed data. However, by exponentiating both sides of the model equation, one sees that the models express the untransformed data as a multiplicative function of the model effects. That is, the effect of a single factor is measured by its multiplicative influence on the untransformed data, and comparisons among factor effects are expressed in terms of ratios of geometric means rather than as differences in arithmetic means.

Boxplots

In each study phase, results of data analysis were summarized in tabular and graphical form. Graphical displays were used to ease interpretation and comparison among sample types. Two-dimensional scatterplots illustrate correlations present among pairs of measurements and portray data values across the study by study unit and location within unit. Boxplots display percentiles and other statistics, as well as extreme data points, in the form presented in Figure 6-1.

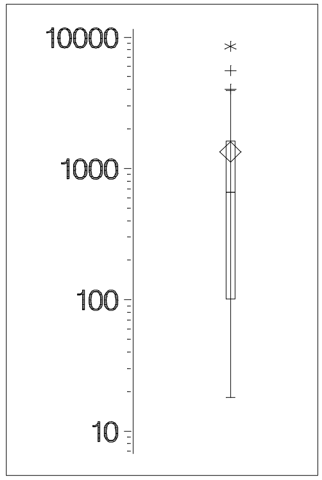


Figure 6-1. Example of a Boxplot

The lower and upper limits of the "box" portion of the boxplot represent the 25th and 75th percentiles, respectively, of the observed data distribution. The length of the box represents the data's interquartile range (IQR), or the difference between the 25th and 75th percentiles, which is an indicator of data variability. The horizontal line within the box is the 50th percentile, or median. The diamond symbol is the arithmetic mean. Vertical lines extend from the top (or bottom) of the box to the value of the most extreme data point which falls within 1.5 IQRs from the box. Each data point extending from 1.5 to 3.0 IQRs from the box is plotted with a "+" symbol, while each data point extending beyond 3.0 IQRs from the box is plotted with a "*" symbol.

6.2.2 Estimating Lead Disturbance in a 6' x 1' Gradient Region

In this study, a statistic was developed to characterize lead disturbance (and potential exposure to occupants) associated with a specific R&R activity. Taking into account the relationship between the amount of lead in the environment and the distance from the activity, this statistic estimated the amount of lead exposed (or disturbed) along a 6-foot line (lead gradient) emanating from the activity source. For each activity, a statistical model (Lead = $\alpha e^{\beta \cdot \text{distance}}$) was fitted to express lead levels in settled dust as a function of distance from activity. Details on the model fitting process are provided in Section C.5 of Appendix C. An example of the fitted model is given in Figure 6-2.

From this model, lead exposure for an activity is quantified by calculating the area under the fitted curve from 0 to 6 feet from the activity. This measure represents an estimate of the amount of lead present in a 6-foot by 1-foot column extending from the activity (Figure 6-2). Throughout the report, this measure will be referred to as the amount of lead in a 6' x 1' gradient region. The 6-foot distance was selected based on distance considered in the sampling design. For each activity, uncertainty in the amount of lead within a 6-foot by 1-foot column was expressed by calculating an approximate 95% confidence interval on the estimated amount.

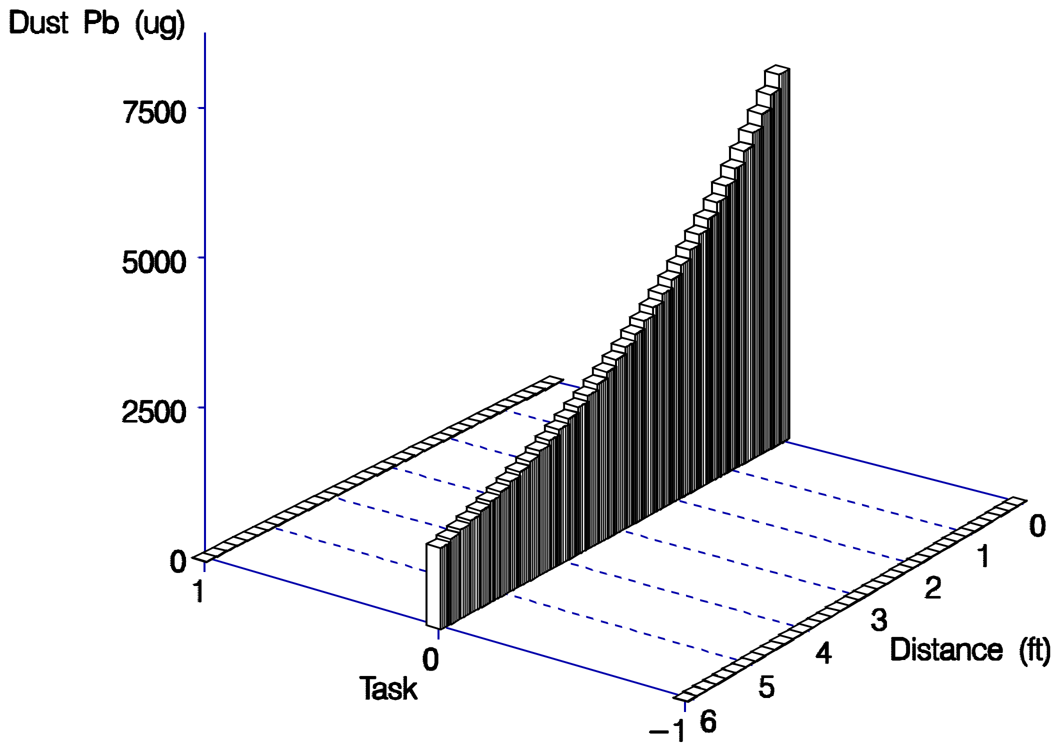


Figure 6-2. Portrayal of Model Predicting Lead Exposure as a Function of Distance from R&R Activity

Two alternative calculations to characterizing lead disturbance and potential exposure to occupants were considered but not implemented in this study: 1) a weighted combination of estimated lead amounts at one and six feet from the activity, and 2) total volume of lead exposed within a hypothetical (6 by 12 foot) area adjacent to the activity. The development of a weighting scheme for the 1- and 6-foot estimates involved assumptions about potential cleanup activities and occupant behavior. For example, is a greater exposure potential posed by lead six feet away from the activity than lead one foot away? Given the limited existing information upon which to base such assumptions, this calculation was rejected. The total volume measure would have provided an interesting measure of lead exposure but required assumptions about the character of the dust dispersion resulting from the activity. For example, would dust generated by sawing through plaster disperse symmetrically from the cutting area? What would be the shape of the response surface that would characterize dispersion over a two-dimensional area? Since the

EFSS was not designed to assess such questions, these assumptions would have been based on field experiences and mathematical convenience, and therefore this estimation scheme was rejected.

6.2.3 Significant Digits

Laboratory results from the chemical analyses of samples collected in this study were reported to five significant digits. However, the precision of most analytical methods employed in the analyses would suggest that the analytical data have less than five significant digits. Therefore, all results in this report are reported to three significant digits. Descriptive statistics and results reported in tables in the Appendices present all digits as calculated.

7.0 METHODOLOGY ISSUES AND RESULTS

As discussed in Section 4.3, the method used in the EFSS for obtaining settled dust samples from floors differs from the standard "pre- versus post-activity sample" method taken in previous studies. In the EFSS, stainless steel dustfall collectors (SSDCs) were placed on the floor immediately before the start of an activity, and a single dust sample was collected from each SSDC at specified time points following conclusion of the activity. An investigation was conducted to evaluate the different approaches to collecting dust samples, relative to their ability to recover and estimate lead loadings in settled dust. This chapter presents the findings of this evaluation.

Section 7.1 compares lead loadings from SSDC dust samples versus those from paired dust samples taken via the standard method of sampling directly from the floor surface (post- minus pre-activity). Section 7.2 evaluates the amount of time necessary to allow lead-dust to settle following conclusion of the activity before sample collection. Lead loadings of SSDC samples collected via vacuum techniques are compared to those collected via wipe techniques in Section 7.3. Finally, Section 7.4 addresses differences in lead loadings between adjacent ("side-by-side") samples, and how these differences may indicate whether taking the first sample unduly influences the outcome associated with the second sample.

7.1 STAINLESS STEEL DUSTFALL COLLECTORS VS. POST- MINUS PRE-ACTIVITY FLOOR DUST METHOD

In the carpet removal and window replacement phases of the EFSS, two competing approaches to measuring the lead disturbed by the R&R activity were compared. Both approaches yielded estimates of lead levels in dust that settled on floors during the activity and up to one hour following the activity's completion. The protocols for the sampling approaches, both employing vacuum dust sampling techniques, were as follows:

- ***Post- minus pre-activity floor****:* Collect two samples directly from the floor surface, where one sample was taken immediately prior to start of the activity (baseline) and the other was taken at one hour following the activity's conclusion from an area adjoining the first sample area. Dust lead levels are estimated by subtracting the pre-activity result from the post-activity result.

- ***Stainless steel dustfall collectors (SSDC)****:* Place a clean, uncontaminated SSDC on the floor surface immediately prior to start of the activity, and collect one dust sample from the SSDC surface at one hour following the activity.

The first sampling approach (floor dust) has been taken in a number of previous programs to measure settled dust levels resulting from some activity. The second approach (the SSDC) addresses the same objective, but does not require an adjustment for a baseline level, thereby using only one dust sample rather than two to estimate lead levels. For this reason, it was expected that variability attributable to spatial trends and biases, sampling, and analysis would be reduced by use of the SSDCs.

In both the carpet removal and window replacement phases, each sampling location containing a SSDC for post-activity dustfall sampling also contained two one-square-foot areas for pre- and post-activity floor dust sampling. Plots of the SSDC lead loadings versus the post- minus pre-activity floor dust loadings at the same location indicate that loadings from the post- minus pre-activity floor dust method cover a much larger range than the SSDC lead loadings. The plot for carpet removal is shown in Figure 7-1. Figures 7-2 and 7-3 show the plot for window replacement samples collected at zero feet and six feet from the window, respectively. Figures 7-1 and 7-3 show the large discrepancy in the variability between SSDC and floor samples. The range of post- minus pre-activity floor loadings required the horizontal axes of these plots to be broken to more clearly illustrate all the data.

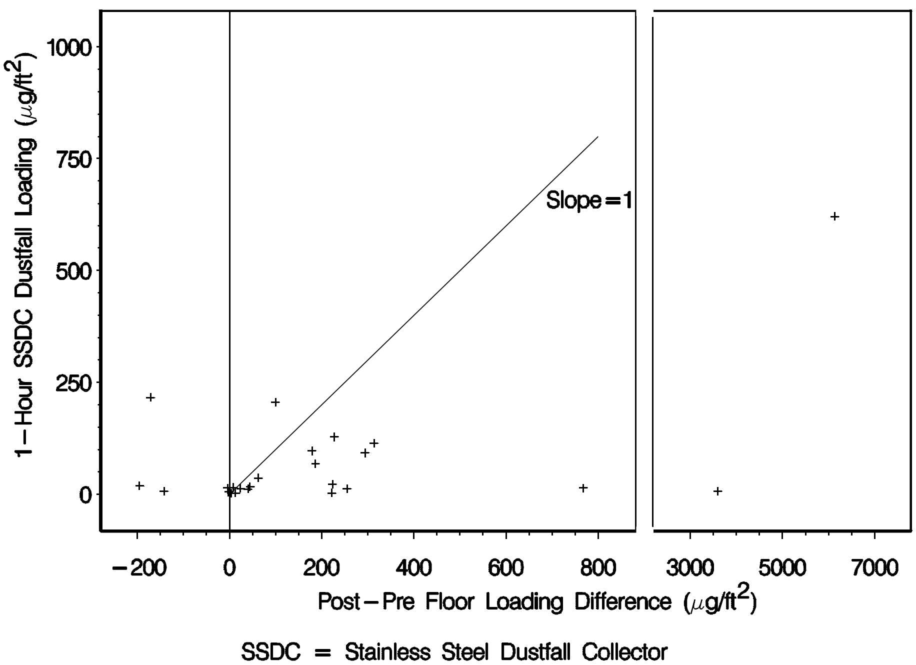


Figure 7-1. Lead Loadings (μg/ft²) for 1-Hour Stainless Steel Dustfall Collector Samples Versus the Difference in Loadings Between Post-Activity and Pre-Activity Floor Dust Samples in the Carpet Removal Phase

Additional plots of the observed SSDC sample loadings and post- minus pre-activity floor loadings are found in Figure 7-4 for carpet removal and Figures 7-5a and 7-5b for window replacement. These plots illustrate the difference in magnitude of variability between the two sampling methods on a unit-by-unit basis. It should be noted that the variability observed in the EFSS for side-by-side floor samples is similar to what has been observed in previous studies. EPA's Comprehensive Abatement Performance Study (CAPS) (Battelle, 1994) estimated the log standard deviation of for floor side-by-side sample loadings to be 0.93, similar to that observed in the EFSS. NIOSH's Ohio University study reported coefficients of variation over 50 percent for side-by-side wipe samples, again indicating high expected variability (NIOSH, 1993). Moreover, from a statistical standpoint, it is expected that variability would be reduced when using the SSDC methodology, since the SSDC method involves the variability of a single measurement

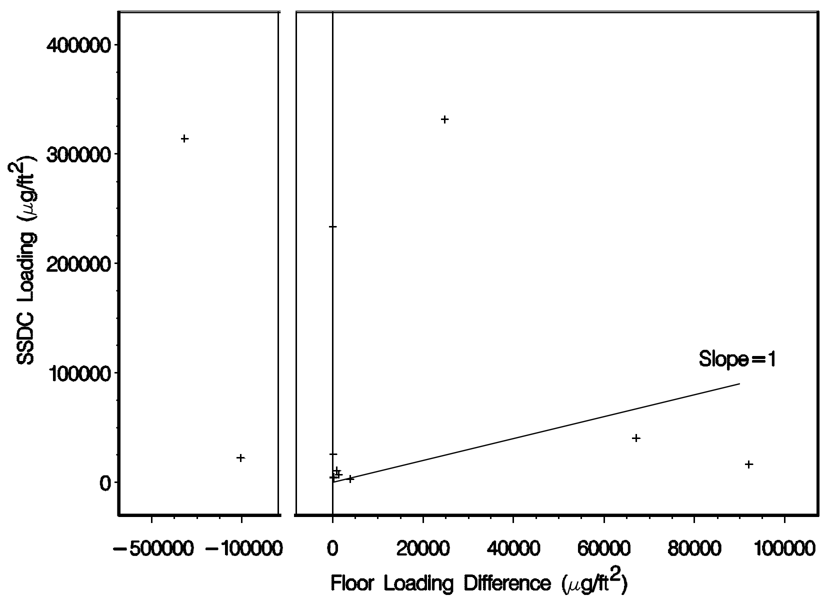


Figure 7-2. Lead Loadings ($\mu g/ft^2$) for 1-Hour Stainless Steel Dustfall Collector Samples Versus the Difference in Loadings Between Post-Activity and Pre-Activity Floor Samples Taken Zero Feet from the Windows in the Window Replacement Phase

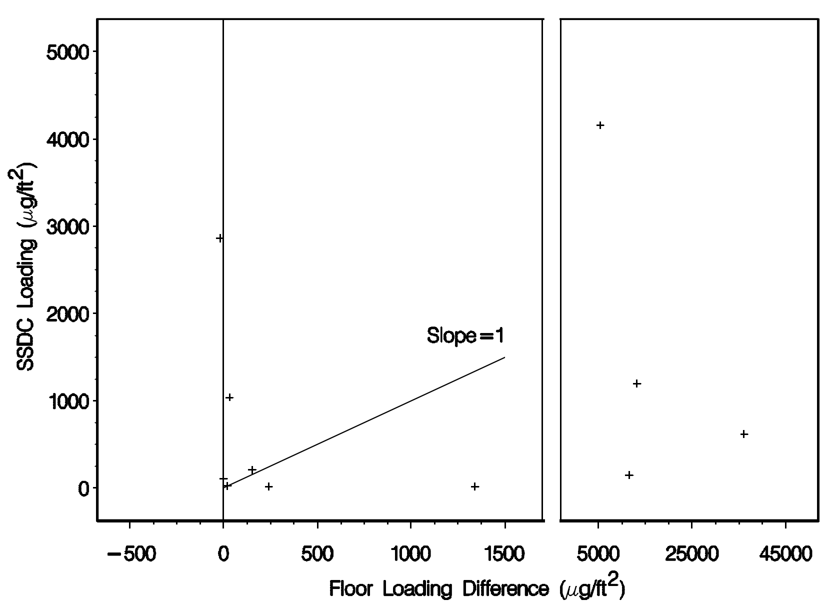


Figure 7-3. Lead Loadings ($\mu g/ft^2$) for 1-Hour Stainless Steel Dustfall Collector Samples Versus the Difference in Loadings Between Post-Activity and Pre-Activity Floor Samples Taken Six Feet from the Windows in the Window Replacement Phase

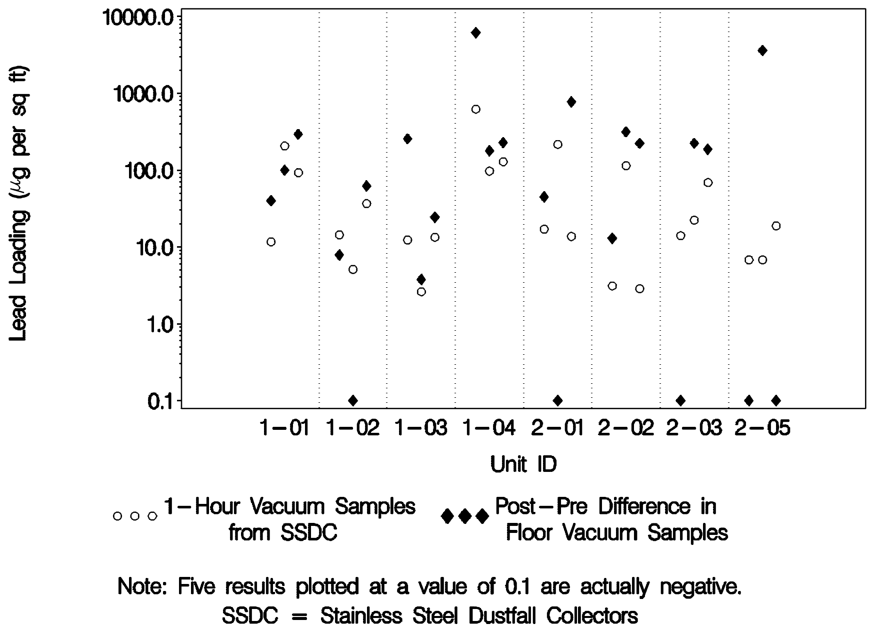


Figure 7-4. Lead Loadings (μg/ft²) for 1-Hour Stainless Steel Dustfall Collector Samples, and the Difference in Loadings Between Post- and Pre-Activity Floor Dust Samples in the Carpet Removal Phase

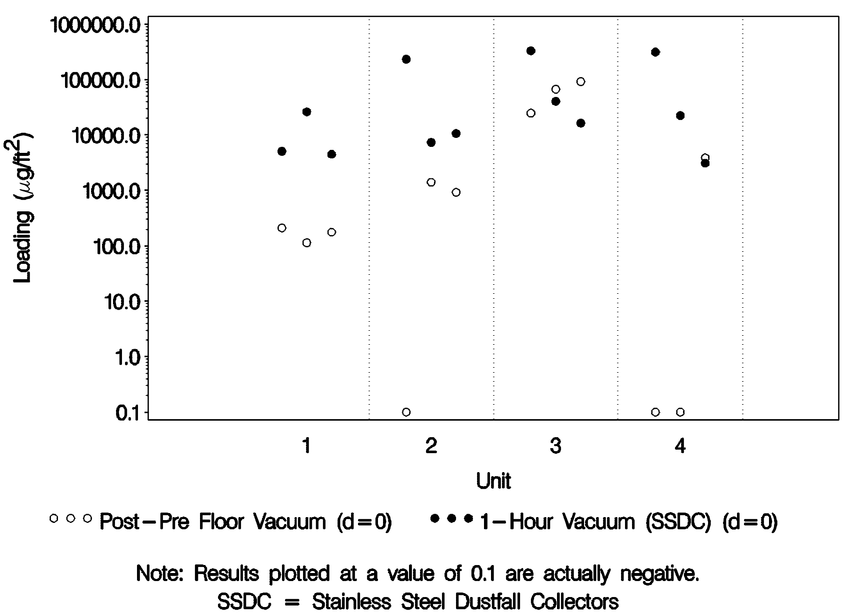


Figure 7-5a. Lead Loadings (μg/ft²) for 1-Hour Stainless Steel Dustfall Collector Samples, and the Difference in Loadings Between Post- and Pre-Activity Floor Samples, Collected at Zero Feet from the Windows in the Window Replacement Phase

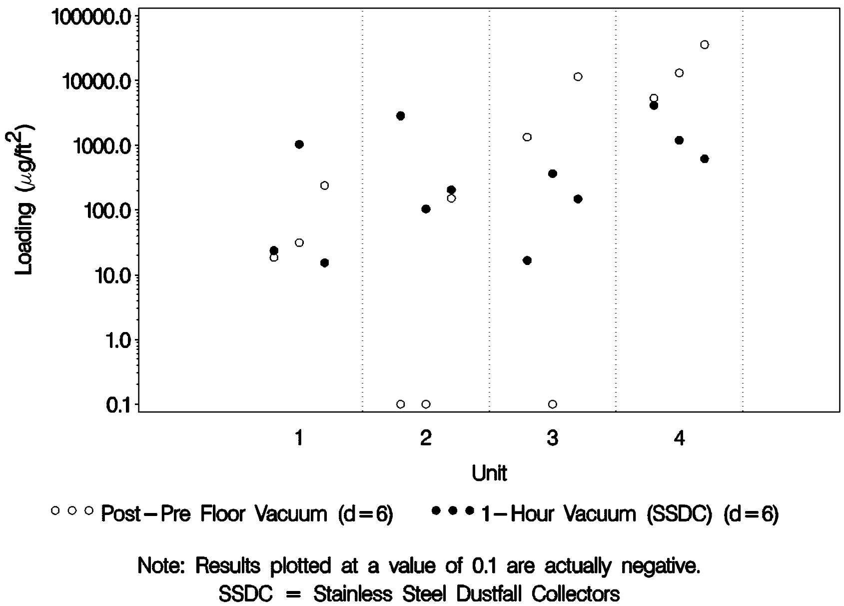


Figure 7-5b. Lead Loadings (μg/ft^2) for 1-Hour Stainless Steel Dustfall Collector Samples, and the Difference in Loadings Between Post- and Pre-Activity Floor Samples, Collected at Six Feet from the Windows in the Window Replacement Phase

rather than the additive variability of a linear combination of two measurements. The SSDC also eliminates the possibility of negative values (post minus pre) that can occur with side-by-side samples but are not reasonable estimates of the amount of lead disturbed by an activity.

Preference for using the SSDC approach over the post- minus pre-activity floor approach is further supported by the high linear correlation between the lead loadings from SSDC dust samples and the lead concentrations from worker personal air samples. A correlation of 0.98 was observed between these two measurements in the carpet removal phase, and a correlation of 0.94 was observed in the window replacement phase. Both correlations were higher than the corresponding correlations between personal exposure concentrations and post-activity floor loadings. These findings, presented in more detail in Chapter 8, support the hypothesis that the SSDC approach yields a better measure of the lead disturbed by the R&R activity than the post- minus pre-activity floor approach.

In summary, the SSDC methodology was judged to be superior to the post- minus pre-activity floor sample approach for the following reasons:

1. The SSDC method exhibited less variability, consistent with expectations from previous experience and statistical theory.

2. The SSDC method does not produce negative estimates of the amount of lead disturbed by an activity.

For these reasons, a decision was made to base estimates of the amount of lead disturbed by a specific R&R activity on the results of samples taken from SSDCs. As a result of this decision, only the SSDC method for estimating the lead generated by an R&R activity was used in the third phase of the EFSS, the Controlled Experimentally-Designed (CED) phase.

7.2 STAINLESS STEEL DUSTFALL COLLECTORS: COLLECTING SAMPLES 1 HOUR VS. 2 HOURS AFTER R&R ACTIVITY

When defining the post-activity settled dust sampling approach, the study team had limited information available in assigning a wait time to allow sufficient fallout of lead dust prior to sample collection. Preliminary calculations based on particle physics indicated that roughly 90% of lead particles greater than five µm that are disturbed as a result of R&R activity should settle within one hour, even in turbulent air situations. As a result, the one-hour post-activity settled dust sample from SSDCs was chosen as a reasonable indicator of lead disturbance in the R&R study. However, it was of interest to test whether a one-hour wait was adequate, or whether allowing a longer period of time for dust to settle would result in significantly higher lead loadings. Therefore, at selected floor locations in the carpet removal and window replacement phases, two SSDCs were placed side-by-side. One SSDC was sampled at one-hour post-activity, and the other at two-hours post-activity. The lead loadings between the side-by-side samples were compared to determine the magnitude of additional dustfall that occurs over a period of two hours compared to one hour.

Figure 7-6 presents a scatterplot of the difference in loadings between the paired two-hour and one-hour samples versus the difference in elapsed wait time between the two samples. Due to the pace of the field activity and the number of samples collected, samples could not be taken exactly at the time they were scheduled following the activity. At a given location, the difference in elapsed wait times between the one-hour and two-hour samples ranged from 20 to 72 minutes; most time differences ranged from 40 to 60 minutes. Figure 7-6 indicates no apparent increasing trend in the differences in lead loadings as the difference in elapsed wait time increases (fitted regression lines were not significantly different from the horizontal line at difference = 0). In fact, the differences in sample results for three of the four sample pairs with the largest elapsed wait times are close to zero. However, the plot does show that in 24 of the 36 paired samples (67%) the two-hour sample loading is larger than the one-hour sample loading. In only one sample pair does the one-hour loading exceed the two-hour loading by greater than 50 µg/ft^2, while the two-hour loading exceeds the one-hour loading by greater than 50 µg/ft^2 for ten pairs. Since an effect of the exact sampling time cannot be detected, a simple categorical classification of results into one-hour and two-hour samples was maintained.

Figure 7-7 is a log-log scatterplot showing the relationship between the paired two-hour and one-hour lead loadings among the study units in the carpet removal and window replacement phases. The solid line within the plot corresponds to equality between the two responses. This plot further illustrates that two-thirds of the sample pairs had higher lead loadings for the two-hour sample compared with the adjoining one-hour sample. This outcome supports the hypothesis that loadings tend to increase during the additional hour wait. Based on the analysis of pre/post floor dust samples, one might anticipate that much of the difference between the adjoining one-hour and two-hour sample results is due to spatial variability. However, a strong

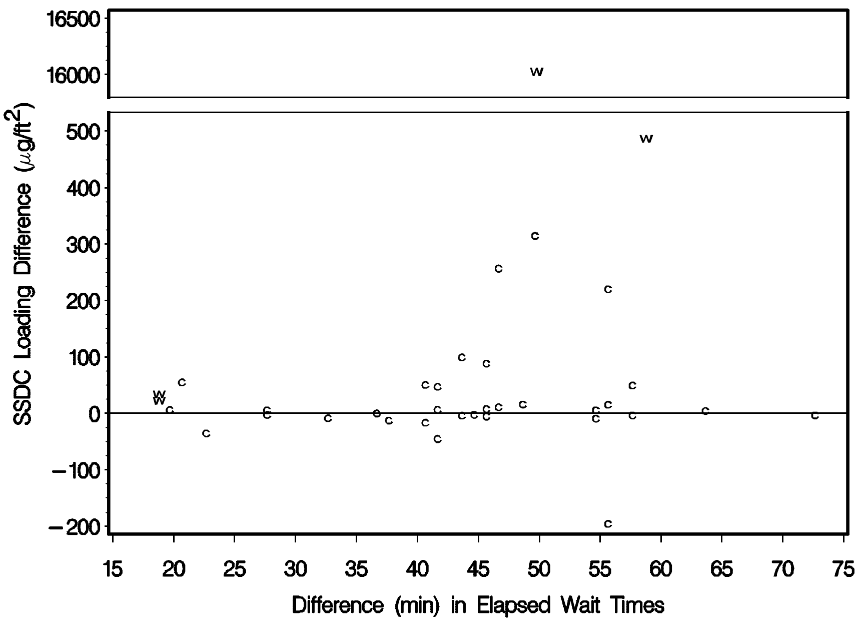


Figure 7-6. Difference in Loadings Between Two-Hour and One-Hour SSDC Samples (Two-Hour Minus One-Hour) Versus the Difference in Elapsed Wait Times Between the Two Samples, for Carpet Removal (c) and Window Replacement (w) Phases

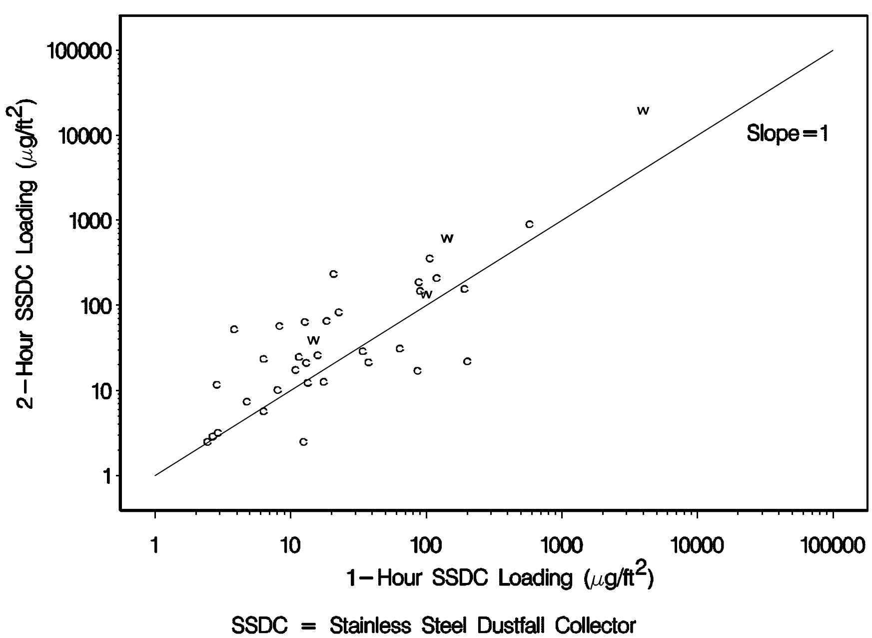


Figure 7-7. Two-Hour SSDC Lead Loadings Versus One-Hour SSDC Loadings for the Carpet Removal (c) and Window Replacement (w) Phases

linear relationship, though not centered around the line of equality, was observed between the two results in Figure 7-7. The Pearson correlation was 0.85 between the one- and two-hour lead loading results (after taking logarithms). As a result, the extent of differences between adjoining one- and two-hour lead loadings appears to be consistent across the range of observed data, with higher readings associated with the two-hour results.

To further characterize the statistical relationship between the one-hour and two-hour lead loadings from adjoining sample areas, a paired t-test was performed to determine whether the difference in the log-transformed loadings at a location was significantly different from zero (or equivalently, that the ratio of untransformed loadings at a location was significantly different from one). Data were pooled across the carpet removal and window replacement phases for this test. The p-value resulting from the paired t-test was 0.008, indicating that the difference in the log lead loadings between one- and two-hour lead loadings was highly significant statistically. Similar results occurred when the Wilcoxon signed-rank nonparametric test was applied. These results are equivalent to concluding that the geometric mean of the ratio of 2-hour to 1-hour lead loadings is significantly different from one. The estimated geometric mean is 1.57, which is an estimate of the median ratio. Therefore, there is statistical evidence that waiting two hours after an activity leads to increased lead loadings. Since statistical comparisons between activities within the EFSS were based only on one-hour dustfall measurements (Chapters 8 and 9), effects due to elapsed wait times do not enter into the comparisons.

7.3 COLLECTING SAMPLES VIA VACUUM TECHNIQUES VS. WIPE TECHNIQUES

For a given R&R activity, lead loadings from dustfall samples collected via vacuum techniques were used to statistically characterize lead disturbance and potential lead exposure to occupants. Using pre-moistened wipes to collect settled dust samples is a competing sampling collection procedure that was employed in previous lead exposure characterization studies. The vacuum and wipe sampling techniques from SSDCs were compared within the EFSS by analyzing data from paired dust samples, where one sample in each pair was collected from an SSDC using wipe techniques and the other from an adjoining SSDC using vacuum techniques. Paired vacuum/wipe sampling was performed for carpet removal and for the demolition of plaster walls within the CED phase. Differences between paired vacuum and wipe results were statistically analyzed across the two activities.

In the carpet removal phase, two pairs of vacuum/wipe samples were collected within each of the eight study units, providing 16 sample pairs. All 32 samples were collected from locations immediately adjacent to rooms where carpet removal activity occurred. In the CED phase, 12 pairs of vacuum/wipe samples were collected following wall demolition within the two Baltimore units. These pairs were collected at distances ranging from 6 to 10 feet from the demolished wall one hour following conclusion of the R&R activity.

The scatterplot in Figure 7-8 includes lead loadings for dust samples within the wipe/vacuum sample pairs in the carpet removal and CED phases. Results from the same pair are plotted immediately above and below each other. The extent of a linear relationship between the (log-transformed) wipe and vacuum sample results within a pair is illustrated in Figure 7-9, where wipe loadings are plotted versus vacuum loadings.

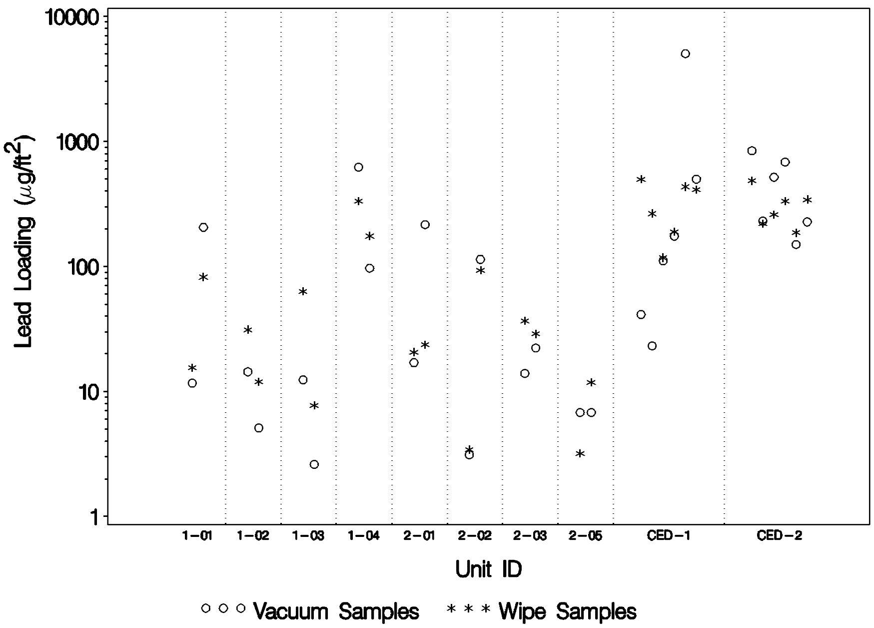


Figure 7-8. Plot of Lead Loadings for Paired Vacuum/Wipe Samples at Each Location and Study Unit in the EFSS

The correlation coefficient between (log-transformed) vacuum and wipe sample results in Figure 7-9 is 0.83, which is highly significantly different from zero (p=0.0001). Thus, as expected, a strong positive relationship exists between log-transformed vacuum and wipe loadings at a given location.

For the carpet removal phase, both wipe and vacuum loadings appear to have similar variability and cover approximately the same ranges (the stars in Figure 7-9). However, in the CED phase, variability among vacuum sample loadings was substantially higher than for wipe sample loadings. This is evident in Figure 7-9, where the CED data (the circles) cover a wider range horizontally than vertically. This result may indicate that wipe sampling is less sensitive than vacuum sampling in environments with considerable amounts of dust, especially in situations where the wipes may become saturated with dust.

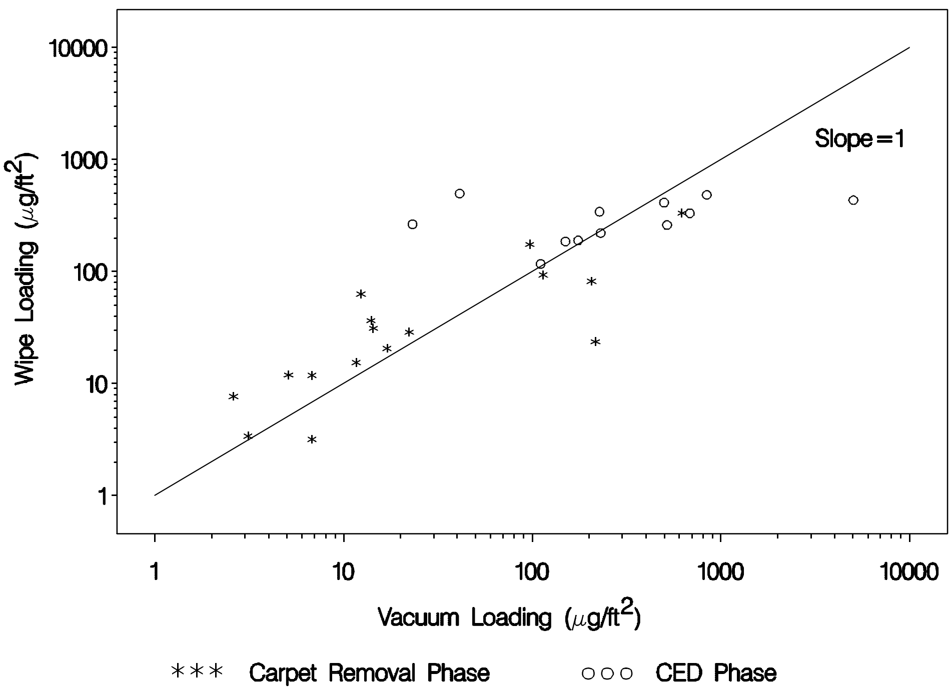


Figure 7-9. Plot of Wipe Sample Loading Versus Vacuum Sample Loading for Paired Samples in the EFSS

The solid line in Figure 7-9 represents the line of perfect agreement between wipe and vacuum sample results. In the carpet removal phase, 11 of the 16 pairs (69%) had higher loadings for the wipe sample than for the vacuum sample. For 10 of these 11 pairs, the vacuum sample loadings were less than 30 μg/ft^2. In the CED phase, 6 of 12 pairs had higher results for the wipe sample, as vacuum samples were more highly variable in both directions from the median of the wipe loading data. Generally, vacuum and wipe sample loadings were higher in the CED phase than the carpet removal phase, as seen in Figure 7-8. This figure also suggests that wipe methods may provide higher recoveries at low loadings, whereas vacuum methods may provide higher recoveries at high loadings.

To statistically characterize the relationship in dust lead loadings between adjoining wipe and vacuum samples collected one hour post-activity, a statistical model was fitted to the data in Figure 7-8 (data from 28 vacuum/wipe pairs). The statistical model assumes that this relationship is log-linear:

$$\ln(\text{loading}_{\text{vacuum}}) = \ln(\alpha) + \beta\ln(\text{loading}_{\text{wipe}}) + \text{error}$$

where α and β are unknown parameters. Statistical methods took into account that loadings for both sample types are subject to error. If α and β both equal one, then the log-loading for the vacuum sample differs from the log-loading for the adjoining wipe sample by random error. If α is not equal to one, then the vacuum log-loading is consistently different from the wipe log-loading by an amount equal to $\ln(\alpha)$. If β is not equal to one, the extent of the difference between the two results changes with the magnitude of the measurements.

The estimate of β in the above model was 1.04, with a standard error of 0.14. Thus, β was declared not significantly different from one (p=0.79), concluding that any difference between the wipe and vacuum loadings was assumed constant across the observed measurements. The estimate of α was 0.88, with an approximate 95% confidence interval of (0.57, 1.35). This estimate is less than one, reflecting the decreased vacuum sample loadings relative to the wipe sample loadings, as seen primarily in the carpet removal data. However, its 95% confidence interval contains 1.0, implying that the estimate is not significantly different from one at the 0.05 level. Therefore, there is no statistical evidence (given the observed data) that the results for paired wipe and vacuum samples differ significantly.

7.4 COMPARING RESULTS BETWEEN SIDE-BY-SIDE SAMPLES

In each of the three R&R phases (carpet removal, window replacement, and CED phases), additional lead dust samples were collected from areas adjoining "regular" sample areas at selected sampling locations. These samples, simulating field duplicates, were labeled "side-by-side" samples, and were taken from floors and SSDC surfaces. Because the sample areas between a regular and side-by-side sample were adjoining, and the same sampling technique was used to collect both samples, any spatial variability between the two sample results was assumed to be minimized. Also, both samples were collected within a few minutes of each other at specified times during the activity process. As a result, one expects any differences between the two results to reflect only variability in the sample collection and measurement processes. However, in the summary and analysis of loading data obtained from vacuum dust sampling, the first sample collected within a pair had consistently higher results than the second sample collected.

Figure 7-10 presents a log-log scatterplot of loadings between the first sample collected versus the second sample collected for each regular/side-by-side pair collected in the study, when vacuum sampling techniques were used. The majority of points in this plot fall above the 45° line, indicating that the first sample collected in a pair was consistently higher than that of the second sample collected.

For settled dust loadings, concentrations, and physical sample weights, Tables D-2a through D-2c in Appendix D (one table for each study phase) list the results of regular and side-by-side sample pairs as well as the differences in results between two samples in a pair. Results are listed according to whether the sample was collected from a floor or SSDC surface, and whether the sample was collected pre- or post-activity. In each of these breakdowns, loadings for the first sample collected were larger than for the second sample collected in a majority of the sample pairs.

To test the hypothesis that the results for the first sample taken from two adjoining sample areas were significantly different from results for the second sample taken, two statistical tests were performed. First, a binomial test was performed to test whether the percentage of sample pairs having larger results in the first sample collected was significantly different from 50%. Next, a Wilcoxon signed-rank test was performed to determine whether the first result minus the second result (i.e., the differences in Tables D-2a through D-2c) was significantly different from

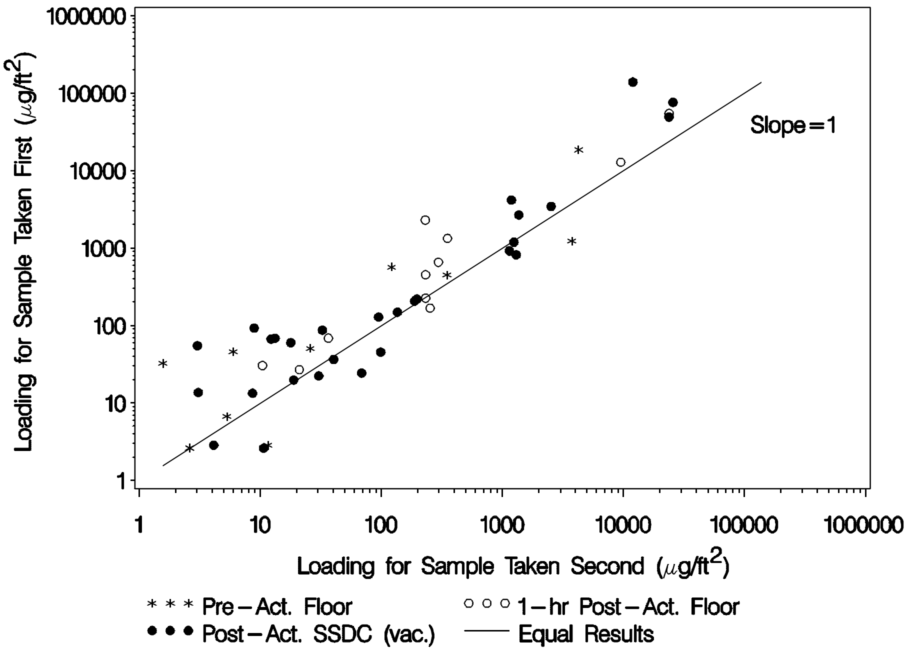


Figure 7-10. Lead Loadings for Adjoining Samples Collected via Vacuum Techniques (Sample Collected First Versus Sample Collected Second)

zero. The results of these tests are included in Table 7-1, where symbols indicate whether statistical significance was observed at the 0.05 level. Significance was seen for sample loadings in pooled sample pairs for the carpet removal and window replacement phases, as well as across all phases. Significance was not as apparent for sample concentrations and weights. A lack of significance in some cases may be the result of low statistical power to detect differences, due to the small sample size.

As a result of the investigation of side-by-side data in the EFSS, it is hypothesized that taking a vacuum dust sample may bias lead loadings that exist in adjoining areas. This conclusion affects the interpretation of side-by-side vacuum sampling designs that are applied to simulate field duplicates or to observe pre- and post-activity lead levels. However, a more detailed study that solely addresses this hypothesis is necessary to make such a conclusion with sufficient confidence.

Table 7-1. Percentage of Sample Pairs (Regular and Side-by-Side QC Samples) Where Result for the First Sample Collected Was Different From the Result for the Second Sample Collected (Vacuum Samples Only)

Phase	Floor Samples (Pre-Activity)	Floor Samples (Post-Activity)	SSDC Samples[(1)] (Post-Activity)	All Samples
Sample Loadings				
Carpet Removal	62.5% (5/8)	75.0% (6/8)	68.8%† (11/16)	68.8%*† (22/32)
Window Replacement	66.7% (2/3)	100% (3/3)	100% (3/3)	88.9%*† (8/9)
CED	---	---	55.6% (5/9)	55.6% (5/9)
All Phases	63.6% (7/11)	81.8%† (9/11)	67.9%† (19/28)	70.0%*† (35/50)
Sample Concentrations				
Carpet Removal	62.5% (5/8)	50.0% (4/8)	56.3% (9/16)	56.3% (18/32)
Window Replacement	100% (3/3)	33.3% (1/3)	33.3% (1/3)	55.6% (5/9)
All Phases	72.7%† (8/11)	45.5% (5/11)	52.6% (10/19)	56.1% (23/41)
Sample Weights				
Carpet Removal	50.0% (4/8)	75.0% (6/8)	68.8% (11/16)	65.6% (21/32)
Window Replacement	0.0% (0/3)	100% (3/3)	66.7% (2/3)	55.6% (5/9)
All Phases	36.4% (4/11)	81.8% (9/11)	68.4% (13/19)	63.4% (26/41)

* Percentage is significantly different from 50% at the 0.05 level by the binomial test.

† Results of the first sample taken are significantly different from the results of the second sample taken, at the 0.05 level according to the Wilcoxon signed rank test.

(1) Stainless steel dustfall collectors

8.0 STUDY RESULTS FOR INDIVIDUAL PHASES

This chapter presents the results of data summary and statistical analysis of environmental exposure data collected in the EFSS. Each phase in the EFSS was a substudy in itself, with specific sampling designs and data organization. Consequently, the study designs and results for each phase are presented as stand-alone sections, as follows:

Section 8A — Carpet removal phase

Section 8B — Window replacement phase

Section 8C — Controlled, Experimentally-Designed (CED) phase.

Data summaries and statistical analyses in these three sections were centered around data analysis objectives (see Section 6.1) established for the EFSS. Analysis to address objectives on sampling methodology evaluation was presented in Chapter 7.

Two additional sections in this chapter document other types of data collected and/or summarized to address issues concerning study objectives:

Section 8D — Cleanup Investigation. Determine the effects associated with two types of post-activity cleanup procedures on reducing settled dust lead levels following R&R activity.

Section 8E — Data from Other Sources. Summarize data obtained from other extant sources that relate R&R activities to lead exposures.

The appendices to this report (Volume II) provide supporting information to the main results presented in this chapter. Supporting information includes additional data summaries and detailed discussion of statistical methods.

8A-1.0 STUDY DESIGN IN THE CARPET REMOVAL PHASE

Chapter 4 presented aspects of the EFSS study design that were common across all phases. This section presents specific details of the study design as it was applied in the carpet removal phase. This section also presents characteristics of the eight dwelling units monitored in this phase.

8A-1.1 SAMPLING DESIGN FOR THE CARPET REMOVAL PHASE

The sampling design for the carpet removal phase was developed to address the objectives presented in Section 6.1. Table 8A-1 presents the proposed types and numbers of environmental field samples (both regular and QC samples) collected within each dwelling unit. These samples included the following:

- ***Personal exposure samples*** taken during the activity
- ***Ambient air samples*** taken during the activity
- ***Settled dust samples*** taken before the activity ***from the carpet to be removed***
- ***Settled dust samples*** taken before and after the activity ***from floor and window sill surfaces***
- ***Settled dust samples*** taken following completion of the activity ***from stainless steel dustfall collectors (SSDCs)*** placed on the floor immediately prior to the activity.

Three vacuum dust samples were collected prior to the start of the activity from the carpet to be removed. The Battelle field team leader selected the sample locations from the entire area of carpet to be removed, in an attempt to represent average carpet debris across the activity area in the unit. Areas with unusually high amounts or types of debris were not considered. A given dust sample was collected from a total area defined by a 1-ft^2 steel template, and lead content of all these samples was used as a covariate in the statistical analysis to predict lead exposure which can result from carpet removal.

Dust samples from floors and SSDCs were collected at three distinct locations in each unit. The locations (labeled L1, L2, L3) were in "adjacent areas" or areas outside of, but at the entrance to, an activity room. The sampling plan called for the three locations to be randomly distributed among adjacent areas throughout the unit; however, the locations were also dictated by logistical constraints, such as the ability of adjacent areas to accommodate the total area required for dust sampling (from 5 to 8 square feet). Sampling locations were partitioned into five, six, or eight subareas, each one square-foot in area, as illustrated in Figure 8A-1. A single settled dust sample was collected from each subarea at a specific time during the activity.

Table 8A-1. Numbers and Types of Environmental Samples (Regular and QC) Proposed in the EFSS Carpet Removal Phase Within Each Study Unit

Regular Samples

When Sample Was Taken	Sample Collection Method	Sample Type/Location[1]	# Samples Proposed
Pre-activity	Vacuum	Settled dust (Floor)	3
		Settled dust (Window sill)	2
		Settled dust (Carpet surface)	3
	Ambient air pump	Ambient air	1
During activity	Personal air pump	Personal air (R&R workers)	2
	Ambient air pump	Ambient air (adjacent room)	2
1-hr. Post-activity	Vacuum	Settled dust (Floor)	3
		Settled dust (SSDC)	3
		Settled dust (Window sill)	2
	Wipe	Settled dust (SSDC)	2
2-hr. Post-activity	Vacuum	Settled dust (SSDC)	3
		Total	26

Field QC Samples

When Sample Was Taken	Sample Collection Method	Sample Type/Location[1]	# Samples Proposed
Pre-activity	Vacuum	SBS settled dust (Floor)	1
		Field blank	1
	Wipe	Field blank	1
	Personal air pump	Field blank	1
	Ambient air pump	Field blank	1
1-hr. Post-activity	Vacuum	SBS settled dust (Floor)	1
		SBS settled dust (SSDC)	1
	Wipe	SBS settled dust (SSDC)	1
2-hr. Post-activity	Vacuum	SBS settled dust (SSDC)	1
		Total	9

(1) SSDC = stainless steel dustfall collector
SBS = sample taken side-by-side with a regular sample

Immediately prior to the start of carpet removal, the field team collected one vacuum dust sample within a one-square-foot area of the floor surface in each of the three sampling locations designated in Figure 8A-1. The field team also collected one vacuum dust sample from one-half of each of two window sills located in activity rooms. Lead content of these floor and window sill dust samples represented baseline levels which were compared to lead levels in samples taken upon completion of carpet removal from areas adjoining the pre-activity sample areas.

Location L1:

Cell #1 Floor vacuum (Pre-activity)	Cell #2 Stainless steel surface -- vacuum (1 hr. post-activity)	Cell #3 Stainless steel surface -- wipe (1 hr. post-activity)
Cell #4 Floor vacuum (1 hr. post-activity)	Cell #5 Stainless steel surface -- vacuum (2 hr. post-activity)	

Location L2:

Cell #1 Floor vacuum (Pre-activity)	Cell #2 Stainless steel surface -- vacuum (1 hr. post-activity)	Cell #3 Stainless steel surface -- wipe (1 hr. post-activity)
Cell #4 Floor vacuum (1 hr. post-activity)	Cell #5 Stainless steel surface -- vacuum (2 hr. post-activity)	Cell #6 Stainless steel surface -- wipe (1 hr. post-activity) (side-by-side)

Location L3:

Cell #1 Floor vacuum (Pre-activity) (side-by-side)	Cell #2 Floor vacuum (Pre-activity)	Cell #3 Stainless steel surface -- vacuum (1 hr. post-activity)	Cell #4 Stainless steel surface -- vacuum (1 hr. post-activity) (side-by-side)
Cell #5 Floor vacuum (1 hr. post-activity) (side-by-side)	Cell #6 Floor vacuum (1 hr. post-activity)	Cell #7 Stainless steel surface -- vacuum (2 hr. post-activity)	Cell #8 Stainless steel surface -- vacuum (2 hr. post-activity) (side-by-side)

Note: Due to space considerations, no wipe samples were taken at location L3. In shaded subareas, dust samples were taken directly from the uncarpeted floor surface.

Figure 8A-1. Three Settled Dust Sampling Locations at Adjacent Areas Within Each Unit, and the Types of Regular and QC Samples Collected Within Each Location, in the Carpet Removal Phase

One pre-activity ambient air sample was taken to obtain an estimate of baseline airborne lead. Because the ambient air samples took two hours to collect, the pre-activity ambient air sample was sometimes taken on the day prior to carpet removal.

Personal and ambient air samples were collected during carpet removal activities. Personal exposure sampling was conducted on up to two R&R workers per dwelling unit to measure lead levels in air within the workers' breathing zones while they were performing carpet removal. Ambient air samples were collected in two rooms adjacent to the activity to measure lead levels in air dust that could be inhaled by others present.

When possible, doors to rooms where ambient air samples were being collected were closed while carpet removal was being performed.

Post-activity sampling included settled dust samples from floors, window sills, and SSDCs positioned immediately prior to the start of the activity. At one hour following completion of all carpet removal activities, vacuum dust samples were collected from the remaining halves of the two window sills where pre-activity dust samples were collected. Vacuum dust samples were collected at three floor sampling locations one hour following the activity. Samples were taken from the floor surface and from a SSDC adjacent to the pre-activity vacuum floor dust sample area (as indicated in Figure 8A-1).

To compare results between wipe and vacuum sampling protocols, dust samples from SSDCs were collected at one hour following conclusion of carpet removal. These samples were taken from locations L1 and L2 (see Figure 8A-1) using wipe sampling techniques. To evaluate whether there was an increase in lead "fallout" in settled dust after waiting two hours rather than one hour, dust samples were collected from SSDCs in each sample location (Figure 8A-1) using vacuum techniques. All three samples were taken at two hours following the activity from areas adjoining the one-hour post-activity vacuum sample area. The results of these additional samples are presented in Chapter 7.

Table 8A-1 specifies 35 environmental samples in each dwelling unit, nine of which were field quality control (QC) samples. One field blank was taken prior to the start of carpet removal for every sampling medium (vacuum dust, wipe dust, personal air, ambient air) to determine the extent of contamination present during sample collection. At one settled dust sampling location (L3), side-by-side vacuum dust samples were taken from the floor surface and from SSDCs to allow sampling and measurement error to be characterized.

The number of samples made it was impossible to collect all settled dust samples at precisely the time at which they were to be collected (i.e., at one hour or two hours following completion of carpet removal). The time period for settled dust sample collection ranged from 15 minutes before to 40 minutes after the scheduled time.

Air samples were taken at relatively high flow rates (20 L/min for ambient air samples and 5 L/min for personal air samples) in the carpet removal phase. To make these rates more compatible with NIOSH specifications, the rates were lowered to 12.5 L/min and 4 L/min, respectively, in later phases of the EFSS. In addition, ambient and personal air samples taken in the carpet removal phase were collected open-faced (with the entire inlet section of the cassette assembly removed), in contrast to the NIOSH standard method (used in later phases of the EFSS) of removing only the inlet plug. The fact that different results could be obtained from the two methods should be considered when interpreting the results.

More details on the sampling design, including the protocols used to collect the samples, are given in the Quality Assurance Project Plan.

8A-1.2 UNIT CHARACTERISTICS

Field sampling in the carpet removal phase took place in eight occupied dwelling units. Table 8A-2 provides information on these units, including the days on which carpet removal and field sampling were performed, the rooms from which carpet was removed, and the approximate square footage of carpet removed.

Details on the recruitment of the units are presented in Chapter 5. Table 5-2 in Chapter 5 contains summaries of pre-activity dust lead loadings from floors and window sills in these units. Chapter 5 also contains discussions of worker characteristics. It should be noted that carpet removal was conducted by professional abatement workers in the four Alameda County units and by homeowners in the four St. Louis units. While the work practice of these two types of workers may differ, they reflect the wide variety of workers conducting R&R activities.

Table 8A-2. Dwelling Units Included in the EFSS Carpet Removal Phase

Study Unit ID	Date of Activity	Unit Description	Type of R&R Workers	Activity Areas (approx. square feet of carpet removed is in parentheses)
1-01	06/22/93	Two-story house; Oakland, CA; 100 years old; peeling ext. paint; rehabbed 15 yrs ago;	Prof. Contractor	Living Room (260) Dining Room (143) Hall (floor 1) (90) Stairway (60) Hall (floor 2) (72)
1-02	06/23/93	Basement apartment; Oakland, CA; 100 year-old building; Int. walls 10 yrs old; Frequent flooding Across from highway;	Prof. Contractor	Living Room (162) Bedroom #1 (127) Bedroom #2 (149)
1-03	06/24/93	Single-story house; Oakland, CA; 50 years old; peeling ext. paint;	Prof. Contractor	Living Room (212) Hallway (34)

Table 8A-2. Dwelling Units Included in the EFSS Carpet Removal Phase (Continued)

Study Unit ID	Date of Activity	Unit Description	Type of R&R Workers	Activity Areas (approx. square feet of carpet removed is in parentheses)
1-04	06/25/93	Two-story duplex; Alameda, CA; 75 years old; Little soil covering;	Prof. Contractor	Living Room (256) Dining Room (206) Stairway (170) Hall (level 2)(100)
2-01	07/13/93	Three-story house; St. Louis, MO; 90 years old; R&R work in progress (2nd floor family room);	Nonprof. Resident	Family Room (224) Bedroom #1 (224)
2-02	07/15/93	Two-story house; Webster Groves, MO; 50 years old;	Nonprof. Resident	Living Room (168) Dining Room (144) Stairway (120)
2-03	07/14/93	Two-story house; St. Louis, MO; 96 years old; Brick exterior;	Nonprof. Resident	Living Room (210) Dining Room (180)
2-05	07/16/93	Two-story house; St. Louis, MO; 60 years old; Brick exterior;	Semiprof. Resident	Office (120) Bedroom (120) Hall (floor 1) (21)

8A-2.0 STUDY RESULTS FOR THE CARPET REMOVAL PHASE

This chapter presents the results of the statistical analysis of environmental sample data from the carpet removal phase of the EFSS study.

Analytical data were available for statistical analysis from all environmental field samples that were collected in the study. Table 8A-1 specifies 35 samples to be collected in each of the eight study units, for a total of 280 samples. Of these proposed samples, 278 were successfully collected. The two uncollected samples were personal air samples from units 2-03 and 2-05, where both units had only a single worker conducting carpet removal activity. In addition, two cassette samples were necessary to monitor personal air over the entire carpet removal activity for both workers in unit 1-01 and for the single worker in unit 2-03. This resulted in three additional samples collected making analytical data available for 281 regular and QC field samples in the carpet removal phase. A summary of the samples collected and data received is displayed in Table CR-1 of Appendix A.

This section presents results and conclusions of the statistical analysis of data from the carpet removal phase. It is organized according to data analysis objectives (see Section 6.1). Supporting discussion and materials are included as Appendices A through D.

8A-2.1 CHARACTERIZE LEAD DISTURBANCE AND POTENTIAL LEAD EXPOSURE

Tables CR-2a through CR-6b in Appendix A contain summaries of lead concentrations in personal and ambient air samples, and physical sample weights, lead loadings, and sample lead concentrations in dust samples. The summaries, presented for each study unit as well as for the entire carpet removal phase, include the arithmetic and geometric means, the standard deviation of the log-transformed data, and the minimum and maximum observed values. As discussed in Chapter 6, statistical analysis of dust lead levels focused primarily on log-transformed lead loadings, or the amount of lead per unit surface area sampled.

The lead disturbance and exposure data observed in the carpet removal phase are characterized below, according to the sample type or component sampled.

8A-2.1.1 Personal Worker Exposures

The duration of carpet removal activity (and of personal air monitoring) across the workers in this phase ranged from 46 to 173 minutes, with an arithmetic mean of 92 minutes. Total activity monitored included preparation, carpet removal, disposal, and cleanup (if any). Monitoring occurred for two workers in six of the eight units, and for one worker in each of the remaining two units, resulting in 14 estimates of personal air lead concentration. The two workers who worked alone in a unit had the longest durations of personal air monitoring in the study (155 and 173 minutes).

The amount of lead collected within the sample cassette(s), the air pump flow rate, and the duration of monitoring were used to calculate a given worker's *task-length average (TLA)* personal air lead concentration in $\mu g/m^3$. The concentrations, each representing instrument data above the detection limit, are plotted in Figure 8A-2 for each study unit. A worker's TLA exposure represents average exposure over the duration of performing the activity.

A boxplot of TLA lead concentrations is included as the rightmost boxplot in Figure 8A-3. Descriptive statistics on personal air lead concentrations are displayed in Tables CR-2a and CR-2b in Appendix A.

Four of the 14 monitored workers (29%) had TLA lead exposures above the OSHA PEL of 50 $\mu g/m^3$. These four results occurred for the two workers in unit 1-01 (results of 51.3 and 59.9 $\mu g/m^3$) and for the two workers in unit 1-04 (results of 128 and 221 $\mu g/m^3$). Activity in both of these units took more than 90 minutes per worker, and the carpets were visually observed as excessively dirty. In contrast, the TLA lead exposure among the other six study units ranged from 0.86 to 8.44 $\mu g/m^3$, well below the OSHA PEL.

The arithmetic mean of the 14 worker TLA lead exposures was 35.9 $\mu g/m^3$. However, because the data are more closely characterized by a lognormal distribution than a normal distribution, the geometric mean of 8.44 $\mu g/m^3$ is considered a better representation of the data, as it estimates the median (or central tendency) of the data distribution.

Figure 8A-2 illustrates that the range of TLA lead concentration data across the different units is greater than the range of data within a unit. This result is further investigated in Section 8A-2.2.4.

8A-2.1.2 Potential Occupant Exposures to Airborne Lead

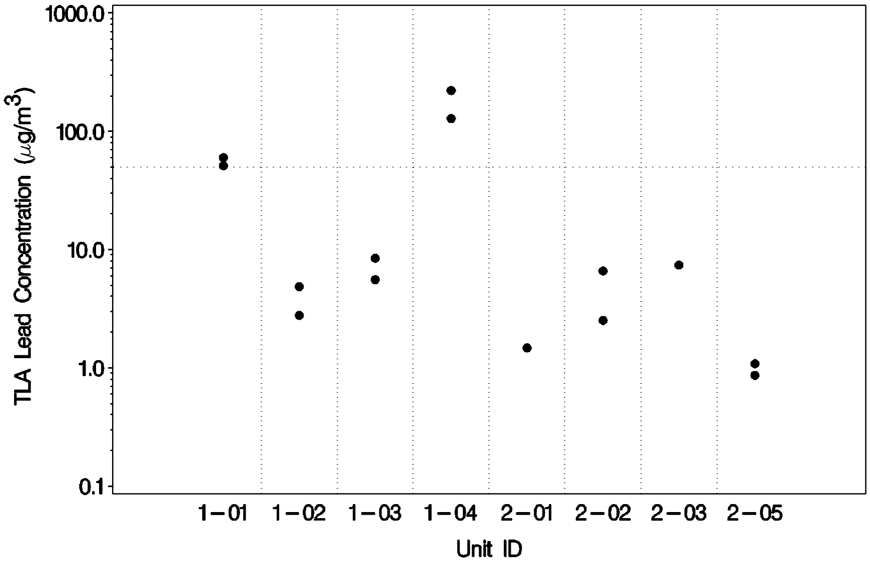
Within each unit, one pre-activity ambient air sample and two during-activity ambient air samples were collected in the carpet removal phase. Each sample was collected for a 120-minute duration (±4 minutes). The amount of lead collected within the sample cassette, the air pump flow rate, and the duration of monitoring were used to calculate lead concentration in $\mu g/m^3$ air for each sample. The lead concentrations are plotted in Figure 8A-4 for each study unit. Boxplots of pre-activity and during-activity ambient air lead concentrations are included in Figure 8A-3. Descriptive statistics on ambient air lead concentrations are displayed with those for the personal worker exposure concentrations in Tables CR-2a and CR-2b of Appendix A. All instrument data on ambient air samples were reported above the detection limit.

The leftmost boxplot in Figure 8A-3 illustrates the range of lead concentrations in ambient air observed during pre-activity periods within each unit. The concentrations were approximately symmetric about the arithmetic mean of 0.10 $\mu g/m^3$, ranging from 0.05 to 0.17 $\mu g/m^3$. The relatively low unit-to-unit variability in these concentrations indicates that the eight study units were relatively homogeneous in their baseline airborne lead levels. Thus, no baseline adjustment was made to the during-activity ambient air concentration prior to statistical analysis.

The lead concentrations for ambient air samples collected during carpet removal activity, summarized by the center boxplot within Figure 8A-3, ranged from 0.06 to 13.4 $\mu g/m^3$ with a geometric mean of 0.33 $\mu g/m^3$. The maximum reading of 13.4 $\mu g/m^3$, flagged by statistical outlier tests (Appendix B), was more than twice that of the next largest reading (5.36 $\mu g/m^3$). The ambient air samples associated with the two largest concentrations were collected within the same two units where the largest worker personal exposure concentrations were observed. However, the other two ambient air concentrations observed in these units were comparable to concentrations in the other units.

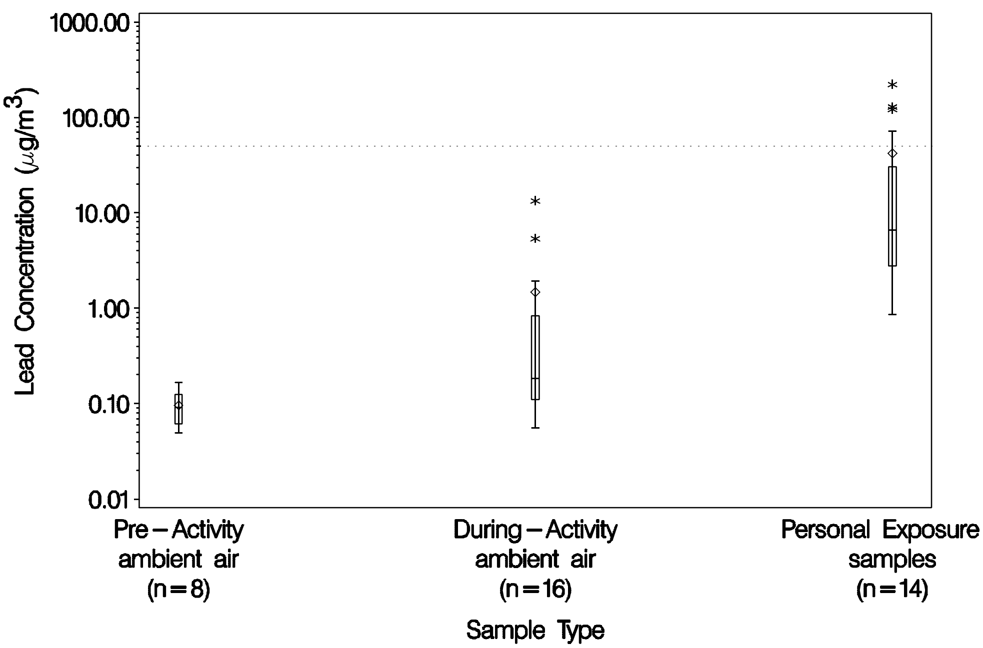
As illustrated in the center boxplot of Figure 8A-3, the arithmetic mean for during-activity ambient air lead concentrations (1.48 $\mu g/m^3$) was heavily influenced by the two largest concentrations. The geometric mean of 0.33 $\mu g/m^3$, more representative of the data than the arithmetic mean, was approximately three times higher than the geometric mean for the baseline (pre-activity) concentrations. However, such low levels as observed here imply that the difference is likely of little practical significance.

For one study unit, the geometric mean ambient air lead concentration during carpet removal was less than the unit's baseline concentration. In contrast, three study units had geometric means exceeding ten times their respective baseline concentrations.



The dotted line at 50 $\mu g/m^3$ represents the OSHA PEL.

Figure 8A-2. Scatterplot of Task-Length Average Personal Exposure Lead Concentrations ($\mu g/m^3$ air) for Each Worker Within Each Study Unit in the Carpet Removal Phase



The dotted line at 50 $\mu g/m^3$ represents the OSHA PEL.

Figure 8A-3. Boxplots of Lead Concentrations ($\mu g/m^3$ air) for Personal Exposure and Ambient Air Samples in the Carpet Removal Phase

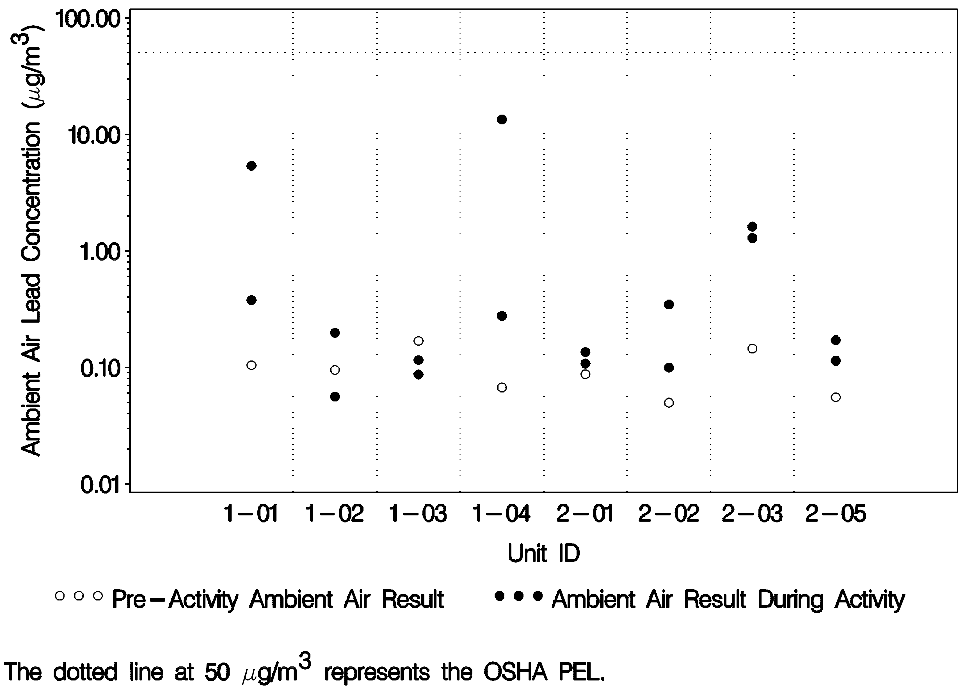


Figure 8A-4. Scatterplot of Ambient Air Lead Concentrations ($\mu g/m^3$ air) Within Each Study Unit in the Carpet Removal Phase

8A-2.1.3 Lead Disturbance and Potential Occupant Exposure to Lead In Dust

In the carpet removal phase, settled dust was collected from three types of flat surfaces to characterize lead disturbance and potential occupant exposures to lead in dust. The three surface types, and when they were sampled, were as follows:

- floor surfaces in adjacent rooms, sampled pre- and post-activity
- SSDCs in adjacent rooms, placed immediately prior to activity and sampled post-activity
- window sills in activity rooms, sampled pre- and post-activity.

The results of analysis on settled dust samples taken from the three surface types are summarized below.

8A-2.1.3.1 Vacuum Dust Samples Taken Pre- and Post-Activity from Floor Surfaces

Vacuum dust samples were collected from one-square-foot areas on floor surfaces prior to the start of the activity and one hour following completion of the activity. One pre-activity and one post-activity sample were taken from adjoining areas in three distinct locations in each unit (Figure 8A-1). Each location was immediately adjacent to an activity room. The difference in lead levels between the adjoining (or paired) pre- and post-activity samples within each location was an estimate of lead exposure in settled dust generated by carpet removal activity.

Results of vacuum floor dust sampling (physical sample weight, lead loading, and lead concentration) are summarized in Tables CR-3a through CR-3d in Appendix A. Appendix A also includes boxplots of lead loadings and concentrations (Figures CR-1a and CR-1b for pre-activity vacuum floor samples; Figures CR-2a and CR-2b for post-activity vacuum floor samples). The geometric mean sample weight increased fourfold from pre- to post-activity (from 0.03 to 0.12 g), while the geometric mean lead concentration more than doubled (from 475 to 1080 µg/g). Larger increases in geometric mean were observed for lead loadings, which increased nine times (from 14.4 to 130 µg/ft^2) from pre- to post-activity. These increases are equivalent to the geometric mean of the ratio of post-activity to pre-activity results at a given sample location.

Lead loading was the measurement of most interest to compare between adjoining pre- and post-activity samples. Lead loadings at a given sample location were expected to increase as a result of the activity. However, at five of the 24 sample locations in the study, lower lead loadings were reported for the post-activity sample than for the adjoining pre-activity sample. This result indicates that spatial variability and/or measurement (analytical) error were considerable for lead loadings on floors. A plot of the difference in loadings between post- and pre-activity samples for each study unit was presented in Figure 7-4 of Chapter 7.

Section 7.1 of Chapter 7 gives an evaluation of the relative merit of using paired pre-/post-activity floor samples versus single samples from SSDCs to measure the amount of lead disturbed during carpet removal. This evaluation concluded that results for dustfall samples from SSDCs were less variable and more highly correlated with results from other sampling media, and were thereby preferred over the pre-/post-activity floor dust results to characterize lead levels. SSDC results are given in the next subsection.

8A-2.1.3.2 Vacuum Dust Samples from Stainless Steel Dustfall Collectors.

In addition to the floor dust samples described above, vacuum dust samples were taken from SSDCs as an alternative measure of lead disturbance. At each floor sample location (Figure 8A-1), a single settled dust sample was collected one hour following completion of carpet removal activities from a SSDC placed adjacent to the post-activity floor dust sample area. For this phase and the window replacement phase, other SSDCs were placed at each floor sample location to address sampling methodology issues. The results of samples from SSDCs taken two hours following completion of carpet removal were presented in Section 7.2 of Chapter 7, where they were compared with the one-hour results. In Section 7.3 of Chapter 7, the one-hour post-activity vacuum results were compared with the wipe dust sampling results from adjoining sample areas. These two sections also provide additional summary and display of the results presented herein.

Tables CR-4a through CR-4d in Appendix A present a summary of the results of vacuum dust sampling from SSDCs one hour following completion of carpet removal activities. Boxplots of lead loadings and concentrations within one-hour post-activity dustfall collectors samples are also included as Figures CR-2a and CR-2b, respectively, in Appendix A. These lead loadings ranged from 2.61 (the detection limit) to 621 µg/ft^2, with a geometric mean of 24.3 µg/ft^2. A plot of the loadings on a unit-by-unit basis is presented in Figure 7-4 in Section 7.1.

8A-2.1.3.3 Vacuum Dust Samples from Window Sill Surfaces Taken Pre- and Post-Activity.

Similar to the floor dust sample approach presented in Section 8A-2.1.3.1, pre- and post-activity dust sampling was performed on two window sill surfaces per unit. The window sill was located in a room where carpet removal activity took place. One-half of the window sill area was sampled for settled dust prior to the start of carpet removal activities, and the other half was sampled one hour following completion of these activities. These sample results provided information on lead exposures in settled dust within an activity room.

Tables CR-5a through CR-5d of Appendix A present data summaries for the pre- and post-activity window sill dust samples. Also in Appendix A are boxplots of lead loadings and concentrations for pre-activity window sill dust samples (Figures CR-1a and CR-1b) and for post-activity window sill dust samples (Figures CR-2a and CR-2b). All window sill dust samples taken in this study contained detectable amounts of lead.

Across all samples, the geometric mean loadings on window sills increased from pre- to post-activity by approximately 58% (from 418 to 661 µg/ft^2), a smaller percentage increase than the 800% increase observed within floor dust. However, for each of these measures, the geometric means at pre- and post-activity were higher for window sills than for floors. The larger data values for window sills (pre-activity) may be one reason for the smaller percentage increases associated with window sills over floor surfaces.

Three of the eight study units had geometric mean values of less than one for the ratio of post- to pre-activity lead loadings on window sills. This indicates that, similar to the finding for floor dust loadings, spatial variability and/or analytical error associated with window sill lead loadings were considerable.

8A-2.2 ASSESS FACTORS OR MEASUREMENTS RELATED TO LEAD DISTURBANCE

In order to characterize the statistical relationship between lead exposure in various media and potential predictors of this exposure, as well as to quantify the various components of total variability in lead exposures, statistical models were developed and fitted to lead measurements obtained in the carpet removal phases. The models were fit to data across all study units using analysis of variance (ANOVA) techniques.

Sections 8A-2.2.1 through 8A-2.2.3 present the results of fitting log-linear models to predict lead measurements from a series of selected covariates. These covariates included pre-activity lead loadings in the carpet removed, pre-activity lead loadings on floors and window sills, and the duration of activity. The models test whether a change in the value of a specific covariate significantly affects (in a multiplicative fashion) the value of the lead measurement being predicted. The forms of these statistical models are found in Section C.1 of Appendix C.

The approach to characterizing variance components associated with a specific type of lead measurement involves fitting the same models described in the previous paragraph, with only the random effects associated with each variance component represented in the model (i.e., covariates are excluded). These models are documented in Section C.2 of Appendix C. When estimable based on the data, variance components in the model include variability associated with sampling from different study units ("unit-to-unit" variability), variability associated with sampling multiple locations or workers within a given unit ("within-unit" or "location-to-location" variability), and variability associated with taking samples from multiple areas within the same location ("within-location" or "replicate-to-replicate" variability). Results of estimating variance components are found in Section 8A-2.2.4.

It should be noted that the model fittings in this section were performed on small numbers of data points having relatively high variability. Therefore, tests for significant covariate effects tended to have low power.

8A-2.2.1 Personal Worker Exposures

Model (CPT-1) in Section C.1 of Appendix C was fitted to 14 log-transformed lead concentrations ($\mu g/m^3$) from samples collected through personal air monitoring of R&R workers during carpet removal activities. These data were plotted in Figure 8A-2 and represent average exposure over the duration of performing an activity. Covariates in the model included:

- geometric mean lead loading in the removed carpet for the unit
- geometric mean pre-activity lead loading on floor surfaces in adjacent rooms of the unit
- geometric mean pre-activity lead loading on window sill surfaces in activity rooms of the unit
- amount of time that carpet removal took place in the unit.

Each of the coefficients associated with the above four (log-transformed) covariates was not significantly different from 0 at the 0.05 level, indicating no evidence exists that these covariates have a significant effect on personal worker exposure. This result could be due to high variability observed in the data, relative to the small sample size.

8A-2.2.2 Potential Occupant Exposures to Airborne Lead

Model (CPT-2) in Section C.1 of Appendix C was fitted to log-transformed lead concentrations ($\mu g/m^3$) in air within adjacent rooms, obtained from ambient air monitoring during carpet removal activities. The sixteen data points obtained from this phase are plotted in Figure 8A-4. Covariates in the ambient air model included:

- geometric mean lead loading in the removed carpet for the unit

- geometric mean pre-activity lead loading on floor surfaces in adjacent rooms of the unit

- geometric mean pre-activity lead loading on window sill surfaces in activity rooms of the unit

- amount of time that carpet removal took place in the unit

- pre-activity ambient air lead concentration in the unit.

Each of the coefficients associated with the above five (log-transformed) covariates was not significantly different from 0 at the 0.05 level. Thus, no significant effect on log-lead concentration in ambient air was observed for these covariates, relative to the small sample size and the level of variability in the data.

8A-2.2.3 Predicting Lead Disturbance and Potential Occupant Exposures to Lead in Dust

Modeling results are presented in the following subsections for models fitted to lead loadings from floor, SSDC, and window sill dust-fall samples. The form of each model, and estimates of model parameters that result from mixed-model analysis of variance, are found in Section C.1 of Appendix C.

8A-2.2.3.1 Vacuum Dust Samples Taken Post-Activity from Floor Surfaces

Model (CPT-3) in Section C.1 of Appendix C was fitted to one-hour post-activity lead loading data ($\mu g/ft^2$) from floor surfaces in adjacent rooms. The covariates used to predict these lead loadings included:

- geometric mean lead loading in the removed carpet for the unit

- pre-activity lead loading on the floor surface adjoining the post-activity sampling area

- geometric mean pre-activity lead loading on window sill surfaces in activity rooms of the unit

- amount of time that carpet removal took place in the unit.

None of the above covariates were found to be significantly associated with post-activity floor lead loading at the 0.05 level when the model was fitted to the study data.

8A-2.2.3.2 Vacuum Dust Samples from Stainless Steel Dustfall Collectors

As with lead loadings from floor surfaces, Model (CPT-3) in Section C.1 of Appendix C was fitted to one-hour post-activity lead loading data ($\mu g/ft^2$) from SSDCs in adjacent rooms. At the 0.05 significance level, similar results were observed with SSDC samples as with the floor dust samples: none of the covariates were significantly associated with SSDC lead loadings.

8A-2.2.3.3 Vacuum Dust Samples Taken Post-Activity from Window Sill Surfaces

Similar to Model (CPT-3), Model (CPT-4) in Section C.1 of Appendix C was fitted to one-hour post-activity lead loading data ($\mu g/ft^2$) from window sill surfaces in activity rooms. The covariates used to predict these lead loadings included:

- geometric mean lead loading in the removed carpet for the unit
- pre-activity lead loading on the window sill surface adjoining the post-activity sampling area
- geometric mean pre-activity lead loading on floor surfaces in adjacent rooms of the unit
- amount of time that carpet removal took place in the unit.

The coefficient associated with lead loading in the adjoining pre-activity window sill sample was significantly different from 0 at the 0.05 level (p=0.044). The estimate of this coefficient was positive, indicating that high lead loadings in the pre-activity sample were associated with high lead loadings in the post-activity sample from the adjoining sample location. None of the other covariates were found to be significantly associated with post-activity window sill lead loading at the 0.05 level.

8A-2.2.4 Estimating Variance Components

The sampling design for the carpet removal phase directed that samples be collected over multiple study units, multiple locations (or workers) within a study unit, and multiple areas within selected locations (i.e., side-by-side QC samples). In this way, key sampling components of total data variability could be isolated and characterized. Therefore, when estimable, the magnitudes of the following variance components were estimated using random-effects analysis of variance:

- "unit-to-unit" variability
- "location-to-location" (or worker-to-worker) variability within a unit
- "replicate-to-replicate" variability within a location.

Variance components were estimated for the following lead measurements:

- pre-activity floor dust lead loadings

- pre-activity window sill dust lead loadings
- 1-hour post-activity floor dust lead loadings
- 1-hour post-activity window sill dust lead loadings
- 1-hour post-activity SSDC vacuum lead loadings
- 1-hour post-activity SSDC wipe lead loadings
- 2-hour post-activity SSDC vacuum lead loadings
- during-activity ambient air lead concentrations
- TLA personal exposure lead concentrations.

Replicate-to-replicate variability could only be estimated for lead loadings on floors and SSDCs as these were the only sample types where side-by-side QC samples were taken.

It is assumed that total variability is the sum of the variabilities associated with the above three components. Any additional variance components are confounded within one or more of these components.

Table 8A-3 contains the estimated total variability in log-transformed lead measurements, plus estimates of the variance components, for each sample type. The results represent variability in the log-domain, so they are expressed in log units.

The estimated variance components for the settled dust sample types in Table 8A-3 (i.e., the first seven rows of the table) were obtained from fitting a random effects analysis of variance model (Model (C-2) of Appendix C) to data from regular and side-by-side QC samples. Results for these sample types indicate that the estimated total variability was approximately one-third to one-half of the estimated mean of the log-transformed measurements. For pre-activity floor and window sill dust samples and post-activity window sill dust samples, the majority of total variability in the data was attributed to results from different units. Variable results in side-by-side 2-hour dustfall collector dust samples led to high replicate-to-replicate variability for this sample type. For the post-activity floor dust and 1-hour post-activity dustfall collector dust samples (both vacuum and wipe), more variability was attributed to differing sampling locations within a unit than to any other variance component.

Nearly all of the variability in log-transformed personal air lead concentrations was attributable to variability across the different study units. This indicates that workers involved in carpet removal at a given site are exposed to similar lead levels within their breathing zones. In contrast, almost two-thirds of the total variability in ambient air concentrations was attributable to differences between the two samples within a study unit.

Table 8A-3. Estimates of Total Variability and its Estimable Components in Log-Transformed Lead Measurements by Sample Type for the Carpet Removal Phase

Sample Type[1]	Model-Estimate of Mean Log Measurement[2]	Square Root of Estimated Total Variability[3]: σ_{tot}	Square Roots of Estimated Variance Components[4]		
			Unit-to-unit (σ_U)	Location-to-location within a unit (σ_L)	Replicate-to-replicate within a location (σ_R)
Pre-Activity Floor Dust	2.69	1.99	1.76 (79%)	0.00 (0.0%)	0.92 (21%)
Pre-Activity Window Sill Dust	6.03	2.39	2.21 (85%)	0.92 (15%)	---
1-hr Post-Activity Floor Dust	4.92	1.71	0.82 (23%)	1.30 (57%)	0.76 (20%)
1-hr Post-Activity Window Sill Dust	6.49	2.28	1.90 (70%)	1.25 (30%)	---
1-hr Post-Activity SSDC Dust (vacuum)	3.08	1.49	0.74 (25%)	1.02 (47%)	0.79 (28%)
1-hr Post-Activity SSDC Dust (wipe)	3.33	1.47	0.68 (22%)	1.14 (60%)	0.63 (18%)
2-hr Post-Activity SSDC Dust (vacuum)	3.43	1.53	0.94 (38%)	0.00 (0.0%)	1.20 (62%)
Personal air	2.02	1.77	1.73 (95%)	0.39 (5%)	---
Ambient air	-1.12	1.60	0.97 (37%)	1.26 (63%)	---

(1) SSDC = Stainless steel dustfall collectors.
(2) Estimates of the intercept term from the random effects model.
(3) Total variability = $\sigma^2_{tot} = \sigma^2_U + \sigma^2_L + \sigma^2_R$, where these parameters were estimated from the random effects model using restricted maximum likelihood.
(4) Number in parentheses is the percent of total variability (σ^2_{tot}) represented by the given variance component (the square of the tabled value).

8A-2.3 EVALUATE DIFFERENT MEDIA AND METHODS AS INDICATORS OF EXPOSURE

To quantify the extent of linear relationship between lead exposure estimates from different sample types and sample collection approaches, Table 8A-4 presents Pearson correlation coefficients among pairs of ten variables that measure lead loadings in various media through the study. These variables include:

- pre-activity dust lead loadings on floors, window sills, and carpet
- 1-hour post-activity dust lead loadings on floors and window sills (collected via vacuum), and SSDCs (collected via vacuum and wipe)
- 2-hour post-activity dust lead loadings on SSDCs (collected via vacuum)
- lead concentrations in personal air and ambient air samples collected during carpet removal activity.

For each variable, the geometric mean was calculated for each of the eight study units. Pearson correlation coefficients were calculated on these geometric means for each pair of variables. Note that low correlation between two variables does not necessarily mean that no relationship exists between them, but rather that the relationship is not linear in nature.

Correlations of greater than 0.9, indicating a high positive linear relationship, were observed in lead loadings between the following pairs of dust collection methods:

- SSDCs sampled at one-hour post-activity using wipe techniques versus the same sampling approach using vacuum techniques
- SSDCs sampled at one-hour post-activity using wipe techniques versus SSDCs sampled at two-hours post-activity using vacuum techniques
- SSDCs sampled using vacuum techniques at one-hour post-activity versus that taken at two-hours post-activity.

Table 8A-4. Pearson Correlations[1] of Geometric Mean Lead Loadings Between Pairs of Sample Types and Approaches in the Carpet Removal Phase

Sample Type[2]	Pre-Activity			Post-Activity					Air	
	Floor	Window Sill	Carpet to be Removed	Floor	Window Sill	S.Steel Dustfall Collector: 1 hr. Wipe	S.Steel Dustfall Collector: 1 hr. Vacuum	S.Steel Dustfall Collector: 2 hr. Vacuum	Ambient Air	Personal Exposure
Pre-Act. Floor	1.00	-0.06	0.72	0.42	0.20	-0.30	-0.26	-0.27	-0.41	-0.33
Pre-Act. Window Sill		1.00	-0.33	-0.21	0.77	-0.14	-0.14	-0.03	0.32	-0.23
Pre-Act Carpet			1.00	0.34	-0.35	-0.30	-0.23	-0.29	-0.21	-0.18
Post-Act. Floor				1.00	-0.14	0.70	0.70	0.73	0.41	0.67
Post-Act. Window Sill					1.00	-0.14	-0.09	-0.06	0.08	-0.25
1-hr. Post-Activity SSDC (wipe)						1.00	0.98	0.99	0.72	0.97
1-hr. Post-Activity SSDC (vac.)							1.00	0.97	0.77	0.98
2-hr. Post-Activity SSDC (vac.)								1.00	0.78	0.95
Ambient Air									1.00	0.78

[1] Correlations calculated on geometric means calculated for each study unit (n=8). All correlations greater than 0.71 are significantly different from zero at the $\alpha=0.05$ level.
[2] SSDC = Stainless steel dustfall collectors.

In addition, correlations of greater than 0.9 were observed between personal worker exposure lead concentrations and dustfall lead loadings obtained from the following sampling approaches:

- SSDCs sampled at one-hour post-activity using wipe techniques
- SSDCs sampled at one-hour post-activity using vacuum techniques
- SSDCs sampled at two-hours post-activity using vacuum techniques.

One expected to see high correlations between one-hour and two-hour post-activity dust sample results and between vacuum and wipe dust sample results. However, the high correlation between personal worker exposure and loadings in dust on SSDCs indicated that samples collected from the dustfall collectors may contain more information on lead exposed by carpet removal than do pre- versus post-activity floor dust samples.

Correlations between post-activity floor dust lead loadings and other loadings from dust collection methods were in the range of 0.7. While these correlations were lower than that documented in the previous paragraph, they were still significantly different from 0 at the 0.05 level. Significant correlation was also observed between personal worker and ambient air concentrations (0.78).

Correlations between pre-activity dust lead loadings from carpet to be removed and the other variables were quite low and generally not significantly different from zero. Pre-activity lead loadings versus post-activity lead loadings from adjoining sampling locations had moderately positive correlation: 0.42 for floors and 0.77 for window sills.

8A-2.4 SUMMARY OF RESULTS

Following are the major results of the R&R carpet removal phase:

- Lead concentrations in personal air samples exceeded the OSHA PEL (50 $\mu g/m^3$) in four of the 14 workers sampled and in two of the eight study units. Other than these four results, personal air lead concentrations were less than 10 $\mu g/m^3$. The dominant variance component of these data appeared to be the result of sampling in different study units.

- Lead concentrations in ambient air samples collected during carpet removal activity ranged from 0.06 to 3.38 $\mu g/m^3$, with a geometric mean of 0.33 $\mu g/m^3$.

- The difference in lead loadings from vacuum floor dust samples taken pre- and post-activity had high variability in this study. In contrast, lead loadings from SSDC samples had substantially lower variability. In addition, SSDC lead loadings had a very high correlation with personal exposure lead concentrations. This indicates that the dustfall collectors may be a more accurate and precise measure of the lead disturbed by carpet removal than the difference in pre- and post-activity floor dust samples.

- Within the vacuum floor dust samples, the geometric mean lead loadings increased nine times (from 14.4 to 130 $\mu g/ft^2$) from pre- to post-activity. However, a wide range of values, including negative results, was observed in post- minus pre-activity floor dust lead loadings at a given location (-195 to 6130 $\mu g/ft^2$).

- Lead loadings from SSDC samples ranged from 2.61 to 621 $\mu g/ft^2$, with a geometric mean of 24.3 $\mu g/ft^2$. High unit-to-unit variability was observed with these data.

- Generally, the covariates considered in the statistical modeling to predict log-transformed lead loadings in various sample types were not significant at the 0.05 level, partially due to the small sample sizes considered. Pre-activity lead loadings on window sills had a significant effect (at the 0.05 level) on post-activity window sill lead loadings.

- Significantly positive linear correlation was observed between personal worker exposure concentrations and dust sample loadings from SSDCs, whether wipe or vacuum techniques were used. This implies that, for carpet removal, dustfall samples may provide some information on potential lead concentrations in personal exposure samples from workers, and vice versa.

8B-1.0 STUDY DESIGN IN THE WINDOW REPLACEMENT PHASE

Chapter 4 presented aspects of the EFSS study design that were common across all phases. This section presents specific details of the study design as it was applied in the window replacement phase.

8B-1.1 SAMPLING DESIGN FOR THE WINDOW REPLACEMENT PHASE

The sampling design for the window replacement phase was developed to address each of the objectives presented in Section 6.1. Table 8B-1 presents the proposed types and numbers of environmental field samples (both regular and QC samples) collected within each of four dwelling units. The types of samples included the following:

- ***Personal exposure samples*** taken during the activity

- ***Ambient air samples*** taken during the activity

- ***Settled dust samples*** taken before the activity ***from the wells of three windows to be removed***

- ***Paint chip samples*** taken after the activity ***from interior and exterior components of three removed windows***

- ***Settled dust samples*** taken before and after the activity ***from floor surfaces at varying distances from three windows to be removed***

- ***Settled dust samples*** taken following completion of the activity ***from stainless steel dustfall collectors (SSDCs)*** placed on the floor immediately prior to the activity adjacent to and at 6 feet from each of three windows to be removed.

In addition to these sample types, plastic tarpaulins were to be placed on the ground directly beneath the three selected windows on the exterior of the unit, in order to collect dust and other settled matter which settles on the exterior ground as a result of window replacement. However, exterior dust samples collected from these tarpaulins were archived for future analysis and, therefore, were not included in the analysis in this phase.

In each unit, three windows slated to be removed were considered as the basis for each of the settled dust and paint chip sample types. The windows were selected to represent all approaches to window replacement, all types of windows being replaced, and the various lead levels which could be encountered in the activity at the given unit. In addition, windows were selected based on logistic issues, such as the availability of floor surface at specified distances from the window for settled dust sampling. Figure 8B-1 displays the layout of settled dust sampling locations at each selected window.

Table 8B-1. Numbers and Types of Environmental Samples (Regular and QC) Proposed in the EFSS Window Replacement Phase Within Each Study Unit

Regular Samples

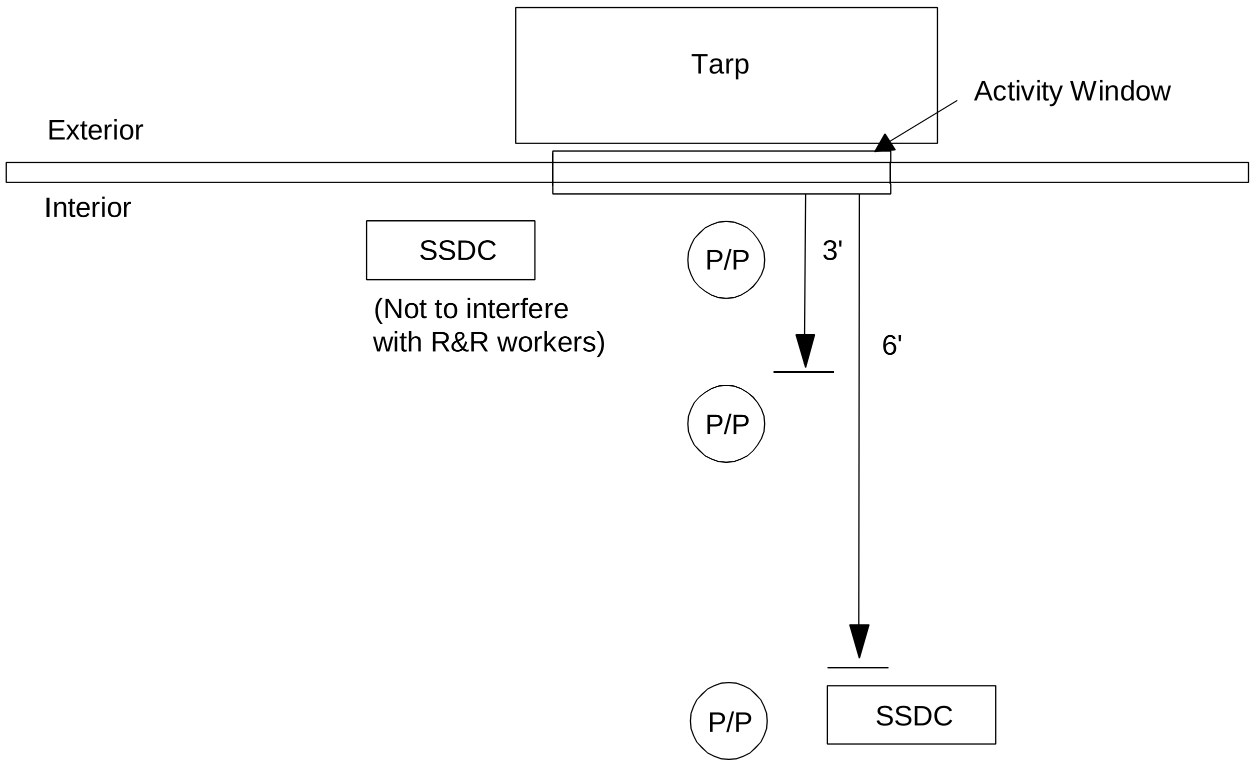
When Sample Was Taken	Sample Collection Method	Sample Type/Location[(1)]	Number Proposed
Pre-Activity	Vacuum	Settled dust (Window well)	3
		Settled dust (Floor)	9
	Ambient air pump	Ambient air	1
During Activity	Personal air pump	Personal air (R&R workers)	2
	Ambient air pump	Ambient air (Adjacent room)	2
1-hr. Post-Activity	Vacuum	Settled dust (Floor)	9
		Settled dust (SSDC)	6
2-hr. Post-Activity	Vacuum	Settled dust (SSDC)	1
30-min. Post-Activity	Tarpaulin	Debris deposit (Exterior)[(2)]	3
Post-Activity	Chipping	Paint chip (Interior Window Sash)	3
		Paint chip (Exterior Window Sash)	3
		TOTAL	42

Field QC Samples

When Sample Was Taken	Sample Collection Method	Sample Type/Location[(1)]	Number Proposed
Pre-Activity	Vacuum	SBS settled dust (Floor)	1
		Field blank	1
	Ambient air pump	Field blank	1
	Personal air pump	Field blank	1
1-hr. Post-Activity	Vacuum	SBS settled dust (Floor)	1
		SBS settled dust (SSDC)	1
		TOTAL	6

(1) SSDC = stainless steel dustfall collector.
SBS = sample taken side-by-side with a regular sample.
(2) Samples archived; no analysis performed on these samples.

Immediately prior to the start of each window replacement, the field team collected one vacuum dust sample within a one-square-foot area in each of the three floor sampling locations represented by "P/P" in Figure 8B-1. The three locations are at 0, 3, and 6 feet perpendicular to the window. Lead content within a pre-activity floor dust sample represented a baseline lead level at the given location.



P/P = locations where pre- and post-activity dust samples were taken from the floor surface.

SSDC = locations where stainless steel dustfall collectors were positioned.

Figure 8B-1. Settled Dust Sampling Locations at a Selected Window in the Window Replacement Phase

A pre-activity ambient air sample was taken to obtain an estimate of baseline airborne lead in the unit. As the ambient air samples took two hours to collect, the pre-activity ambient air sample was sometimes taken on the day prior to window replacement.

Also prior to window replacement activities, the field team collected a vacuum dust sample from the window wells of the selected windows. This sample was taken to assess the level of available lead in dust from the given window, for a statistical evaluation of settled dust lead levels resulting from the activity.

To evaluate how lead disturbance resulting from window replacement is associated with lead levels in paint, paint chip samples were taken from the interior and exterior components of the three windows being monitored. These samples were taken after the window was removed.

During window replacement activities, personal and ambient air samples were collected. Personal exposure sampling was conducted on up to two R&R workers per dwelling unit to measure lead levels in air within the workers' breathing zones while they were performing window replacement. Ambient air samples were collected in two rooms adjacent to one or more "activity rooms" (i.e., rooms where window replacement took place) to measure lead levels in air dust that could be inhaled by others present. No window replacement took place in rooms where ambient air sampling occurred. When possible, doors to rooms where ambient air samples were being collected were closed while window replacement was being performed.

Post-activity samples were taken of settled dust from floors and from one-square-foot SSDCs positioned immediately prior to the start of the activity. At one hour following completion of all window replacement activities (including cleanup), one vacuum dust sample was collected in each of the three "P/P" sampling locations in Figure 8B-1, from an area adjacent to the pre-activity vacuum floor dust sample area at that location. Results from this sample were adjusted for the pre-activity sample result at that location. Also at one-hour post-activity, one vacuum dust sample was collected from a SSDC positioned at 6 feet perpendicular to the window.

A SSDC was also placed as close to each selected window as possible without disrupting the normal activity of the R&R workers. To represent a "worst-case" scenario, a vacuum dust sample was to be taken from this dustfall collector one hour following window replacement but prior to the start of cleanup, or immediately prior to cleanup if the delay factor was unrealistic.

Finally, to determine whether lead "fallout" in settled dust increased after two hours following the activity compared to one hour, a second SSDC was placed 6 feet from one of the three selected windows in a unit. This SSDC was positioned adjoining the SSDC for the one-hour post-activity vacuum sample. A vacuum dust sample was collected two hours following the activity and cleanup. Results of comparison between one-hour and two-hour post-activity sample lead loadings are found in Chapter 7.

The nature of the field work and the number of samples made it impossible to collect a sample at precisely one hour or two hours following completion of window replacement. Settled dust samples were collected in a time frame spanning 15 minutes before to 40 minutes after the scheduled time. Analysis of the effect of the time of sampling on the lead loading results was given in Section 7.2 of Chapter 7.

Of the 48 environmental samples specified in Table 8B-1 within each dwelling unit, six were field quality control (QC) samples. One field blank was taken prior to the start of window replacement for every sampling medium (vacuum dust, personal air, ambient air) to determine the extent to which contamination was present during sample collection. At one window, side-by-side vacuum dust samples were taken from the floor surface and from a SSDC at 6 feet from the window to allow sampling and measurement error to be characterized and variability in results between two adjoining sample areas to be observed.

More details on the sampling design, including the protocols used to collect the samples, are found in the Quality Assurance Project Plan.

8B-1.2 UNIT CHARACTERISTICS

Table 8B-2 lists the four dwelling units included in the window replacement phase, the activity dates, and the rooms ("activity areas") within each unit that contained the three windows selected for environmental sampling. The activity areas in two units were occupied, while the activity areas of the other two units (Units 3-01 and 4-01) had been vacant and neglected for some time.

Table 5-2 in Chapter 5 contains summaries of pre-activity lead loadings in these units. Chapter 5 also contains discussion of worker characteristics.

Table 8B-2. Dwelling Units Included in the EFSS Window Replacement Phase

Study Unit ID	Date of Activity	Unit Description[1]	Type of R&R Workers	Activity Areas[2]
1-01	8/24/93	Two-story house; Piketon, OH; 100 years old; new siding; 1968 remodeling;	Professional Contractor	Den Kitchen Bathroom
2-01	9/14/93	Two-story house; Columbus, OH; no age estimate; peeling ext. paint;	Professional Contractor	2 Bedrooms Hall
3-01	9/15/93	One-story business; Richwood, OH; 150 years old; brick/wood/concrete exterior; activity area vacant	Self-Employed Professional	Large Room
4-01	12/22/93	Second-floor apt.; Plain City, OH; 100 years old; peeling ext paint; activity area vacant	Self-Employed Professional	2 Living Rooms Bedroom

(1) All windows to be removed had painted wood frames.

(2) Except for unit 3-01, one window within each specified room (activity area) was selected for monitoring dustfall and paint lead levels. Other windows may also have been replaced within these rooms. Unit 3-01 was not divided into rooms, so all three selected windows were in the same large room.

8B-2.0 STUDY RESULTS FOR THE WINDOW REPLACEMENT PHASE

This chapter presents the results of the statistical analysis of environmental sample data from the window replacement phase of the EFSS.

Analytical data were available for statistical analysis from all environmental field samples that were collected in the window replacement phase. Table 8B-1 specifies 48 samples from each of the four study units, for a total of 192 samples. Of these proposed samples, 186 were successfully collected. The 6 uncollected samples included three tarpaulin samples and three floor dust samples. In each unit, it was necessary to replace cassette samples during personal air monitoring, resulting in additional cassette samples for analysis. One cassette had to be replaced during ambient air sampling in unit 2-01 when a failed air pump was replaced, resulting in an additional area air cassette sample. One additional tarpaulin sample and one additional exterior paint chip sample were collected at unit 2-01, and one additional two-hour post-activity SSDC sample at 6 feet from the window was collected at unit 3-01. (This latter sample was eliminated from the statistical analysis because the SSDC was not placed until after cleanup). Analytical data were available for a total of 193 regular and QC field samples in the window replacement phase. A summary of the samples collected and data received is displayed in Table WR-1 of Appendix A.

This section presents results and conclusions of the statistical analysis of data from the window replacement phase. It is organized according to the method of organizing statistical objectives given in Section 6.1. Supporting discussion and materials are included as Appendices A through D.

8B-2.1 CHARACTERIZE LEAD DISTURBANCE AND POTENTIAL LEAD EXPOSURE

Tables WR-2A through WR-6b in Appendix A contain summaries of lead concentrations in personal and ambient air samples, and physical sample weights, lead loadings, and lead concentrations in dust and paint chip samples. The summaries, presented for each study unit as well as for the entire window replacement phase, include the arithmetic and geometric means, the standard deviation of the log-transformed data, and the minimum and maximum observed values. As discussed in Chapter 6, statistical analysis of dust lead levels focused primarily on log-transformed lead loadings, or the amount of lead per unit surface area sampled.

The lead disturbance and exposure data observed in the window replacement phase are characterized below, according to the sample type or component sampled. Summaries are presented for personal exposure, area air, and dustfall samples. Paint chip sample results are summarized in Tables WR-6a and WR-6b, and Figure WR-3 of Appendix A.

8B-2.1.1 Personal Worker Exposures

The duration of personal air monitoring across the workers in this study ranged from 181 to 492 minutes, with an arithmetic mean of 335 minutes. Monitoring was started immediately before area preparation began, and it continued through window replacement, disposal, and cleanup activities (if any). Two workers were monitored in each of the four study units, resulting in eight estimates of average personal air lead concentrations (in µg lead/m^3 of air) over the duration of activity (referred to as task-length averages (TLA)).

The task-length average lead concentrations from the personal air monitors are plotted for each study unit along with lead concentrations from ambient air monitors in Figure 8B-2. All concentrations represent instrument data above the detection limit. Descriptive statistics on personal air lead concentrations are displayed in Tables WR-2a and WR-2b in Appendix A.

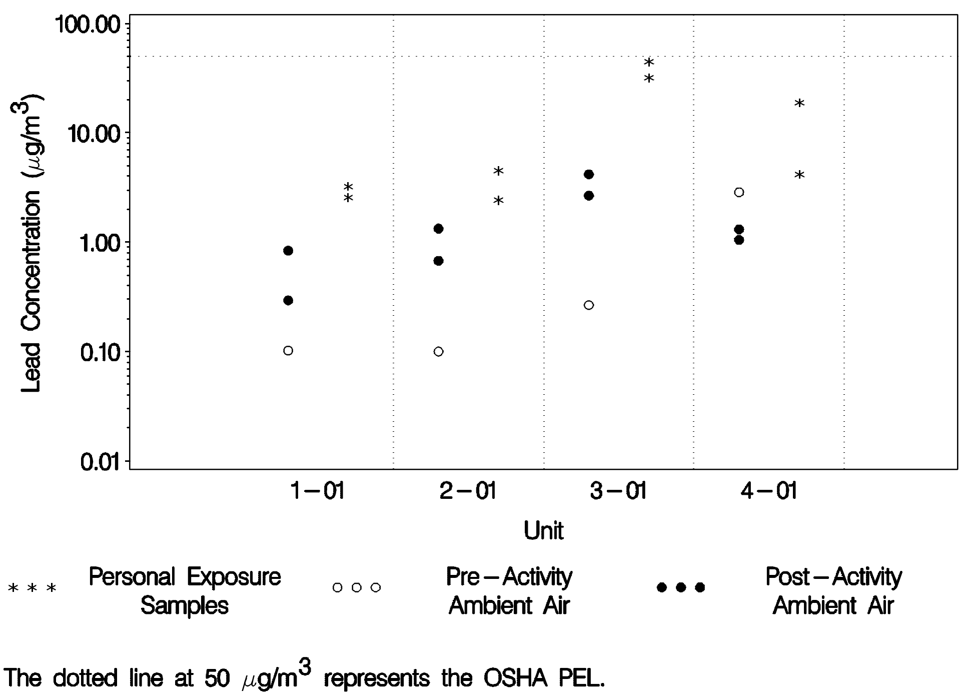


Figure 8B-2. Task-Length Average Personal Air Lead Concentrations, and Ambient Air Sample Lead Concentrations, Within Each Study Unit in the Window Replacement Phase

None of the eight monitored workers had personal air levels above the OSHA PEL of 50 µg/m^3. Personal air lead concentrations among the four study units ranged from 2.41 to 44.3 µg/m^3, with a geometric mean of 7.48 µg/m^3.

Figure 8B-2 illustrates that the variability among TLA personal exposure data from different units is greater than the variability among the two data points within a unit, indicating that workers within a unit are exposed to similar levels of lead while workers in different units are generally exposed to much different levels of lead. Further statistical investigation of these two components of variability is presented in Section 8B-2.2.4.

8B-2.1.2 Potential Occupant Exposures to Airborne Lead

In each study unit, one ambient air sample was collected prior to the activity and two ambient air samples were collected during the window replacement activity. Pre-activity samples were collected over a 120-minute interval (±4 minutes), except for one unit in which the sample was collected over a 100-minute period. The sampler flow rate for pre-activity ambient air samples was 12.5 L/min in three of the four units. In the fourth unit (4-01), which had no electricity, a personal exposure sampler with a flow rate of 4 L/min was used. The ambient air samples obtained during the window replacement activities were collected over intervals ranging from 256 minutes to 486 minutes. The flow rates for all 8 activity samples were approximately 4 L/min.

The amount of lead collected within the sample cassette, the air pump flow rate, and the duration of monitoring were used to calculate lead concentration in $\mu g/m^3$ air for each sample (see Figure 8B-2). Descriptive statistics on ambient air lead concentrations are displayed with the personal worker exposure lead concentrations in Tables WR-2a and WR-2b of Appendix A. All instrument data on ambient air samples were reported above the detection limit.

Figure 8B-2 illustrates the range of ambient air data observed during pre-activity periods within each unit. Ambient air samples had lead levels that ranged from 0.10 to 2.86 $\mu g/m^3$. The highest level occurred in the unit where the air flow rate was lowest. Lead levels for ambient air samples collected during window replacement activity ranged from 0.29 to 4.16 $\mu g/m^3$, with a geometric mean of 1.16 $\mu g/m^3$. The two highest ambient air levels were collected in the same unit where the personal air levels were the greatest.

8B-2.1.3 Lead Disturbance and Potential Occupant Exposure to Lead in Dust

In the window replacement phase, settled dust was collected from three types of flat surfaces to characterize lead disturbance and potential hazards to occupants from lead in dust. These three surface types, and when they were sampled in the study, were as follows:

- floor surfaces, sampled pre- and post-activity
- stainless steel dustfall collectors (SSDCs), placed immediately prior to activity and sampled post-activity
- window wells in activity rooms, sampled pre-activity.

Dust samples from each surface type were collected on and in the vicinity of three windows being removed. Section 8B-1 provides more detail about the sampling procedures, including the locations and timing of each sample collected.

The results of analysis on settled dust samples taken from each of the above three surface types are summarized below.

8B-2.1.3.1 Vacuum Dust Samples Taken Pre- and Post-Activity from Floor Surfaces

Vacuum dust samples were collected from one-square-foot areas on floor surfaces prior to the start of activity and at one hour following completion of activity. Sample locations were at 0, 3, and 6 feet from a window being removed. At each location, one pre-activity and one post-activity sample were taken from adjoining areas (Figure 8B-1). For each distance, results of vacuum dust sampling (physical sample weight, lead loading, and lead concentration) directly from the floor surface are summarized by unit and across all units in Tables WR-3a through WR-3l in Appendix A. Boxplots of lead loadings and concentrations are included in Figures WR-1a and WR-1b for pre-activity vacuum floor samples and in Figures WR-2a and WR-2b for post-activity vacuum floor samples.

Figure 8B-3 shows a scatterplot of the post-activity lead loadings versus the pre-activity floor lead loading at the same window. The plotting symbols indicate the distance from the window at which the samples were collected. Chapter 7 indicated that 9 of the 35 pre/post sample pairs (non-QC samples) had lower lead loadings reported for the post-activity sample, reflecting high spatial variability and/or analytical error in the data. The geometric mean lead loadings (across all units) for regular and side-by-side QC samples taken pre- and post-activity were 1920 and 3910 µg/ft^2 at 0 feet, 491 and 1290 µg/ft^2 at 3 feet, and 334 and 878 µg/ft^2 at 6 feet, respectively. Thus, in spite of high variability, the geometric means of the lead loadings (plotted in Figure 8B-4) indicate that there is a two- to three-fold increase in the lead loadings from pre- to post-activity samples. These results confirm the expectation that the settled dust lead loading decreases (for both pre-activity and post-activity samples) as the distance from the window increases, implying that proximity to the window influences baseline lead loadings as well as the post-activity loadings.

8B-2.1.3.2 Vacuum Dust Samples from Stainless Steel Dustfall Collectors

In addition to the floor dust samples described above, vacuum dust samples were taken from SSDCs as an alternative measure of lead disturbance. Immediately prior to the start of window replacement, SSDCs were placed at 0 feet and at 6 feet from each window to be removed, and dust samples were collected from them at one hour post-activity. At one window, an additional SSDC was placed at 6 feet for sampling at two hours post-activity.

Tables WR-4a through WR-4d in Appendix A summarize physical weights, lead loadings, and lead concentrations in samples from SSDCs collected at one hour and two hours following completion of window replacement activities. The two-hour post-activity sample results were compared with the one-hour results in Section 7.2 of Chapter 7. Also in Appendix A, boxplots of lead loadings and concentrations for the one-hour post-activity dustfall collector samples are presented in Figures WR-2a and WR-2b, respectively.

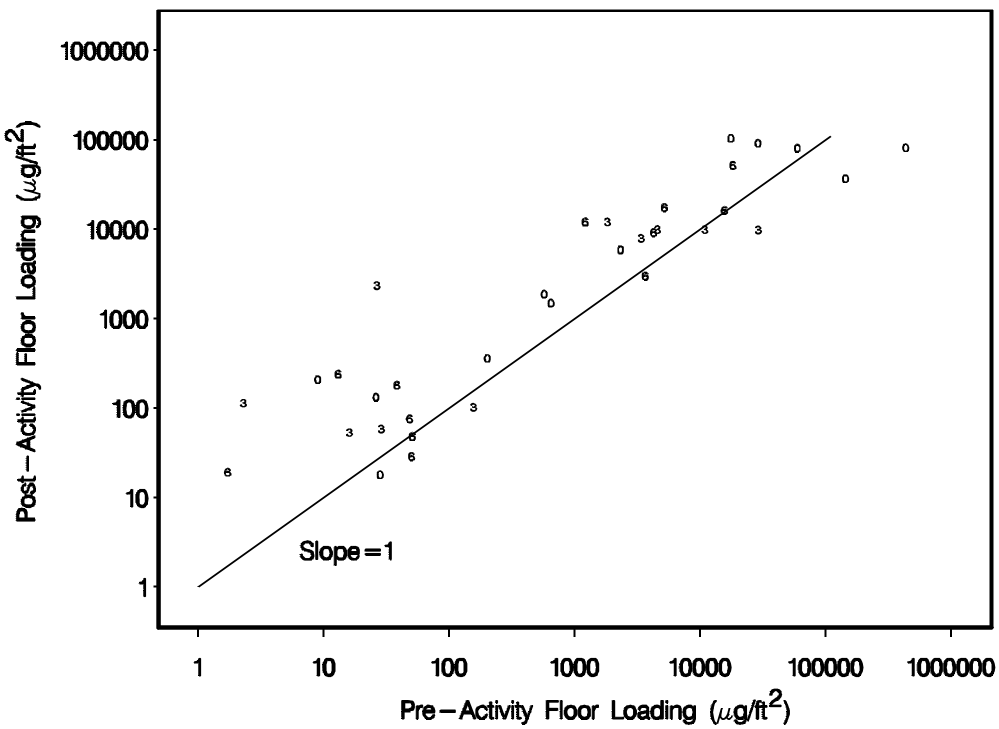


Figure 8B-3. Lead Loadings for Post-Activity Versus Pre-Activity Floor Samples at 0, 3, and 6 Feet from the Windows

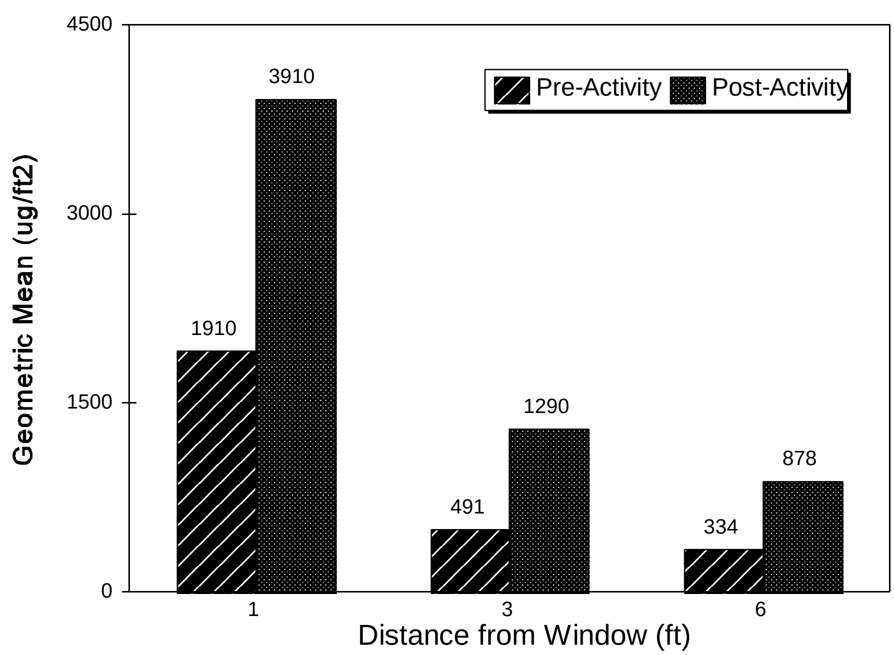


Figure 8B-4. Geometric Mean Lead Loadings from Floor Surfaces as a Function of Distance from the Window

Lead loadings from dust collected on the SSDCs at 0 feet from the windows ranged from 3100 to 331,000 µg/ft^2, with a geometric mean of 24,700 µg/ft^2. At 6 feet from the windows, the lead loadings among regular and side-by-side QC samples ranged from 15.4 to 4160 µg/ft^2, with a geometric mean of 241 µg/ft^2.

As discussed in Chapter 7, the SSDC method yields a better measure of lead disturbed by the window replacement activity than the difference between post- and pre-activity lead loadings. Therefore, the SSDC measurements were used in creating an estimate of the lead disturbed by window replacement that takes into account the "dustfall gradient," or the decrease in dust-lead as distance from the activity increases. As introduced in Chapter 6, the dustfall gradient is characterized by estimating the amount of lead (in µg) that settles within a 6-foot by 1-foot rectangular region lying perpendicular to the window. Section C.5 of Appendix C presents the approach to obtaining this estimate, its variability, and associated 95% confidence intervals.

Table 8B-3 presents estimates of the average amount of lead disturbed in the 6-foot by 1-foot gradient. The table contains estimates across all units and for each unit. The average estimated lead disturbed across all four units was 46,300 µg, with a 95% confidence interval of (251; 92,300) µg. These results were obtained by a single fitting of the model in Section C.5 of Appendix C to all dust-lead results across all units. Average total lead estimates for the individual units ranged from 15,500 µg to 96,000 µg. Because only three data points per unit were available to calculate average lead amounts, the results for individual units were based on calculating a separate estimate of lead disturbance in the 6-foot by 1-foot gradient calculated for each of the three windows in a unit and averaging these three estimates. This difference in method from the approach used when considering all units did not allow confidence intervals to be calculated for the individual units.

Table 8B-3. Estimates of the Average Amount of Lead Disturbed by Window Replacement Activity in a 6' by 1' Rectangular Region Perpendicular to the Window

Unit ID	Lead Disturbed in a 6' by 1' Gradient (µg)	95% Confidence Interval (µg)	
		Lower	Upper
All 4 units	46,300	251	92,300
1-01	15,500		
2-01	51,800		
3-01	96,000		
4-01	66,000		

Note: The methods for calculating lead amounts within each unit was slightly different from the method used to calculate average lead amount across all units.

Further discussion of the dustfall gradient approach to comparing lead exposures among various activities is given in Chapter 9.

8B-2.2 ASSESS FACTORS OR MEASUREMENTS RELATED TO LEAD DISTURBANCE

To characterize the statistical relationship between lead exposure in various media and external predictor variables, as well as unit-to-unit and within-unit variability in the lead exposure data, statistical models were developed and fitted to lead loading data in this phase using analysis of variance (ANOVA) techniques. The models were fitted to lead loading data across all study units.

Appendix C contains a detailed presentation of the statistical models, including tables of the parameter estimates and their standard errors. Models are fit to the personal-air, ambient-air, and SSDC sample results as well as to the estimates of lead disturbed in a 6-foot by 1-foot gradient from a removed window. Because pre-activity floor lead loadings often exceed post-activity floor loadings, floor loading data were not modeled. Covariates considered include lead loadings from all of the pre-activity samples (floor dust, window well dust, and paint chip) taken during the window replacement phase.

In the window replacement phase, model fittings were performed on relatively small numbers of data points. Thus, only one or two covariates were considered at any one time in modeling lead loadings. In addition, because the few data points had relatively high variability, the tests for significant covariate effects tended to have low power. Therefore, findings of statistically insignificant results may indicate no effect or merely little power to detect the effect. Conversely, the relatively large number of separate model fittings required by the small number of data points leads to a concern over the effect of multiple tests on the true significance level of statistically significant parameters. Due to the exploratory nature of the model fitting in this phase, alpha levels for statistical significance were not adjusted for the effect of multiple tests.

ANOVA models also characterized error in log-transformed lead loading data from three sources: unit-to-unit variability, within-unit (window-to-window) variability, and replicate-to-replicate variability at a window. Unit-to-unit variability is estimable because sampling was done at four study units. Within-unit variability is estimable because samples were collected at three windows within each study unit. For some sample types, replicate-to-replicate variability, representing variability in sampling at the same physical location, was estimable due to taking two side-by-side samples at the same distance from a window.

A summary of the results of pre-activity vacuum dust samples from window well surfaces is presented in Section 8B-2.2.1. Results of the model fits on during- and post-activity sample data are presented in Section 8B-2.2.2. In addition, the relationship between dustfall lead loadings and the distance from the windows is examined using the results obtained from SSDCs. The results of fitting the model relating lead exposure to distance are contained in Section 8B-2.2.3. Estimates of variance components for the log-loading data are presented in Section 8B-2.2.4.

8B-2.2.1 Vacuum Dust Samples from Window Well Surfaces Taken Pre-Activity

Pre-activity vacuum dust samples were collected from the window wells selected in each unit. The samples were collected to help characterize the units with respect to the lead levels found prior to window replacement activities, and to use as potential predictors of lead exposure resulting from window replacement.

Tables WR-5a and WR-5b in Appendix A present data summaries for the pre-activity window well dust samples. One sample was eliminated from the statistical analysis because its observed lead concentration and loading were judged to be outliers (significantly smaller than and inconsistent with the results of the other window well samples). Summary statistics shown in Tables WR-5a and WR-5b are calculated both with and without the outlier. Figures WR-1a and WR-1b in Appendix A compare the lead loadings and concentrations, respectively, of the pre-activity window-well samples with the pre-activity floor samples using boxplots.

The lead loadings of the window well dust samples ranged from 26,800 to 415,000 $\mu g/ft^2$ (after removal of the outlier), with a geometric mean of 135,000 $\mu g/ft^2$.

8B-2.2.2 Lead Disturbance as a Function of Pre-Activity Lead Loadings

Model (C-1) presented in Section C.1 of Appendix C was fitted to data from the following sample types collected during or after window replacement activities:

- lead concentrations in personal exposure samples
- lead concentrations in ambient air samples
- lead loadings in SSDC dust samples.

In addition, Model (C-1) was fitted to the estimated amount of lead disturbed in a 6-foot by 1-foot gradient, discussed in Section 8B-2.1.3.2. Each fit of these models contained random effects representing unit-to-unit and within-unit variability (no side-by-side QC sample results were included), as well as one of the following fixed covariates:

#1. pre-activity lead loading on floor surfaces at 0 feet from the window.
#2. pre-activity lead loading on floor surfaces at 3 feet from the window.
#3. pre-activity lead loading on floor surfaces at 6 feet from the window.
#4. pre-activity lead loading on window well surfaces.
#5. lead loadings within paint chips collected from the interior sash/frame of the window.
#6. lead loadings within paint chips collected from the exterior sash/frame of the window.
#7. pre-activity ambient air lead concentrations.

Table 8B-4 summarizes the approach to fitting Model (C-1), indicating those covariates whose effects on the data were significant at the 0.05 level. Model (C-1) takes the form of models (WR-1) through (WR-5) when fitting to a specific data type (Table C-2 of Appendix C). Only one of the covariates was consistently significant when modeling the different sample types: pre-activity lead loading on floor surfaces at 3 feet from the window (covariate #2). Ambient air lead concentrations during the activity were significantly associated with pre-activity floor lead loadings at each distance from the windows, indicating that ambient air results were likely dominated by the pre-activity level of dirtiness existing within the study units.

Table 8B-4. Results of Tests for Significant Covariates in the Model Fitting to Lead Loading Data in the Window Replacement Phase

Modeled Data	Models Fitted (Table C-2 of Appendix C)	Covariates Significant at the 0.05 Level in the Fitted Models
Personal exposure sample concentrations	Model (WR-1) fit seven times, each considering one of the seven covariates.	Covariate #2
Ambient air sample concentrations (during activity)	Model (WR-2) fit six times, each considering one of covariates #1 to #6, with covariate #7 always included in the model.	Covariates #1, #2, #3
SSDC dust-lead sample loadings at 0 feet from window	Model (WR-3) fit six times, each considering one of covariates #1, #2, #4, #5, #6, #7.	Covariate #2
SSDC dust-lead sample loadings at 6 feet from window	Model (WR-4) fit six times, each considering one of covariates #2 to #7.	None
Estimated lead amount in 6'x1' gradient from window	Model (WR-5) fit seven times, each considering one of the seven covariates.	Covariate #2

The significance levels for the tests of significant covariate effects were not adjusted for the large number of tests performed in this exercise.

More detailed results of the model fittings are presented in Section C.1 of Appendix C.

8B-2.2.3 Lead Disturbance as a Function of Distance from the Windows

Lead disturbance resulting from renovation and remodeling activities was expected to vary with the distance from the activity. Field sampling within the window replacement phase of the EFSS was designed so that this relationship could be explored. Floor dust samples were collected (pre- and post-activity) at 0, 3, and 6 feet from the windows being replaced. SSDCs were placed at 0 and 6 feet from the same windows. The sample results can be used to determine how lead loadings change over distance.

In Section 8B-2.1.3.1, a summary of the results of the pre-activity and post-activity floor dustfall samples was presented. The difference between post- and pre-activity floor lead loadings represented lead disturbance resulting from window replacement activities. These observed differences were not well-behaved: nine of the 35 differences were negative, and the variability of the differences was very large (Figure 8B-3).

Figures 8B-5a and 8B-5b are plots of the lead loadings from pre-activity and post-activity floor dust samples, respectively, versus the distance from the windows at which the samples were collected. The plotting symbols indicate the unit from which the samples were collected. Lines are drawn connecting observations taken at the same window. In both cases, measured lead loadings tended to decrease as distance from the windows increased. Figure 8B-5c plots the difference in lead loadings between adjoining post- and pre-activity floor samples versus the distance at which the samples were collected. This figure clearly shows the effect of the negative differences and the large variability in the differences. For this reason, statistical models in the previous section were not fitted to floor sample lead loadings.

Figure 8B-6 is a plot of lead loadings for the one-hour post-activity samples taken from SSDCs versus the distance from the windows at which the samples were collected. Although only two distances per window were considered, this figure indicates that lead loadings from SSDC dustfall samples have a more consistent decreasing trend in the lead loading as the distance from the window increases, compared to trends seen in the other plots for floor dustfall samples.

Model (C-3) in Section C.3 of Appendix C was fitted to evaluate the relationship between one-hour post-activity lead loading data ($\mu g/ft^2$) from SSDCs and distance from the window being removed. The estimated slope parameter associated with distance was -0.732, which was statistically significantly different than 0 at the 0.0001 level. This result indicates that as one moves one foot farther away from the window, the log-transformed lead loading decreases by approximately 0.732, or the untransformed lead loading is reduced by approximately $(1-e^{-0.732}) * 100\% = 52\%$.

Because of the significant distance effect on SSDC lead loadings, it was decided that the amount of lead disturbed in a 6-foot by 1-foot gradient extending from the window would be a better overall estimate of the lead disturbed by window replacement activities than estimates made at a single distance.

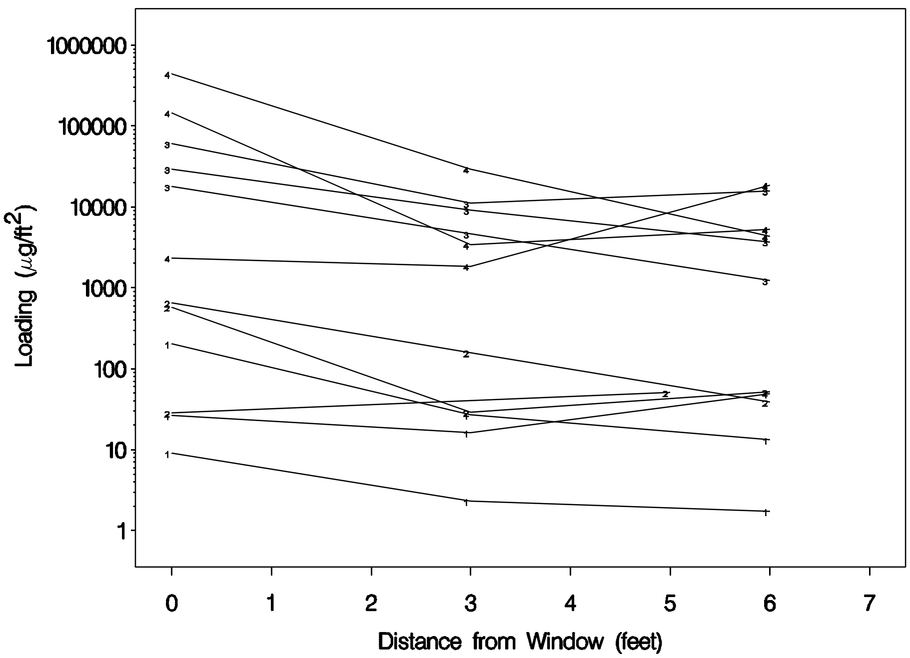


Figure 8B-5a. Lead Loadings ($\mu g/ft^2$) for Pre-Activity Floor Samples Versus Distance from the Windows at Which the Samples Were Taken

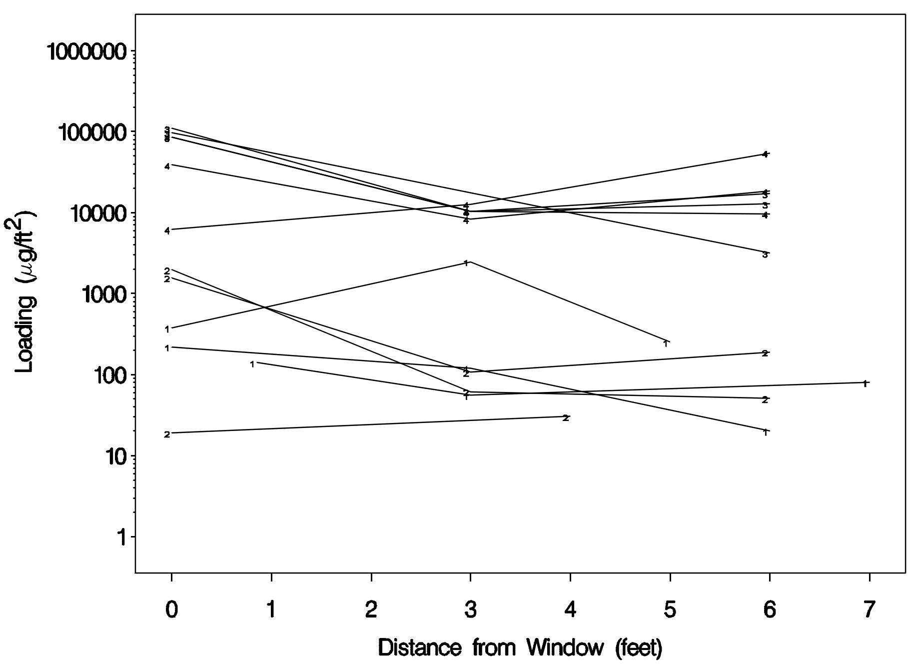


Figure 8B-5b. Lead Loadings ($\mu g/ft^2$) for Post-Activity Floor Samples Versus Distance from the Windows at Which the Samples Were Taken

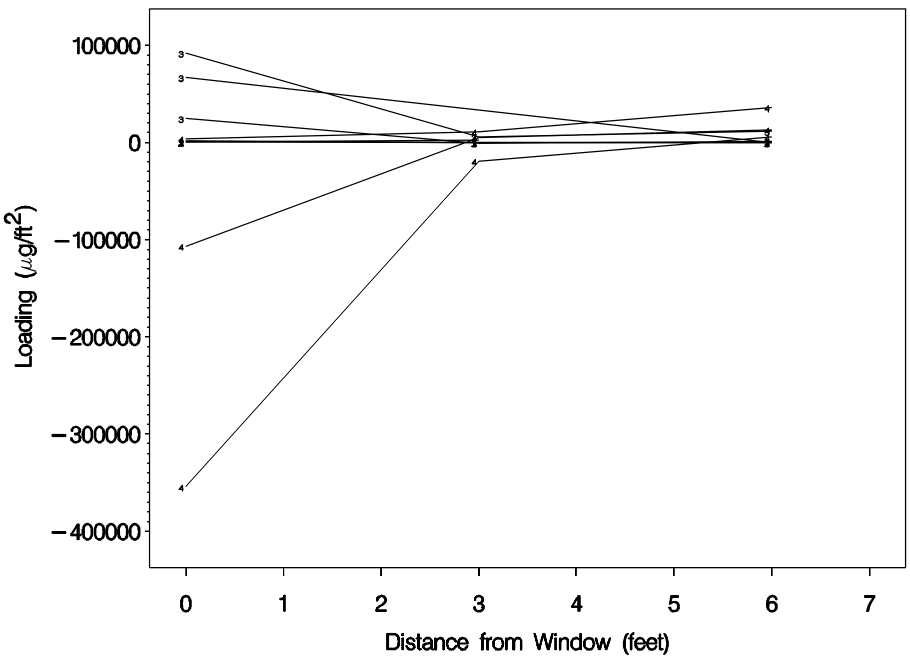


Figure 8B-5c. Lead Loadings ($\mu g/ft^2$) for Differences Between Adjoining Post-Activity and Pre-Activity Floor Samples Versus Distance from the Windows at Which the Samples Were Taken

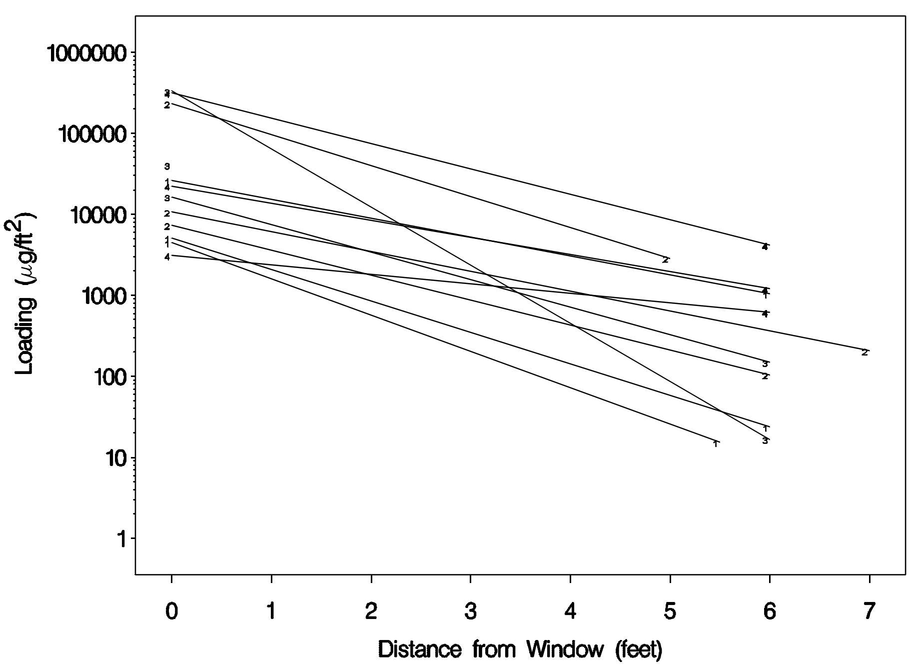


Figure 8B-6. Lead Loadings ($\mu g/ft^2$) for One-Hour Post-Activity SSDC Samples Versus Distance from the Windows at Which the Samples Were Taken

8B-2.2.4 Estimating Variance Components

The sampling design for the window replacement phase specified sample collection over multiple study units, multiple locations (or workers) within a study unit, and that settled dust samples be taken in multiple areas within locations (i.e., side-by-side QC samples). This design provided for key sampling components of total data variability to be isolated and characterized. Therefore, when estimable, the magnitudes of the following variance components were estimated for several sample types (where appropriate) using random-effects analysis of variance:

- "unit-to-unit" variability
- "location-to-location" (or worker-to-worker) variability within a unit (window-to-window)
- "replicate-to-replicate" variability within a location.

Variance components were estimated for the following lead measurements:

- pre-activity floor dust lead loadings (separately at 0, 3, 6 feet)
- post-activity floor dust lead loadings (separately at 0, 3, 6 feet)
- 1-hour post-activity SSDC vacuum lead loadings (separately at 0, 6 feet)
- pre-activity window well dust lead loadings
- paint chip lead loadings (separately for interior, exterior)
- personal air lead concentrations
- pre-activity ambient air lead concentrations
- during-activity ambient air lead concentrations
- lead amounts in a 6' x 1' gradient.

Replicate-to-replicate variability could only be estimated for the lead measurements in the first three items listed, because these were the only sample types where side-by-side QC samples were taken.

It is assumed that total variability is the sum of the variabilities associated with the three components listed above. Any additional variance components are confounded within one or more of these components.

Model (C-2) presented in Section C.2 of Appendix C was fitted to the lead measurements to estimate the variance components for the various sample types. Table 8B-5 contains the estimated total variability in these (log-transformed) measurements, plus estimates of the components of the total variability. The results represent variability in the log-domain, so they are expressed in log units.

Table 8B-5. Estimates of Total Variability and its Estimable Components in Log-Transformed Lead Measurements By Sample Type in the Window Replacement Phase

Sample Type[1]	Model Estimate of Mean Log Measurement[2]	Square Root of Estimated Total Variability[3]: σ_{tot}	Square Roots of Estimated Variance Components[4]		
			Unit-to-unit (σ_U)	Location-to-location within a unit (σ_L)	Replicate-to-replicate within a location (σ_R)
Pre-act. Floor Dust at 0 feet	7.56	3.92	3.46 (77.8%)	1.52 (15.0%)	1.05 (7.2%)
Pre-act. Floor Dust at 3 feet	6.04	3.43	3.23 (88.6%)	0.68 (3.9%)	0.94 (7.5%)
Pre-act. Floor Dust at 6 feet[5]	5.79	3.36	3.21 (91.5%)	0.60 (3.2%)	0.78 (5.4%)
Post-act. Floor Dust at 0 feet	8.27	3.26	2.90 (79.0%)	1.05 (10.4%)	1.06 (10.5%)
Post-act. Floor Dust at 3 feet	7.11	2.66	2.38 (80.4%)	0.31 (1.4%)	1.13 (18.2%)
Post-act. Floor Dust at 6 feet[5]	6.76	3.27	3.11 (90.8%)	0.73 (5.0%)	0.67 (4.2%)
1-hr. Post-Activity SSDC Dust (vacuum) at 0 feet	10.1	1.67	0 (0%)	1.52 (83.7%)	0.67 (16.3%)
1-hr. Post-Activity SSDC Dust (vacuum) at 6 feet[5]	5.4	1.86	1.14 (37.6%)	0.93 (24.8%)	1.14 (37.5%)
Pre-Activity Window Well	11.5	1.54	0.99 (41.6%)	1.17 (58.4%)	---
Interior Paint chip	0.79	2.54	2.46 (93.5%)	0.65 (6.5%)	---
Exterior Paint chip	2.40	1.50	1.02 (46.5%)	1.10 (53.5%)	---
Personal air	2.01	1.26	1.11 (77.6%)	0.60 (22.4%)	---
Pre-Activity Ambient air	-1.21	1.58	1.33 (71.4%)	0.84 (28.6%)	---
Post-Activity Ambient air	0.15	0.86	0.72 (69.5%)	0.47 (30.5%)	---
Six-foot by One-foot Gradient	10.8	1.56	0 (0%)	1.56 (100%)	---

(1) SSDC = Stainless steel dustfall collectors.
(2) Estimate of the intercept term from the random effects model.
(3) Total variability $= \sigma_{tot}^2 = \sigma_U^2 + \sigma_L^2 + \sigma_R^2$, where these parameters were estimated from the random effects model using restricted maximum likelihood.
(4) Number in parentheses is the percent of total variability (σ_{tot}^2) represented by the given variance component (the square of the tabled value).
(5) Side-by-side samples were included with the floor dust and SSDC dust samples when estimating variance components.

For pre-activity and post-activity floor samples at all three distances, over 75% of variability in the lead loadings was attributed to results from different units; there was no clear pattern in the within-unit and replicate-to-replicate variabilities. For samples collected from SSDCs, the results were mixed: at 6 feet from the windows, all three sources of variability made roughly equal contributions to the total variability; at 0 feet from the windows, within-unit variability was about five times as large as the replicate-to-replicate variability. The total variability of both pre-activity and post-activity floor sample data exceeds that of the SSDC samples.

The estimated within-unit variance of window well loadings was about 1.5 times as large as the estimated unit-to-unit variance. The unit-to-unit variance among the interior paint-chip loadings was 14 times greater than the within-unit variability, while the unit-to-unit and within-unit variabilities were roughly equal for exterior paint chip loadings. The unit-to-unit variability in log-transformed personal air lead concentrations was four times greater than the within-unit variability, indicating that workers involved in window replacement at a given site are exposed to similar lead levels within their breathing zones. The results for ambient air samples are similar to those of personal exposure samples, with the unit-to-unit variability 2.5 times greater than within-unit variability for both pre-activity and post-activity samples.

8B-2.3 CORRELATIONS BETWEEN LEAD IN DIFFERENT SAMPLE MEDIA

To quantify the extent of the linear relationship between lead exposure estimates from different sample types and sample collection approaches, Pearson correlation coefficients were calculated among pairs of twelve variables that measure lead levels in various media through the study. The variables of interest include:

- pre-activity dust lead loadings on floors (0, 3, 6 feet)
- pre-activity dust lead loadings on window wells
- 1-hour post-activity dust lead loadings on SSDCs (0, 6 feet)
- 2-hour post-activity dust lead loadings on SSDCs (6 feet)
- estimates of total lead disturbed in a 6-foot by 1-foot gradient
- lead concentrations in personal air and ambient air samples collected during window replacement activity
- lead loadings in interior and exterior paint chips from window sashes and frames.

Post-activity floor dust lead loadings were not included in this analysis because of the previous decision to use SSDC measurements as the preferred indicator of lead generated in settled dust by the activity (see Chapter 7). For each variable, the geometric mean of the observed data was calculated for the four study units. The estimated total lead in the 6-foot by 1-foot gradient was calculated as discussed in Section 8B-2.1.3.2. Pearson correlation coefficients associated with these geometric means were calculated for each pair of variables. Table 8B-6 presents these correlations. A low correlation between two variables does not necessarily imply the lack of a relationship, as the relationship may not be linear in nature or the sample size may have not have been large enough to detect such a relationship.

Because each of the correlations was calculated using only four observations, only correlations that are greater than 0.95 are statistically significantly different from 0 at the 0.05 level. Correlation coefficients greater than 0.9 are statistically significantly different from 0 at the 0.10 level.

Table 8B-6 shows several strong correlations that are of particular interest:

- The strong correlations between personal air lead concentrations, lead loadings in one-hour post-activity SSDC samples at 0 feet from the windows, ambient air lead concentrations, and the estimated lead amount disturbed in a 6-foot by 1-foot gradient indicate a probable relationship between a worker's exposure and the lead generated as a potential exposure to occupants. This suggests that a single medium may be considered in future studies as an indicator of both worker exposure and potential occupant exposure

- The strong correlation between dust lead loadings from pre-activity floor samples at 0 feet from the windows and lead loadings in interior paint chip samples suggests that the high levels of lead in dust on the floor near the windows may be due to high levels of lead in paint on the interior surfaces of the windows rather than from lead tracked or blown into the unit.

A strong correlation between personal worker lead concentrations and post-activity SSDC lead loadings was also noted in the carpet removal phase. While correlation between personal worker exposure, floor dust loadings, and ambient air concentrations was somewhat lower in the carpet removal phase than that observed for window replacement, the small numbers of data points may imply no statistical difference between phases.

8B-2.4 SUMMARY OF RESULTS

Following is a summary of the major results observed in the EFSS window replacement phase:

- None of the lead concentrations within personal air samples exceeded the OSHA PEL of 50 $\mu g/m^3$. Personal air lead concentrations ranged from 2.41 to 44.3 $\mu g/m^3$ with a geometric mean of 7.48 $\mu g/m^3$. Estimated variability in these data were primarily the result of sampling in different study units.

Table 8B-6. Pearson Correlation Coefficients[1] of the Geometric Mean Lead Loadings Between Pairs of Sample Types and Approaches in the Window Replacement Phase

Sample Type	Pre Floor D = 0[2]	Pre Floor D = 3	Pre Floor D = 6	Window Well	Paint Chip Ext.	Paint Chip Int.	1-Hr. SSDC D = 1	1-Hr. SSDC D = 6	2-Hr. SSDC D = 6	Ambient Air	Personal Exp.	6' x 1' Lead Gradient
Pre Floor D=0	1.00	0.847	0.999	0.129	-0.495	0.903	0.463	0.744	0.836	0.420	0.420	0.655
Pre Floor D=3		1.00	0.827	0.267	-0.174	0.754	0.829	0.292	0.416	0.832	0.838	0.892
Pre Floor D=6			1.00	0.119	-0.511	0.902	0.433	0.767	0.855	0.387	0.386	0.632
Window Well				1.00	0.769	-0.296	0.618	0.101	-0.050	0.452	0.327	0.662
Paint Chip Ext.					1.00	-0.772	0.395	-0.513	-0.664	0.309	0.214	0.271
Paint Chip Int.						1.00	0.260	0.596	0.762	0.302	0.360	0.402
1-Hr. SSDC D=0							1.00	-0.110	-0.062	0.978	0.941	0.961
1-Hr. SSDC D=6								1.00	0.972	-0.229	-0.264	0.169
2-Hr. SSDC D=6									1.00	-0.141	-0.147	0.202
Ambient Air										1.00	0.991	0.901
Personal Exp.											1.00	0.851

(1) Correlations calculated on geometric means calculated for each study unit (n=4). All correlations greater than 0.95 are significantly different from zero at the 0.05 level.

(2) Signifies distance from window (in feet).

- Lead concentrations within ambient air samples collected during window replacement activity ranged from 0.29 to 4.16 µg/m^3 with a geometric mean of 1.16 µg/m^3.

- The difference in lead loadings from floor dust samples taken pre- and post-activity had high variability in this study. Across all floor dust samples, the geometric mean lead loading increased from 2.0 to 2.6 times from pre- to post-activity at the various distances from the window. Some pre-activity sample lead loadings were actually larger than the loadings in the adjoining post-activity samples.

- Lead loadings from SSDC samples had substantially lower variability than the difference between post- and pre-activity floor lead loadings. This indicates that the SSDC method may yield a more accurate and precise measure of the lead disturbed by window replacement than the difference in pre- and post-activity floor dust samples. The geometric mean of the lead loadings collected from SSDCs one hour after completion of the window replacement was 24,700 µg/ft^2 at 0 feet from the window and 241 µg/ft^2 at 6 feet from the window, indicating the significant effect of distance from the activity on observed load levels. An estimate of the total amount of lead disturbed in a 6-foot by 1-foot gradient was calculated for each window. The estimate of the average amount of lead disturbed in a 6-foot by 1-foot gradient for window replacement activities in this study was 46,200 µg.

- Of the covariates providing information on pre-activity lead levels, only the pre-activity lead loadings on floor surfaces at 3 feet from the window was consistently significant at the 0.05 level when modeling during- and post-activity lead disturbance in various media. Small sample size, high variability and multiple model fittings make these results very tenuous, however, and only exploratory in nature.

- The strong correlations between the lead loadings from personal worker exposure samples, one-hour post-activity SSDC samples at 0 feet from the windows, area air samples, and the estimated lead disturbed in a 6-foot by 1-foot gradient indicates a probable relationship between a worker's exposure and the lead generated as a potential exposure to the occupants.

8C-1.0 STUDY DESIGN IN THE CED PHASE

This section presents the study design for the Controlled Experimentally-Designed (CED) phase of the EFSS study. The primary objective of this phase was to estimate lead disturbances and potential lead exposures associated with several target R&R activities and generic activities which are difficult to isolate in an actual R&R job or are ingredients to larger R&R activities. In addressing this objective, the CED phase offered a controlled, simulated R&R environment in which R&R activities of interest were performed and environmental samples were collected.

The activities in the CED phase were classified into one of the following three primary categories:

1. simulated R&R target activities (e.g., demolition)
2. generic R&R tasks (e.g., drilling and sawing)
3. a positive control activity (paint removal, for comparison purposes).

The components of each activity category are discussed in Section 8C-1.1.

The CED phase was conducted using skilled R&R workers and laborers who were familiar with protective measures and methodologies used in the lead-abatement industry. These R&R workers were contracted by the project team to perform the designated R&R tasks within each study component, and they were instructed to perform the tasks as they are typically conducted in an unregulated environment. The workers were protected according to the procedures approved by the human subjects review committees of Battelle, MRI, and EPA.

The CED phase consisted of three "case studies" (or "sites"), each constituting one or more related vacant buildings slated for subsequent gutting, gut rehab, or complete abatement and clearance testing before reoccupancy. Two sites, each consisting of a single row house, were located in Baltimore, Maryland. The third site consisted of a group of four dwelling units in Denver, Colorado. It was expected that the unique characteristics of each site would cause slightly differing approaches to applying the overall study and sampling design for each activity occurrence. This was reflected in the decision to develop a separate sampling plan for each site. Nevertheless, for the most part, the different R&R tasks within each study component were able to be replicated across sites and were often replicated within sites. This allows for an assessment of not only the potential lead exposure associated with each different CED activity, but also of the variance components associated with the measures of those lead exposures.

8C-1.1 SAMPLING DESIGN FOR THE CED PHASE

The carpet removal and window replacement phases of the EFSS study (Sections 8A and 8B) were designed as observational studies in which only the types and locations of the samples were specified in the sampling design. In contrast, the CED phase, as its title suggests, was designed to control not only the type and location of samples, but also the type and conduct of R&R activity.

The sections which follow contain discussions of the two aspects of the sampling design for the CED phase: descriptions of the activities that were included in the study, and the types and locations of samples that were collected to monitor lead exposure as a result of performing the activities.

8C-1.1.1 CED Activities

As mentioned above, three primary categories of R&R activities were included in the CED phase: simulated R&R target activities, generic R&R activities, and a positive control activity.

In an attempt to replicate each R&R activity across the different "sites" in the study, the actual work that was to be performed as part of the activity was defined prior to the start of data collection. Because each study site was unique, separate test plans for each study site were also prepared that presented specifications of where, when, and how each activity was to be performed at each of the three sites. Following is a general description of activities conducted within each activity category in the CED phase (more detailed descriptions are provided in the CED QAPjP addendum).

<u>**Category #1: Simulated R&R Target Activities**</u>

1. ***Demolition***. In each study unit, three large structure removal activities were planned. These activities consisted of demolishing one or more walls in the study units. In most cases, a single plaster wall was removed. However, in some situations, one or more walls consisting of drywall, wood, or plaster were removed. Removal of walls that separated rooms were limited to one room, and the activity was planned so that there was no damage to the wall of the room backing the wall that was demolished. Removal of exterior walls was planned so that there was no damage to the underlying structure of the wall (usually brick). In all cases, the end result of the demolition was to be an exposed wall structure completely ready for the installation of new drywall.

2. ***HVAC Removal***. In each study unit, one HVAC repair/ replacement activity was planned. This activity consisted of removing several sections of the HVAC ductwork. The activity was designed to prepare the HVAC system for the installation of new ductwork. (Actual HVAC removal was performed only at the Baltimore units).

3. ***Small Surface Disruption***. The CED QAPjP Addendum lists several examples of activities that fit into the category of small surface disruptions. The activity that was chosen for the CED phase was ***Door Modification***. This activity consisted of two subtasks -- trimming wood from the edge of an existing door (and sanding it smooth), and drilling a hole for installation of a doorknob -- which were designed to mimic actual work that might be performed as part of an R&R job. Two door modification activities were scheduled for each unit. Because it was expected that the time required to perform the modification of a single door would be too short to provide for reasonable samples, several doors were included in the door modification

activity. The activity consisted of trimming an inch from one end of the door (top or bottom), drilling a hole for a doorknob, and trimming an inch from the other end of the door. The choice of tools for performing this activity was left to the discretion of the worker. (Note: When this activity was conducted in the field, workers lost track of the number of doors modified. Therefore, exposure results are presented as a generic R&R task involving cutting and sanding rather than as an example of the small surface disruption target activity.)

Category #2: Generic R&R Activities

An objective of the CED phase was to determine lead exposures associated with several generic components of larger R&R activities. The planned generic activities were as follows:

1. ***Sawing***. The sawing activities involved making a series of fifteen parallel cuts (5 feet in length) into either ***plaster or wood substrates*** using either a rough blade or a fine blade. Four activities were planned, using each combination of substrate and blade. The cuts into plaster walls were separated by three inches in the vertical direction, and the cuts into wood baseboards removed from walls were made at one-inch intervals.

2. ***Drilling***. The drilling activities involved drilling a lattice of holes into either ***plaster or wood substrates*** using either a small or large drill bit. Four activities were planned, using each combination of substrate and drill bit. Wood drilling was done into walls (when available) or into doors, and plaster drilling was done into walls. The lattice of holes for all drilling activities was 3 feet wide and 2 feet high (or vice-versa). With the small drill bit, holes were drilled every inch in both horizontal and vertical directions (925 holes), and with the large drill bit, holes were drilled every 3 inches (117 holes).

3. ***Building Component Removal***. The CED QAPjP Addendum recognized the possibility of monitoring additional R&R activities if the opportunity presented itself. In the first dwelling unit in Denver, different building components needed to be removed prior to conducting R&R activities on them. This opportunity allowed the removal of lead-painted wood trim, baseboards, doors, and door-jams to be monitored in this unit as a simulated R&R target activity.

4. ***Cleanup.*** Cleanup activity was monitored by personal air concentrations only (as opportunity allowed). New filter cassettes were inserted in the personal exposure monitors at the start of cleanup activity, so that cleanup exposures could be clearly separated from exposures resulting from the earlier R&R activity.

The first two activities also provided a basis for comparison of different tools and different substrates with regard to their effect on lead exposure.

Category #3: Positive Control Activity

Paint removal was conducted at each CED study unit. This activity was performed at one location per unit where two or three windows were available. Potential lead exposure associated with paint removal has been studied and cited in the literature in detail; thus paint removal acted as a positive control activity to which results of the other CED activities could be compared. Paint was removed from the windows using abrasive techniques, thereby acting as a "worst-case" positive control. Half of the available area had paint removed by ***hand scraping and sanding*** while the remaining portion had paint removed using ***power sanding***.

In all activities performed in the EFSS, vacuum attachments were not used on any tools. In addition, no dust reduction methods, such as wetting, misting, or negative air, were employed.

Before any of the activities at a given building were performed, the building was prepared according to normal abatement procedures, including creation of a decontamination area, tool cleanup area, sealing of floors and rooms with poly, and other safety and activity preparations.

8C-1.1.2 Sample Types and Locations

The inclusion of different R&R activities at different sites in the CED phase required some flexibility in sampling plans across activities and sites. In general the sampling plan for the collection of environmental field samples was consistent within each type of CED activity. Wherever possible, sampling was done in a consistent manner across CED activities. This section presents the sampling plan and protocols that were consistent across activities and sites. Table 8C-1 presents the specific implementation of the sampling plan for each site and activity in the CED phase.

The primary types of samples taken in the CED study included the following:

- ***Personal exposure samples*** taken during the activity

- ***Paint chip samples*** taken before the activity ***from plaster and painted-wood surfaces disturbed by the activity***

- ***Plaster samples*** taken before the activity ***from plaster walls used for the activity***, to measure the amount of lead in the substrate which can be disturbed during the activity

- ***Settled dust samples*** taken via wipe techniques ***from HVAC components***, to measure the amount of lead which can be disturbed during HVAC removal

- ***Settled dust samples*** taken via vacuum or wipe techniques following completion of the activity ***from stainless steel dustfall collectors (SSDCs)*** placed on the floor immediately prior to the activity, and at areas adjacent to and at varying distances away from the activity.

Table 8C-1. Sampling Design for Each CED Activity Within Each Study Unit

City/ Building No./ Activity No.	Activity	Day/Time	Worker	Room Description	Samples Collected
Baltimore Building 1 Activity 1	Drilling Wood 925 Holes with ¼" Bit	Day 1-1 07:16 - 08:10	1A	South Basement	1 Personal Exposure 5 Settled Dust 1 Paint Chip
Baltimore Building 1 Activity 2	Drilling Plaster 925 Holes with ¼" Bit	Day 1-2 10:17 - 11:42	1A	2nd Floor Bathroom	1 Personal Exposure 5 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 1 Activity 3	Drilling Wood 117 Holes with 1" Bit	Day 1-1 15:34 - 15:54	1B	North Basement	1 Personal Exposure 5 Settled Dust 1 Paint Chip
Baltimore Building 1 Activity 4	Drilling Plaster 117 Holes with 1" Bit	Day 1-2 10:34 - 10:51	1B	North Bedroom 2nd Floor	1 Personal Exposure 5 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 1 Activity 5	Sawing Plaster 40 Feet with Circular Saw	Day 1-1 08:04 - 08:34	1B	Foyer	1 Personal Exposure 5 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 1 Activity 6	Sawing Wood 75 Feet with Circular Saw (Rough Blade)	Day 1-1 14:28 - 15:14	1B	South Bedroom 3rd Floor	1 Personal Exposure 5 Settled Dust 2 Paint Chip
Baltimore Building 1 Activity 7	Door Modification	Day 1-2 08:08 - 09:39	1A	North Bedroom 3rd Floor	1 Personal Exposure 5 Settled Dust 2 Paint Chip
Baltimore Building 1 Activity 9	Sawing Wood 75 Feet with Circular Saw (Smooth Blade)	Day 1-1 09:04 - 09:38	1B	South Bedroom 3rd Floor	1 Personal Exposure 5 Settled Dust 2 Paint Chip
Baltimore Building 1 Activity 10	Door Modification *Doors from Baltimore(2)*	Day 1-1 14:18 - 15:30	1A	North Bedroom 3rd Floor	1 Personal Exposure 5 Settled Dust 2 Paint Chip
Baltimore Building 1 Activity 11	HVAC Removal	Day 1-2 08:24 - 08:46	1B 1C	Basement	2 Personal Exposure 10 Settled Dust 4 Interior Duct Wipes
Baltimore Building 1 Activity 12	Abrasive Paint Removal	Day 1-2 14:30 - 15:53	1A 1B	South Bedroom 2nd Floor	3 Personal Exposure 8 Settled Dust 3 Paint Chip
Baltimore Building 1 Activity 13	Demolition of East Wall	Day 1-3 08:12 - 08:41	1A 1B 1C	Living Room	3 Personal Exposure 10 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 1 Activity 14	Demolition of West Wall	Day 1-3 09:34 - 11:28	1A 1B	North Bedroom 2nd Floor	2 Personal Exposure 10 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 1 Activity 15	Demolition of Closet	Day 1-3 13:37 - 14:01	1A 1B	Basement	2 Personal Exposure 10 Settled Dust 2 Paint Chip/1 Plaster
Baltimore Building 1 Activity 81	Drilling Wood 925 Holes with ¼" Bit	Day 1-3 15:18 - 15:59	1A	North Bedroom 3rd Floor	1 Personal Exposure 5 Settled Dust 1 Paint Chip
Baltimore Building 1 Activity 82	Drilling Plaster 925 Holes with ¼" Bit	Day 1-1 08:33 - 08:48	1A	2nd Floor Bathroom	1 Personal Exposure

Table 8C-1 (Continued)

City/ Building No./ Activity No.	Activity	Day/Time	Worker	Room Description	Samples Collected
Baltimore Building 2 Activity 1	Drilling Wood 925 Holes with ¼" Bit	Day 2-1 09:11 - 10:34	2A	Kitchen	1 Personal Exposure 5 Settled Dust 1 Paint Chip
Baltimore Building 2 Activity 2	Drilling Plaster 925 Holes with ¼" Bit	Day 2-1 11:00 - 12:23	2A	Bathroom 3rd Floor	1 Personal Exposure 5 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 2 Activity 3	HVAC Removal	Day 2-1 14:30 - 15:44	2B 2C	Front Bedroom 2nd Floor	2 Personal Exposure 5 Settled Dust 3 Interior Duct Wipes
Baltimore Building 2 Activity 4	Drilling Wood 117 Holes with 1" Bit	Day 2-1 13:42 - 14:02	2A	Kitchen	1 Personal Exposure 5 Settled Dust 1 Paint Chip
Baltimore Building 2 Activity 5	Drilling Plaster 117 Holes with 1" Bit	Day 2-1 15:05 - 15:26	2A	Bathroom 3rd Floor	1 Personal Exposure 5 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 2 Activity 6	Sawing Wood 75 Feet with Circular Saw (Rough Blade)	Day 2-1 08:23 - 08:52	2B	Rear Bedroom 3rd Floor	1 Personal Exposure 5 Settled Dust 2 Paint Chip
Baltimore Building 2 Activity 8	Door Modification	Day 2-1 08:08 - 09:39	2A	Center Bedroom 3rd Floor	1 Personal Exposure 5 Settled Dust 3 Paint Chip
Baltimore Building 2 Activity 9	Sawing Plaster 47.5 Feet with Sawzall	Day 2-1 15:37 - 15:59	2A	Bathroom 2nd Floor	1 Personal Exposure 5 Settled Dust 1 Paint Chip/1 Plaster
Baltimore Building 2 Activity 10	Sawing Wood 75 Feet with Circular Saw (Smooth Blade)	Day 2-1 11:06 - 11:35	2B	Rear Bedroom 2nd Floor	1 Personal Exposure 5 Settled Dust 2 Paint Chip
Baltimore Building 2 Activity 11	Door Modification	Day 2-1 12:59 - 13:42	2B	Rear Dining Room 1st Floor	1 Personal Exposure 5 Settled Dust 3 Paint Chip
Baltimore Building 2 Activity 12	Abrasive Paint Removal	Day 2-2 08:14 - 10:24	2A 2B	Front Bedroom 3rd Floor	3 Personal Exposure 8 Settled Dust 3 Paint Chip
Baltimore Building 2 Activity 13	Demolition of North and South Walls	Day 2-3 07:43 - 09:21	2B 2C	Bathroom 2nd Floor	2 Personal Exposure 8 Settled Dust 3 Paint Chip/1 Plaster
Baltimore Building 2 Activity 14	Demolition of North and South Walls	Day 2-2 13:15 - 14:02	2A 2B	Bathroom 3rd Floor	2 Personal Exposure 8 Settled Dust 2 Paint Chip/2 Plaster
Baltimore Building 2 Activity 15	Demolition of East Wall	Day 2-2 10:30 - 11:37	2A 2B	Kitchen	2 Personal Exposure 8 Settled Dust 2 Paint Chip/1 Plaster
Denver Building 3 Activity 1	Building Component Removal	Day 3-1 09:11 - 11:52 12:59 - 13:58	3A 3B	Front and Center Bedrooms	2 Personal Exposure 5 Settled Dust
Denver Building 3 Activity 2	HVAC Sampling	Day 3-1 09:41 - 10:00	MRI	Attic	5 Interior Duct Wipes
Denver Building 3 Activity 3	Demolition of West Wall	Day 3-1 14:16 - 15:47	3A 3B	Kitchen	2 Personal Exposure 6 Settled Dust 1 Paint Chip/1 Plaster

Table 8C-1 (Continued)

City/ Building No./ Activity No.	Activity	Day/Time	Worker	Room Description	Samples Collected
Denver Building 3 Activity 4	Demolition of East and West Walls	Day 3-2 10:20 - 11:59	3A 3B	Bathroom	2 Personal Exposure 6 Settled Dust 2 Paint Chip/2 Plaster 2 Pre-Activity Dust
Denver Building 3 Activity 5	Abrasive Paint Removal	Day 3-2 13:07 - 14:45	3A 3B	South Dining Room	2 Personal Exposure 12 Settled Dust 4 Paint Chip 2 Pre-Activity Dust
Denver Building 4 Activity 6	Drilling Wood 925 Holes with ¼" Bit	Day 3-3 09:14 - 09:37	3B	Unit(1)	1 Personal Exposure 5 Settled Dust 1 Paint Chip
Denver Building 4 Activity 7	Drilling Wood 117 Holes with 1" Bit	Day 3-3 09:44 - 09:53	3B	Unit(2)	1 Personal Exposure 5 Settled Dust 1 Paint Chip
Denver Building 4 Activity 9	Sawing Wood 75 Feet with Circular Saw (Smooth Blade)	Day 3-3 10:52 - 11:56	3A	Unit(4)	1 Personal Exposure 5 Settled Dust 2 Paint Chip
Denver Building 4 Activity 10	Door Modification	Day 3-3 13:20 - 14:32	3D	Unit(1)	1 Personal Exposure 5 Settled Dust 3 Paint Chip
Denver Building 4 Activity 11	Door Modification	Day 3-3 13:11 - 14:30	3A	Unit(2)	1 Personal Exposure 5 Settled Dust 3 Paint Chip
Denver Building 5 Activity 12	HVAC Sampling	Day 3-2 10:55 - 11:16	MRI	Basement	5 Interior Duct Wipes
Denver Building 6 Activity 13	HVAC Sampling	Day 3-4 10:55 - 11:16	MRI	Basement	4 Interior Duct Wipes
Denver Building 6 Activity 14	Drilling Plaster 925 Holes with ¼" Bit	Day 3-3 14:50 - 15:06	3B	Center Bedroom	1 Personal Exposure 5 Settled Dust 1 Paint Chip/1 Plaster
Denver Building 6 Activity 15	Demolition of East and West Walls	Day 3-4 8:58 - 9:46	3A 3B 3C	Dining Room	3 Personal Exposure 6 Settled Dust 2 Paint Chip/2 Plaster

Unlike the carpet removal and window replacement phases, ambient air samples were not collected in the CED phase because (1) multiple simulated activities being conducted in a single building did not allow for suitable adjacent non-activity areas, and (2) ambient air samples in previous phases had low lead levels.

Personal exposure sampling was conducted on each participating R&R worker to measure lead concentrations in air within the workers' breathing zones while they were performing the activities. Personal exposure monitoring started immediately prior to the beginning of the activity, and stopped as soon as the activity was completed.

Dust samples from SSDCs were collected approximately one hour after the completion of each activity. Times could not be exactly one hour after completion of the activity because the number of samples per activity was too great to allow simultaneous collection.

At selected locations within the Baltimore units, dustfall samples were taken from SSDC surfaces via wipe techniques, in support of an EFSS study objective to compare results between vacuum and wipe collection techniques. These wipe samples were collected adjacent to vacuum sample areas. Comparisons of wipe and vacuum sample results were found in Section 7.3 of Chapter 7.

Before CED field work started, a work plan was developed that assigned locations to each CED activity to be conducted at a given site. An approximate spot was chosen where the activity was to be performed (designated the activity area). Locations for dustfall samples were also determined.

Table 8C-1 presents the proposed types and numbers of environmental field samples collected during the CED field study. The major difference in sampling plans for the different CED activities was in the layout of the settled dust sampling locations. For most of the CED activities (drilling, sawing, door modification, and HVAC removal) the layout was fairly consistent. One sample site was located adjacent to the surface being disrupted, and 4 others located in a symmetric pattern at approximately 4-6 feet away from the surface being disturbed. The layout for settled dust samples planned for the paint removal activity was similar, but included more sample locations. The sampling design for the demolition activities did not include any settled dust sample located adjacent to the surface being demolished due to the amount of debris distributed adjacent to the surface.

In addition to the environmental field samples associated with CED activities, several field quality control (QC) samples were included in the sampling design. Field blank samples were taken for three types of samples: personal exposure, dust wipe, and dust vacuum. Field blanks were collected at the beginning of each day for the type of sample that was scheduled to be collected. Personal exposure and settled dust field blank samples were to be collected on each day of work; wipe blank samples were to be collected only on the days when the HVAC activity was to be performed.

More details on the sampling design, including the protocols used to collect the samples, are found in the Quality Assurance Project Plan.

8C-2.0 STUDY RESULTS

This chapter presents the results of the statistical analysis of environmental sample data from the CED phase of the EFSS.

8C-2.1 STRUCTURE OF CED DATA

The purpose of the statistical analysis is to evaluate the lead disturbance and lead exposure that results from performing some prescribed R&R activity on a lead-contaminated component. The models that were selected for presentation allow for comparison of different R&R activities on the basis of lead exposure for workers and lead disturbance and potential exposure to occupants.

All of the samples and their associated measurements in the CED phase can be identified by activity, dwelling unit, subunit (i.e., room or portion of a room) within dwelling unit, and replicate. As a result, an ***experimental unit*** (EU_{ijk}) is defined as the occurrence of activity (i) within subunit (k) of dwelling unit (j). Each environmental field sample collected during the CED phase can be linked to one or more experimental units.

The following paragraphs describe the variables or responses included in the statistical analysis.

Activity. As discussed in Section 8C-1.2.1, the following eight different R&R activities were investigated during the CED phase:

1. ***Drilling*** into wood or plaster surfaces using a small or large drill bit
2. ***Sawing*** into wood or plaster surfaces using a coarse or smooth blade
3. ***Abrasive Sanding and Scraping*** of a painted wood surface
4. ***Door Modification*** on wood doors
5. ***Building Component Removal*** of wood baseboards, doorjambs, etc.
6. ***Demolition*** of plaster and wood walls
7. ***HVAC removal*** in houses with interior lead-based paint
8. ***Cleanup*** after R&R activities.

The first six activities were performed on components that were covered with lead-based paint. The components were identified and confirmed as containing lead-based paint prior to the study using a portable XRF analyzer.

Personal Exposure Monitor. During the eight activities, workers who performed the activity were monitored for exposure to airborne lead using personal air pumps. Total activity monitoring included the entire length of the activity and tool cleanup. For each worker, the amount of lead collected within the sample cassette(s), the duration of the monitoring, and the air pump flow rate were used to calculate the worker's task-length average (TLA) lead exposure in $\mu g/m^3$. As discussed in Chapter 6, a natural log-transformation was applied to each TLA for use as a response variable in the statistical models.

PEM_{ijkl} = Personal exposure monitor result ($\mu g/m^3$) measured on the l^{th} worker during the occurrence of activity (i) within subunit (k) of dwelling unit (j).

Settled Dust. Prior to each CED activity, a number of SSDCs were placed on the floor at predetermined distances from the center of the activity. These plates were used to collect the fallout of dust and debris generated by each occurrence of an R&R activity. Approximately one hour after the completion of an activity, the dust located within each plate was collected and then analyzed for lead. Since each SSDC had a surface area of one square foot, the results of the settled dust field samples are reported as a dust-lead loading in units of µg/ft^2. As discussed in Chapter 6, a natural log-transformation was applied to each settled dust loading for use as a response variable in the statistical models. In addition to the dust-lead loading, each SSDC has an associated distance, which measures how far away each dust collector was placed from the surface being disturbed during the activity.

$Dust_{ijkl}$ = Dust lead loading result (µg/ft^2) measured on the l^{th} SSDC from the occurrence of activity (i) within subunit (k) of dwelling unit (j).

$Distance_{ijkl}$ = Distance from the activity of the l^{th} SSDC from the occurrence of activity (i) within subunit (k) of dwelling unit (j).

During the demolition, abrasive sanding, and component removal activities, some SSDC's were placed in adjacent pairs in an effort to assess side-by-side variability within settled dust results. For the demolition activity in particular, some of the side-by-side paired samples were sampled using both dust vacuum and dust wipe collection methodologies. With the exception of the demolition side-by-side vacuum/wipe samples, all other settled dust samples from the CED phase were collected using the vacuum methodology.

Pre-Activity Lead Levels. To understand factors that may affect the potential lead exposure that results from performing an R&R activity on a lead-contaminated component, it is important to also characterize the amount of lead that was on the surface of each disturbed surface prior to the activity. Thus, for each R&R activity, at least one field sample was collected to characterize the pre-activity lead level. For activities which disturbed lead-painted surfaces, the pre-activity lead level was measured using paint chip samples and reported in units of mg/cm^2. For the HVAC removal activity, a number of dust wipe samples were taken from the interior of the duct-work to characterize the pre-activity lead levels. The pre-activity dust wipe samples for the HVAC removal activity are reported in units of µg/ft^2.

$Paint_{ijkl}$ = Lead in paint result (mg/cm^2) measured on the l^{th} surface during the occurrence of activity (i) within subunit (k) of dwelling unit (j).

HVAC $Wipe_{jkl}$ = Lead in wipe sample (µg/ft^2) obtained from the interior of the l^{th} duct surface during the occurrence of the HVAC removal activity within subunit (k) of dwelling unit (j).

For R&R activities which disturbed lead-painted plaster, additional pre-activity samples of the plaster were collected and archived for possible future analysis.

Table 8C-2 summarizes the number of field samples collected and available for statistical analysis for the CED phase:

Table 8C-2. Number of Field Samples Collected and Available for Analysis in the CED Phase

Activity Type	Substrate	Exposure Units	Personal Exposure Monitor	Settled Dust Vacuum	Settled Dust Wipe	Pre Activity Paint	Pre Activity Dust
Drilling	Plaster Wood	6 7	6 7	24 35	0 0	5 7	0 0
Sawing	Plaster Wood	2 6	2 6	10 30	0 0	2 12	0 0
Sanding	Wood	3	9	28	0	10	2
Door Modification	Wood	6	6	30	0	17	0
Removal	Wood	1	2	5	0	0	0
HVAC	Duct	2	4	15	0	0	7
Demolition	Plaster	9	20	51	12	16	2
Cleanup	Plaster Wood	4 2	4 2	0 0	0 0	0 0	0 0

8C-2.2 CHARACTERIZING LEAD DISTURBANCE AND POTENTIAL LEAD EXPOSURES

The lead disturbance and exposure data observed in the CED phase are characterized below, according to the sample or exposure type considered.

For each worker, the amount of lead collected within the sample cassette(s), the duration of the monitoring, and the air pump flow rate were used to calculate the worker's task-length average (TLA) lead exposure in µg/m^3. A discussion of the relationship between a TLA and an 8-hour time-weighted average (TWA), on which the OSHA PEL is based, is given in Section 9.1.2 of Chapter 9.

8C-2.2.1 Personal Worker Exposures

In the CED phase, each worker was monitored for airborne lead exposure for the duration of each R&R task. Duration was defined as the time it took a worker to complete the task and clean his tools. The duration of CED phase activities ranged from 9 to 185 minutes. Table 8C-3 gives a summary of task duration for each CED activity under investigation.

Figure 8C-1 is a plot of the task-length average personal exposure lead concentrations (µg/m^3), or average exposures over the duration of activity, for each CED activity type. In this plot, a horizontal line is drawn at 50 µg/m^3, which represents the OSHA PEL for lead exposure during an assumed eight hours of exposure per day. This plot demonstrates that all CED activities, with the exception of the drilling activities, HVAC removal, and cleanup of plaster, resulted in most worker TLAs above the OSHA PEL. All worker TLAs were at or above the OSHA PEL for cleanup of wood, door modification, wood component removal, abrasive sanding, and sawing activities. Nineteen of twenty TLAs were above the OSHA PEL for demolition. In contrast, for drilling activities, all worker TLAs except one were at or below the OSHA PEL. Further summary of the data in Figure 8C-1 can be found in Table CED-1 of Appendix A.

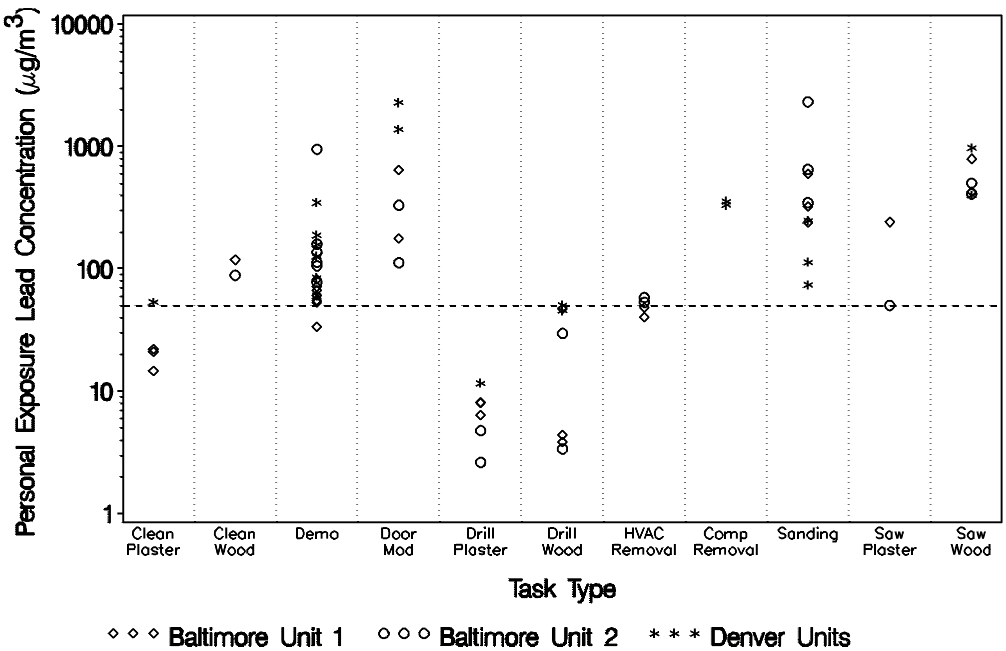
Random-effects model (CED-1) in Appendix C was fit separately to the TLA personal exposure concentrations for each combination of target activity and substrate, in order to characterize four components of variability in the log-transformed TLA concentrations. These variance components are:

- unit to unit variability, or variability resulting from sampling from different study units
- variability resulting from performing the activity at different subunits within a study unit
- variability among different workers
- replication variability, including measurement error.

Table 8C-3. Task Length for Each Combination of Target Activity and Substrate in the CED Phase

Activity Type	Substrate	n	Average Duration (minutes)	Minimum Duration (minutes)	Maximum Duration (minutes)
Drilling	Plaster	6	40	15	85
	Wood	7	36	9	83
Sawing	Plaster	2	19	16	22
	Wood	6	41	14	77
Sanding (Hand)	Wood	6	63	58	75
Sanding (Power)		3	39	22	64
Door	Wood	6	68	43	91
Removal	Wood	2	160	135	185
HVAC	Duct	4	48	21	74
Demolition	Plaster	20	61	25	99
Cleanup	Plaster	4	49	14	129 (1)
	Wood	2	15	12	18

(1) The second-highest duration was 27 minutes.



The dotted line at 50 μg/m^3 represents the OSHA PEL for R&R workers.

Figure 8C-1. Scatterplot of Personal Exposure Loadings by Task Type and Unit ID

Table 8C-4 displays model estimates of the geometric means and variance components (standard deviations) of worker personal exposure to airborne lead for each CED activity, resulting from fitting model (CED-1). The actual number of variance components that can be estimated from the CED data is different for each target activity and is based on the number of observations per target activity and the CED experimental design. For example, if only two observations of worker exposure to airborne lead are available, we can only estimate the geometric mean and residual standard deviation for the given activity.

Table 8C-5 displays estimates of the 50th, 75th, and 95th percentiles of the distribution of personal exposure concentrations for each target activity, with approximate 95% confidence intervals. The approaches for calculating the percentiles and confidence intervals are found in Appendix C. Figure 8C-2 presents a graphical display of the estimated 75th percentile (and associated confidence interval). The vertical line in this figure represents the OSHA PEL of 50 μg/m^3. Results such as these percentiles, with their estimates of variability, can be used to compare potential lead exposures for R&R workers across activities.

Table 8C-4. Model Estimates of the Geometric Mean and Standard Deviation of Variance Components of Worker Personal Exposure to Airborne Lead (Task Length Average) for Each CED Activity Based on a Variance Components Model of log(PEM_{ijkl})

Activity	Substrate	Number of Samples	Geometric Mean Estimated from Model	Residual (σ_{Error})[1]	Worker-to-Worker (σ_{Worker})	Unit-to-Unit (σ_{Unit})	Task-to-Task Within Unit ($\sigma_{Task(Unit)}$)
Drilling	Plaster Wood	6 7	6.76 15.1	0.313 1.29	0.434 0.000		
Sawing	Plaster Wood	2 6	110 546	1.11 0.380	 0.000		
Sanding (Hand Sanding (Power)	Wood	6 3	254 571	0.589	0.000	0.860	
Door Modification	Wood	6	590	0.847	0.896		
Component Removal	Wood	2	344	0.0451			
HVAC	Duct	4	49.6	0.101		0.147	
Demolition	Plaster	20	108	0.475		0.463	0.451
Cleanup	Plaster Wood	4 2	24.5 102	0.550 0.205			

[1] Standard deviation of the log transformed data (expressed in log measurement units).

Table 8C-5. Estimates of the 50th, 75th, and 95th Percentiles for Worker Personal Exposures, Along With 95% Confidence Intervals, by Activity in the CED Phase

Activity	Substrate	Number of Samples	50th Percentile ($\mu g/m^3$)		75th Percentile ($\mu g/m^3$)		95th Percentile ($\mu g/m^3$)	
			Estimate	95% C.I.	Estimate	95% C.I.	Estimate	95% C.I.
Drilling	Plaster Wood	6 7	6.76 15.1	(3.00, 15.3) (4.57, 50.2)	9.70 36.3	(5.71, 40.3) (13.8, 214)	16.3 127	(9.47, 226) (42.9, 2490)
Sawing	Plaster Wood	2 6	110 546	(0.01, 2.32×10^6) (366, 813)	232 705	(11.9, 2.40×10^{13}) (518, 1300)	681 1020	(149, 2.15×10^{27}) (726, 2890)
Sanding (Hand) Sanding (Power)	Wood	6 3	254 571	(23.7, 2720) (42.9, 7600)	513 1150	(150, 63800) (286, 170000)	1410 3170	(447, 2.03×10^7) (940, 5.03×10^7)
Door Modification	Wood	6	590	(93.5, 3730)	1360	(410, 35200)	4480	(1300, 1.89×10^6)
Component Removal	Wood	2	344	(229, 516)	354	(314, 995)	370	(348, 3680)
HVAC	Duct	4	49.6	(11.4, 216)	56.0	(37.7, 3070)	66.6	(53.0, 588000)
Demolition	Plaster	20	108	(26.6, 435)	185	(95.7, 5500)	403	(186, 542000)
Cleanup	Plaster Wood	4 2	24.5 102	(10.2, 58.7) (16.2, 646)	35.5 118	(19.9, 159) (67.9, 12800)	60.5 143	(34.0, 925) (108, 4.89×10^6)

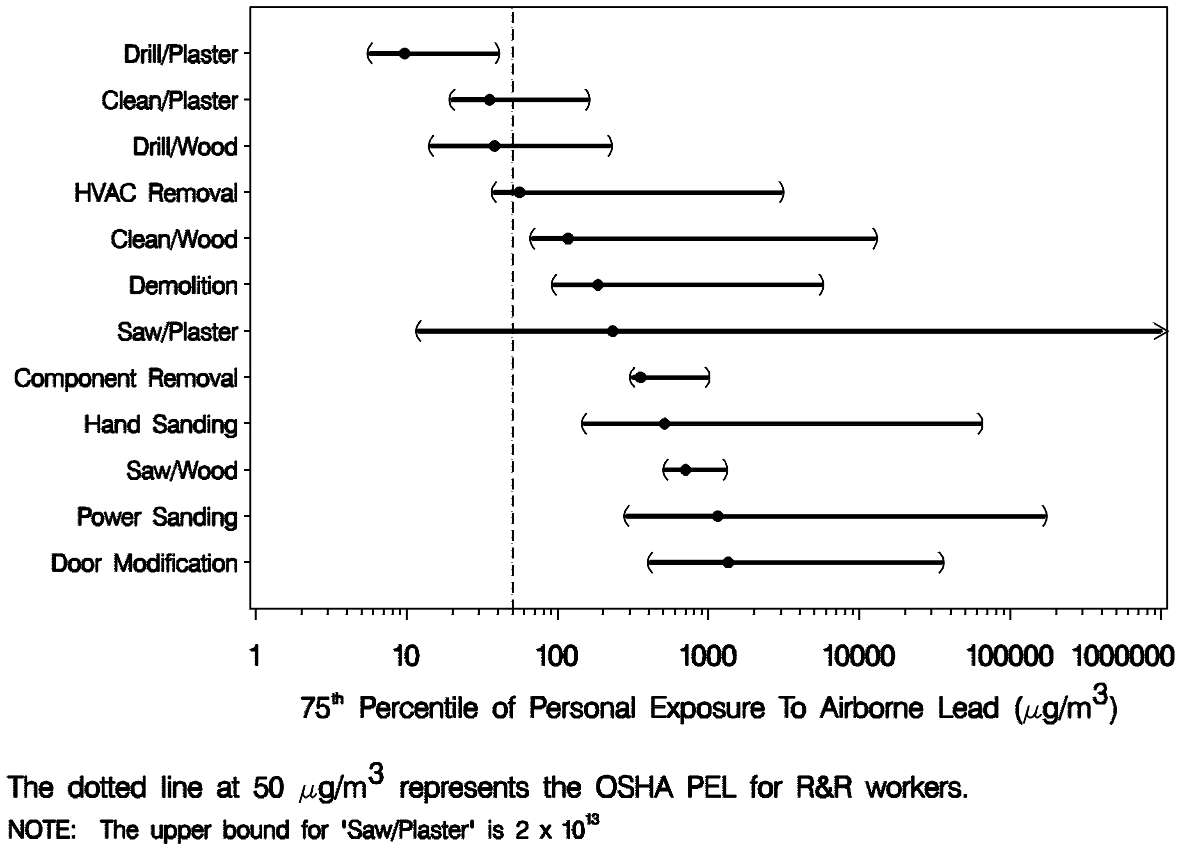


Figure 8C-2. 75th Percentile and Associated 95% Confidence Interval for Personal Exposure to Airborne Lead ($\mu g/m^3$) from Each Combination of CED Activity and Substrate

The results presented in Table 8C-4 demonstrate that for R&R activities that are performed on both wood and plaster surfaces in the CED phase, the estimated median worker exposure (as given by the geometric mean) is much higher for wood surfaces. This trend is consistent for the drilling, sawing, and cleaning activities, and is possibly attributable to a higher concentration of lead in paint on wood surfaces. Table 8C-6 provides parameter estimates (in the log domain) for the effect of a wood substrate on personal exposure levels when performing the same activity on wood versus plaster surfaces. These results are based on fitting Model (CED-2) in Appendix C. (Note that the estimates are similar to, but not in complete correspondence with those obtained from the geometric means in Table 8C-4. This difference is caused by fitting different models to the data.)

Table 8C-6. Estimates of the Increase in Personal Air Exposures that are Attributable to a Substrate Effect (Wood versus Plaster) in the CED Phase

Activity	Parameter Estimates of Increase in log(PEM_{ijkl}) Associated with Wood Over Plaster	Standard Error of Estimate	Degrees of Freedom	P-Value for Test of Significance from Zero	Multiplicative Increase in PEM Results When the Activity is Performed on Wood Rather Than Plaster
Drilling	0.798	0.529	8	0.17	2.2
Sawing	1.60	0.465	4	0.03	5
Cleanup	1.70	0.248	2	0.02	5.5

The interpretation of the estimated increase in log(PEM_{ijkl}) with wood versus plaster substrates is multiplicative. The final column in Table 8C-6 shows that drilling into wood results in a 2.2 fold increase in the personal exposure level over drilling into plaster, while a 5 fold increase in wood over plaster is seen with sawing, and a 5.5 fold increase in wood over plaster is seen during cleanup. The increases associated with the latter two activities are significant at the 0.05 level.

8C-2.2.2 Lead Disturbance and Potential Occupant Lead Exposure

SSDC Approach to Settled Dust Sampling

Immediately prior to the occurrence of each CED activity, a number of SSDCs were placed at various distances away from the surface about to be disrupted. These SSDC's measured one square foot in area, and were designed to collect the fallout of dust and debris generated during an R&R activity.

Approximately one hour following the conclusion of each CED activity, the settled dust and debris were collected from each SSDC through vacuum sampling, and then chemically analyzed for lead.[*] As discussed in Section 8C-2.1, each settled dust sample has an associated measure of the lead-loading in units of micrograms of lead per square foot ($\mu g/ft^2$) and a measure of distance from the activity. Distance for each settled dust sample was measured as how far away (in feet) its SSDC was from the nearest surface that was disturbed during the activity.

The goal of the statistical analysis of settled dustfall lead-loadings is to characterize the potential lead exposure to occupants from dust and debris generated by each CED activity. The settled dustfall loadings from each CED activity represent the amount of lead generated by the performance of the activity at varying distances away from the surface being disturbed.

[*] A small number of settled dust samples were collected from the SSDC's using wipe sampling. These wipe sampling results were not utilized in the determination of potential occupant exposures. They were used only for the vacuum/wipe methodology comparisons presented in Chapter 7.

For most of the CED activities (drilling, sawing, door modification, and HVAC removal) the placement of SSDC's was fairly consistent, with one SSDC adjacent to the surface being disrupted, and four other SSDC's placed in a symmetric pattern at approximately 4-6 feet away from the nearest surface. The adjacent SSDC was expected to capture the fallout of both large debris and dust generated by each activity, while the other four plates were expected to capture mostly dust and smaller airborne particles. The sampling design for the abrasive sanding activity was similar, but included more SSDCs. The sampling design for demolition activities did not include any SSDC's located adjacent to the surfaces being demolished, for two reasons: (1) they would have been an obstacle to the workers, and (2) the expected amount of large debris in a sample collected by an adjacent SSDC would have been difficult to chemically analyze.

Relating Lead Loadings in Settled Dust to Distance from Activity

Exploratory analysis of the settled dustfall results demonstrated an approximate linear relationship between log-transformed lead loadings and distance from the activity. Model (CED-3) in Appendix C was fitted separately to log-lead loading data for each experimental unit (i.e., activity/unit/subunit combination) to estimate this linear relationship to distance. This model took the form

$$\log(\text{dust}) = \beta_0 + \beta_1 \text{ Distance} + \text{error}.$$

Averages of the parameter estimates for each activity/substrate combination are given in Table C-8 of Appendix C.

For most experimental units, the slope estimate within Model (CED-3) was negative, which implied two things:

1. The highest settled dust lead-loading results are associated with SSDC's that are positioned adjacent to the surface being disrupted.

2. The amount of lead found on each SSDC diminishes exponentially with respect to distance, at a rate determined by the slope parameter.

After Model (CED-3) estimated the relationship between lead loading and distance from activity for each experimental unit, it was then necessary to summarize these results across all experimental units. Two different models, a two-stage model and a population model, were examined to summarize the relationship across experimental units. The two models produced similar results. (Details concerning the choice of model are provided in of Appendix C). Therefore we chose to focus our conclusions on the population model, given by Model (CED-5) in Appendix C. This model was fit separately for each combination of activity and substrate, to model lead-loading as a function of distance.

Estimating Lead Disturbance Within a 6' x 1' Gradient

As stated earlier, the goal of the statistical analysis of settled dust lead-loadings is to determine the potential occupant exposure to lead that results from each CED activity. The result of fitting the population model (CED-5) to lead loading data allows us to estimate an overall average curve which explains the average amount of lead in settled dust that is expected to occur at varying distances for each activity, and the components of variation about that curve. For a given activity (i), the population average response curve has the following form:

$$\text{Lead in dust } (\mu g/ft^2) = \exp(\beta_{0i}) \cdot \exp(\beta_{1i} \cdot \text{Distance})$$

By integrating the area underneath the estimated curve for Activity (i) from 0 to 1 foot, we obtain the expected lead-loading of an SSDC located adjacent to the surface of activity (i) (denoted by "[0-1] foot SSDC"). Similarly, by integrating the area underneath the estimated curve for activity (i) from 5 to 6 feet, we obtain the expected lead-loading of an SSDC located 5-6 feet from the surface of activity (i) (denoted by "[5-6] foot SSDC"). The measure used to characterize lead disturbance and potential exposure to occupants for each CED activity is the amount of lead in a 6-foot by 1-foot gradient region, which is obtained by integrating the area underneath the estimated curve from 0 to 6 feet.

Table 8C-7 displays the parameter estimates (and associated standard errors) for the population average lead loading curve, and the calculated average lead loadings ([0-1] foot SSDC, [5-6] foot SSDC, and 6-foot by 1-foot gradient; and associated standard errors) for each CED activity. The average lead loadings are relative to the total amount of activity performed in the CED phase. The standard errors of the average lead loadings for each activity were calculated by using the Delta Method (Bishop, Fienberg, and Holland, 1975), which is based on asymptotic normal theory. However, the sample sizes (number of experimental units) within each CED activity are small, making these estimates only approximate. Details of the statistical methodology are presented in Section C.5 of Appendix C.

The estimated 6-foot by 1-foot gradient lead loadings for each CED activity are displayed in Figure 8C-3.

The estimated [0-1] foot SSDC and [5-6] foot SSDC loadings have different interpretations with respect to each CED activity. The [0-1] foot SSDC loading is representative of the amount of lead that is likely to fall directly underneath the surface being disrupted, while the [5-6] foot SSDC is more representative of the amount of lead that becomes airborne in dust and small particles. By comparing the estimates of the [0-1] foot SSDC to estimates for the entire gradient, we can gain some perspective on the amount of lead disturbed that is likely to stay localized, versus the amount of lead that is likely to become airborne for each activity. For example, approximately 80% of the lead in the gradient remains localized in the [0-1] foot area for the two drilling activities, while only 33% stayed localized in the abrasive sanding activity. Thus, a higher percentage of the lead disturbed becomes airborne when performing abrasive sanding in comparison to drilling. This type of information may be useful in the design of final cleanup procedures for R&R workers to help protect occupants from lead exposure.

Table 8C-7. Estimates of Lead Disturbance for Each CED Activity Based on the "Population" Random Effects Modeling of Settled Dust Lead-Loading Results[(1)]

Target Activity (i)	Substrate	Number of EU_{ijk}'s	β_{0i} ($se(\beta_{0i})$)	β_{1i} ($se(\beta_{1i})$)	[0-1] Foot SSDC Mean ($\mu g/ft^2$) (Standard Error)	[5-6] Foot SSDC Mean ($\mu g/ft^2$) (Standard Error)	6' × 1' Gradient Mean ($\mu g/6\ ft^2$) (Standard Error)
Drilling	Plaster	4	10.5 (1.10)	-1.67 (0.344)	17400 (17500)	4.08 (5.40)	21400 (20600)
Drilling	Wood	7	12.9 (0.602)	-1.47 (0.121)	205000 (116000)	130 (51.9)	266000 (143000)
Sawing	Plaster	2	11.2 (1.20)	-0.929 (0.247)	50000 (55700)	480 (330)	82300 (81400)
Sawing	Wood	6	12.6 (0.474)	-0.668 (0.117)	223000 (97500)	7900 (3450)	449000 (167000)
Abrasive Sanding	Wood	3	11.5 (0.737)	-0.341 (0.047)	85500 (62800)	15500 (11500)	257000 (188000)
Door Modification	Wood	6	11.1 (0.707)	-0.417 (0.094)	54000 (36300)	6700 (2630)	145000 (82700)
HVAC Removal	Duct	2	8.08 (2.21)	-0.375 (0.226)	2690 (5690)	414 (516)	7710 (14100)
Demolition	Plaster	9	8.77 (0.839)	-0.263 (0.071)	5690 (4630)	1530 (948)	19500 (14300)

(1) Lead in Dust ($\mu g/ft^2$) = exp (β_{0i}), exp (β_{1i} Distance).

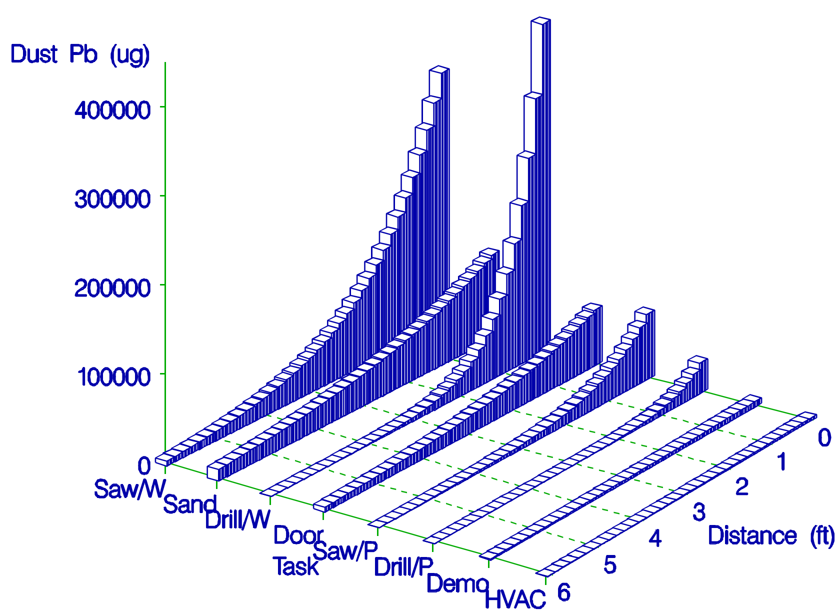


Figure 8C-3. Estimated Lead Fallout Gradient in Settled Dust from 0 to 6 Feet Away from the Edge of the Activity Space

The above results are based on the total amount of activity performed in the CED phase. To facilitate comparability in results across phases, this analysis was repeated after adjusting the amount of each activity to a "real-world" standard. The results of the standardized analysis are found in Section 8C-2.2.3.

Exposure Potential for Wood Versus Plaster Components in Drilling and Sawing

The estimated results of the lead disturbed in the 6-foot by 1-foot gradient region suggest that CED activities which disturb lead-painted wood surfaces have higher loadings than activities which disturb lead-painted plaster surfaces. This trend for the gradient lead loading is consistent with the results from the personal exposure monitoring results. Table 8C-8 presents the results of fitting statistical Model (CED-6) in Appendix C to estimate differences in slopes and intercepts that result in considering wood substrate over plaster substrate. Results are presented for drilling and sawing activities.

Although the differences in parameter estimates between wood and plaster surfaces are not statistically significant at the 0.05 level, they suggest the following:

- the positive increase in the intercept term suggests that the amount of lead found directly underneath a wood surface is greater than that for a plaster surface.

- the slight positive increase in the slope term, coupled with the negative slope estimates for both wood and plaster, suggests that the exponential decline in lead amounts with respect to distance is slower with wood than with plaster surfaces.

Table 8C-8. Estimates of the Log Increase in Intercept and Slope for the Relationship Between log ($Dust_{ijkl}$) and $Distance_{ijkl}$ that are Attributable to a Substrate Effect (Wood versus Plaster)

Activity	Parameter[1]	Parameter Estimates of the Increase in Parameter Estimates for Wood Versus Plaster	Standard Error	Degrees of Freedom	P-Value
Drilling	Intercept	2.54	1.18	9	0.06
	Slope	0.133	0.321	9	0.69
Sawing	Intercept	1.35	1.34	6	0.35
	Slope	0.271	0.254	6	0.33

(1) "Intercept" represents the baseline increase in log(Dust) associated with disturbing wood substrate versus plaster substrate. "Slope" represents the amount this baseline increase is inflated by moving 1-foot closer to the activity.

Another method of interpreting the substrate effect within these two CED activities is to examine the differences between the 6-foot by 1-foot gradient lead loading estimates for wood versus plaster. Table 8C-9 presents estimates of the log-transformed gradient region loadings (and associated standard errors) for each substrate, along with the corresponding two-sample t-test statistic. The lead gradient loadings are transformed to the natural log scale in an effort to improve the assumption of normality that is required by the two-sample t-test.

Table 8C-9. Estimated Differences in the 6' × 1' Lead Loading Gradient Attributable to a Substrate Effect (Wood verses Plaster)

CED Activity	Wood log(6' × 1' Gradient) (Std. Error.)	Plaster log(6' × 1' Gradient) (Std. Error.)	t-Statistic	Degrees of Freedom[1]	P-value
Drilling	12.5 (0.54)	9.97 (0.96)	2.29	5.0	0.07
Sawing	13.0 (0.37)	11.3 (0.99)	1.61	1.3	0.31

[1] Determined by Satterthwaite's approximation.

While the observed difference between wood and plaster results were not statistically significant at the 0.05 level, the power of the test is limited by the small sample sizes.

The estimated positive differences in measures of potential occupant exposure (intercept, slope, and lead loading gradient) between wood and plaster surfaces for these two activities might be attributable to the fact that the concentration of lead in paint on wood surfaces is generally higher than the concentration of lead in paint on plaster surfaces. This issue will be further investigated in Section 8C-2.3.2.

8C-2.2.3 Adjusting Estimates of Lead Disturbance for the Amount of R&R Activity

The generic activities of sawing and drilling, as designed in the CED phase, were not intended to reflect sawing or drilling activities to the extent that they are performed in the R&R industry. Rather, they were intended to provide sufficient activity to allow for estimating a task length average worker exposure, as well as estimating the lead disturbed by the specified amount of activity. However, the measure of the amount of lead disturbed by a CED activity is directly related to the amount of activity performed. As a result, it is desirable to express settled dustfall relative to a *"standard unit of activity"*.

As they exist in this study, the simulated target activities of demolition and HVAC duct removal represent a "real-world" standard unit of activity. For demolition, the standard unit of activity is the demolition of interior wall(s) in a single room of a building. For HVAC work, the standard is the removal of all duct work in a single room of a building. As a result, the unit of activity will not be adjusted for these two task activities. In contrast, because the generic activities of drilling and sawing, as conducted in this study, were not judged to be a reasonable representation of any "real-world" R&R activity, the amount of lead disturbed will be adjusted to a "standard unit" of activity for these activities. For drilling, this standard unit represents 10 small holes or 1 large hole. For sawing, this standard unit represents 1 linear foot cut. Subsequent estimates of the average amount of lead disturbed by that activity can then be interpreted as the amount of lead disturbed per unit activity.

Two activities could not be considered when defining standard units of activity. The positive control activity, abrasive sanding, was conducted primarily to obtain personal worker exposure measurements for comparison to other activities and cannot be accurately quantified according to the "amount of activity." Likewise, the door modification task was originally designed as a repeated task for a specified amount of time out of concern over obtaining detectable levels of airborne lead exposure. Therefore, neither of these two tasks can be adequately defined per unit of activity and are not included in the adjusted results.

Table 8C-10 presents the amount of lead in the [0-1] foot SSDC, [5-6] foot SSDC, and 6-foot by 1-foot gradient region for the "standard unit of activity" for each CED activity in which a standard unit of activity could be determined. Figure 8C-4 demonstrates the amount of lead in the gradient region per standard unit of activity. Note that by comparing Table 8C-7 with Table 8C-10, and Figure 8C-3 with Figure 8C-4, one can observe how adjusting for the "standard unit of activity" qualitatively affects the comparison of lead disturbance across different activities. Lead disturbance resulting from demolition and HVAC removal is more substantial relative to other activities when these other activities are adjusted for the amount of activity performed.

Table 8C-10. Estimates of the Potential Occupant Lead Exposure for Each CED Activity Relative to a Standard Unit of Activity[1]

CED Activity (i)	Substrate	Standard Unit of Activity	Estimated Intercept β_{0i}	Estimated Slope β_{1i}	[0-1] Ft SSDC (μg/ft^2) Mean (Std Error)	[5-6] Ft SSDC (μg/ft^2) Mean (Std Error)	6' × 1' Gradient (μg/6 ft^2) Mean (Std Error)
Drilling	Plaster	10 ¼" Holes or a 1" Hole	5.85 (1.05)	-1.68 (0.343)	168 (163)	0.04 (0.05)	207 (191)
Drilling	Wood	10 ¼" Holes or a 1" Hole	8.25 (0.605)	-1.47 (0.120)	2000 (1140)	1.27 (0.49)	2590 (1400)
Sawing	Plaster	1 Linear Foot	7.53 (1.59)	-0.947 (0.305)	1200 (1780)	10.6 (6.63)	1970 (2560)
Sawing	Wood	1 Linear Foot	8.31 (0.474)	-0.668 (0.117)	2970 (1300)	105 (46.0)	5990 (2230)
Demolition	Plaster	1 Room	8.78 (0.839)	-0.263 (0.071)	5690 (4640)	1530 (948)	19500 (14300)
HVAC Removal	Duct System	1 Room of Duct Work	8.08 (2.21)	-0.375 (0.226)	2690 (5700)	414 (516)	7710 (14100)

[1] Lead in Dust = exp(β_{0i}) exp(β_{1i} Distance)

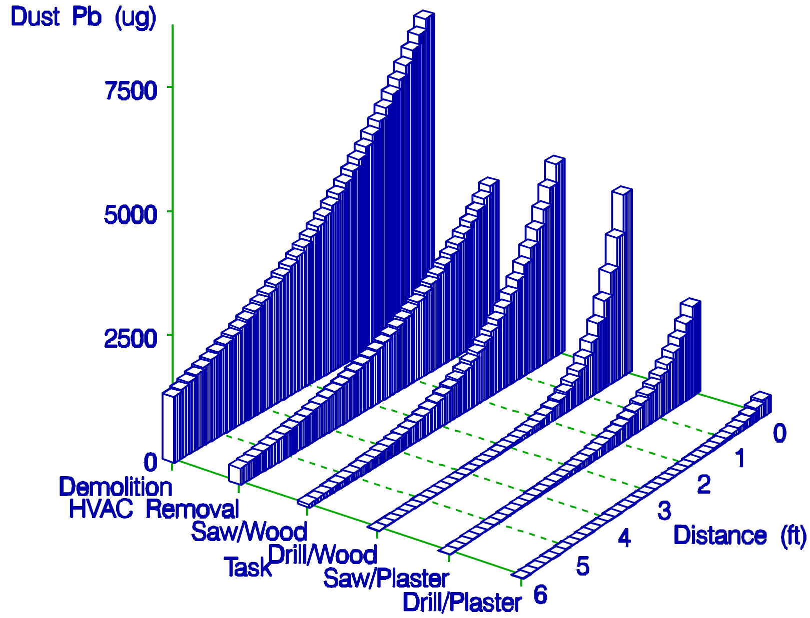


Figure 8C-4. Estimated Lead Fallout Gradient in Settled Dust, From 0 to 6 feet Away From the Edge of the Activity Space - Adjusted to the "Standard Unit of Activity"

8C-2.3 FACTORS OR MEASUREMENTS RELATED TO LEAD DISTURBANCE

8C-2.3.1 Pre-activity Measures of Lead Contamination

This section provides descriptive characterizations on the three types of pre-activity sample media considered in the CED phase. These characterizations include distributional qualities, descriptive summaries and plots for paint chip samples, dust wipe samples from HVAC systems, and pre-activity dust vacuum samples. Tables of descriptive summaries in this section present number of observations, arithmetic and geometric means, log standard deviation and minimum and maximum values.

8C-2.3.1.1 Results of Paint Chip Samples

A total of 62 paint chip samples were collected during the CED phase prior to the occurrences of those activities which disturbed lead-painted surfaces. The lead loading (mg/cm^2) for each paint chip sample was calculated by dividing the measurement of lead in the sample (mg lead) by the area of the sample in square centimeters. Table 8C-11 provides descriptive statistics on the distribution of paint chip lead loadings from samples collected from within each CED activity. The number of samples listed in Table 8C-11 total 69 (instead of 62) because samples were collected from building components disturbed by more than one CED activity. Table 8C-12 provides descriptive statistics for the distribution of paint chip lead loadings based on substrate (wood vs. plaster).

Table 8C-11. Descriptive Summaries of Paint Chip Lead Loadings (mg/cm²) from Samples Collected Within Each Activity in the CED Phase

Task Type	Number	Arithmetic Mean	Geometric Mean	Log Std. Dev.	Minimum Value	Maximum Value
Demolition	16	5.24	0.840	3.22	0.0002	17.7
Door/Wood	17	8.78	4.90	1.50	0.0587	28.7
Drill/Plaster	5	3.18	0.639	2.54	0.0130	12.7
Drill/Wood	7	7.38	5.51	1.08	0.519	13.4
Sand	10	10.4	5.03	1.61	0.285	39.9
Saw/Plaster	2	2.11	0.0401	6.58	0.0004	4.21
Saw/Wood	12	7.26	4.06	1.71	0.0266	19.5

Table 8C-12. Descriptive Summaries of Paint Chip Lead Loadings (mg/cm²) by Substrate in the CED Phase

Substrate	Number	Arithmetic Mean	Geometric Mean	Log Std. Dev.(1)	Minimum Value	Maximum Value
Wood	44	8.65	4.87	1.48	0.0266	39.9
Plaster	18	4.78	0.397	3.63	0.0002	17.7

Exploratory plots are included in Figures 8C-5 and 8C-6. Figure 8C-5 is a plot of lead loadings in paint chip samples, identified by the activity which disrupts the surface. This plot demonstrates the variability for paint chip samples within each CED activity. Figure 8C-6 is a scatterplot of paint chip lead-loadings separated by substrate (wood vs. plaster), with different symbols representing different dwelling units. Although the geometric means for paint chip loadings from wood and plaster surfaces were an order of magnitude apart, this plot indicates that the difference in paint chip lead loadings between wood and plaster surfaces was primarily the result of the difference in only one unit (Baltimore Unit 1) .

The differences in geometric mean loadings for paint chip samples collected from wood versus those collected from plaster (Table 8C-12) may help to explain the higher personal exposure and settled dust lead loadings observed for activities that disturb wood surfaces compared to plaster-disturbing activities. This issue is examined further in Section 8C-2.3.2.

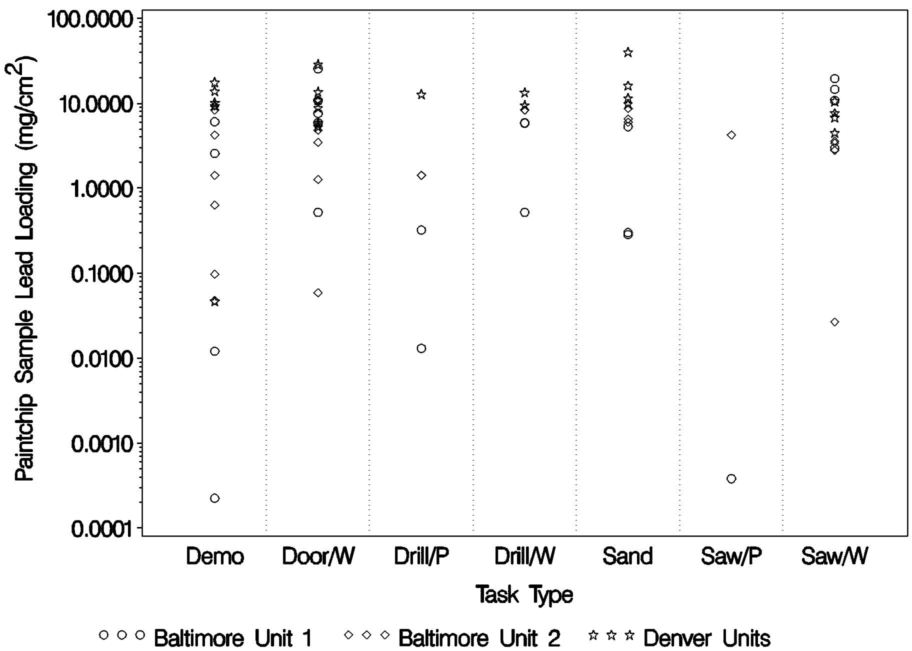


Figure 8C-5. Scatterplot of Paint Chip Loadings by Task/Unit in the CED Phase

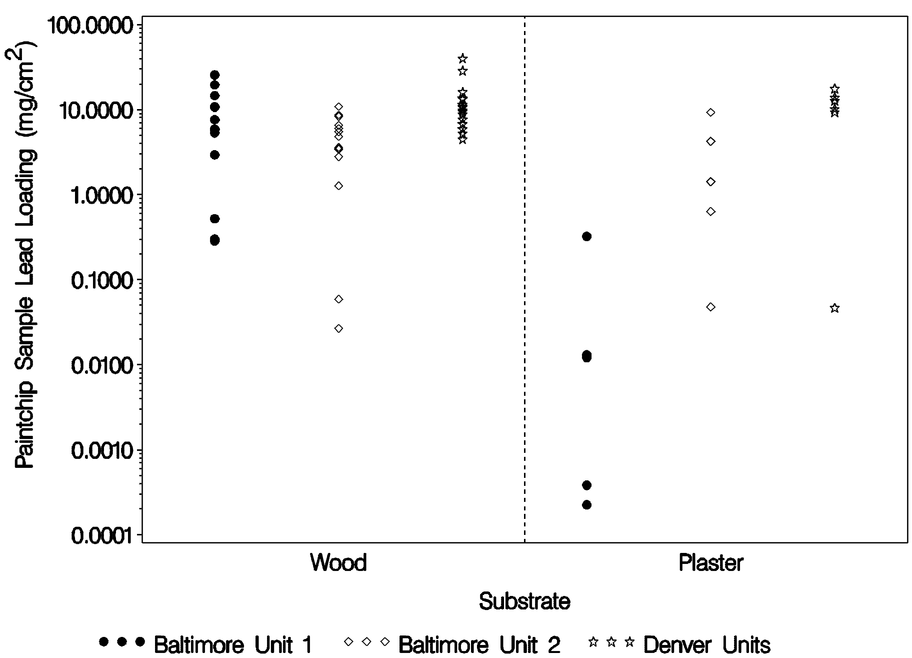


Figure 8C-6. Scatterplot of Paint Chip Loadings by Substrate in the CED Phase

8C-2.3.1.2 Results of Dust Wipe Samples from HVAC Systems

A total of 21 wipe samples were collected from HVAC systems in the CED phase. Seven wipe samples were taken from the HVAC systems in the two Baltimore housing units prior to removing portions of these systems. The remaining 14 HVAC wipe samples were collected from the HVAC systems from three housing units in Denver, where no HVAC removal was performed. Table 8C-13 presents the descriptive summaries on lead loadings for HVAC samples across units and within each unit. Geometric means suggest lead loadings in the Denver units (units 3 through 5 in Table 8C-13) were lower than the corresponding lead loadings in the Baltimore units.

Table 8C-13. Descriptive Statistics for HVAC Wipe Sample Lead Loadings Across and Within Units in the CED Phase

Unit ID	N	Arithmetic Mean ($\mu g/ft^2$)	Geometric Mean ($\mu g/ft^2$)	Log Std. Dev.	Minimum Value ($\mu g/ft^2$)	Maximum Value ($\mu g/ft^2$)
All	21	5870	2900	1.28	205	30900
1	4[(1)]	17900	14800	0.784	4880	30900
2	3[(1)]	6940	6880	0.168	5800	8120
3	5	2060	2040	0.184	1610	2650
4	5	1060	709	1.04	205	2140
5	4	3850	2700	1.01	1000	8280

(1) Samples taken before HVAC removal activities (Baltimore dwelling units).

The loading data summarized in Table 8C-13 are plotted in Figure 8C-7. This plot illustrates the variability within and between housing units. It should be noted that the unit with the lowest lead loadings contained an HVAC system attached to a furnace that was installed in 1985. These results provide an estimate of the amount of lead dust present in an HVAC system that could be made available for human exposure if the system is disturbed.

8C-2.3.1.3 Results of Dust Vacuum Samples (Pre-Activity in Denver)

Only four pre-activity settled dust samples were collected from window sills and shelves during the CED phase. These samples were taken from the same dwelling unit. Two samples were taken before a demolition activity, and two samples were taken before an abrasive sanding activity. Table 8C-14 presents the loadings and concentrations for these four samples.

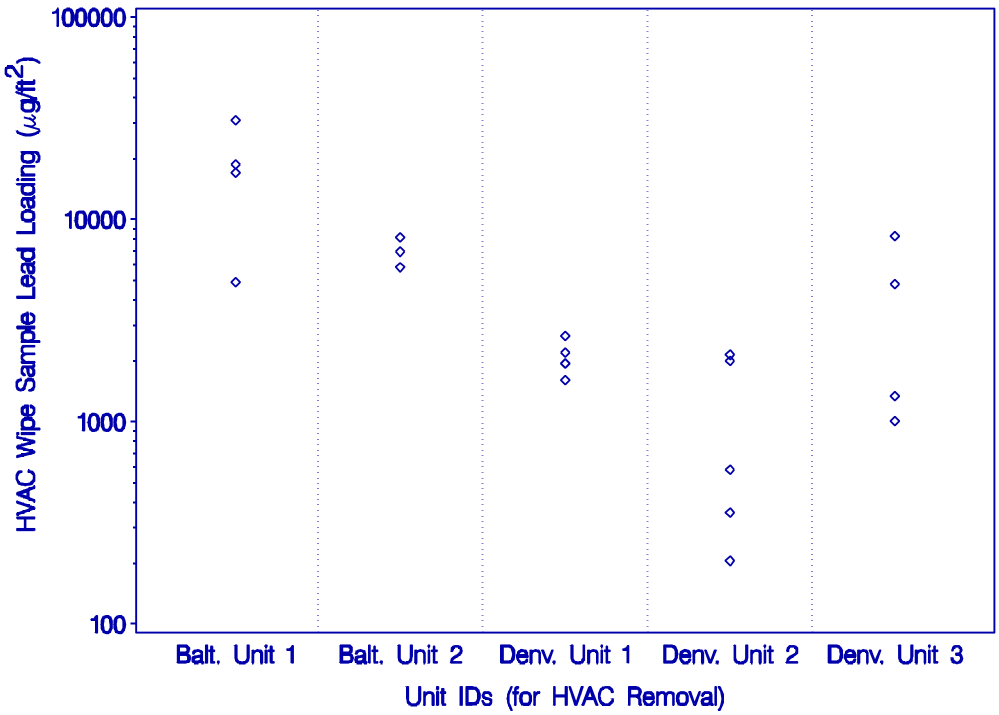


Figure 8C-7. Lead Loadings Within Wipe Dust Samples Collected from Inside HVAC Ductwork

Table 8C-14. Pre-activity Settled Dust Results (Lead Loading and Sample Concentration) from Window Sills and Shelves in the CED Phase

Activity	Surface	Loading (μg/ft^2)	Concentration (μg/g)
Sanding	Window Sill	9730	31600
	Window Sill	825	3240
Demolition	Window Sill	29100	19000
	Lower Shelf	129	431

8C-2.3.2 The Relationship Between Airborne Lead, Lead in Settled Dust, and Paint Lead Levels

In the previous sections, two hypotheses were made based on the outcome of statistical analysis that investigated the relationship between airborne lead, lead in settled dust, and paint lead levels:

1. Within a given CED activity, the observed substrate (wood vs. plaster) differences in personal exposure and settled dust results can be attributed to differences in substrate paint loadings.

2. The estimated lead loading in the [5-6] foot SSDC is representative of airborne dust and smaller particles, while the estimated lead loading in the [0-1] foot SSDC is more representative of larger debris that fell directly from the disturbed surface.

In this section, the validity of these two interpretations is tested by considering how paint lead loadings affect observed substrate differences, how [5-6] foot SSDC results are correlated with personal exposure results, and how [0,1] foot SSDC results are correlated with paint lead loadings.

The Effect of Paint Loadings

If the first hypothesis is valid, then adding a fixed effect for paint lead loadings to the statistical models that characterize personal exposure and settled dust lead loadings should substantially reduce any remaining substrate effect on these data. Tables 8C-15 (personal exposure concentrations) and 8C-16 (settled dust lead loadings) summarize the estimated substrate effects before and after adjusting for paint lead loadings, and are obtained by fitting Models (CED-7) and (CED-8) in Appendix C, respectively.

Table 8C-15. Estimated Substrate Effect on Log-Transformed Personal Exposure Concentrations (log(PEM)), Before and After Adjusting for Paint Lead Loading, in the CED Phase

Activity	Model Adjusted for Paint Lead Loadings?[1]	Parameter[2]	Estimate	Standard Error	Degrees of Freedom	P-Value
Drilling	Unadjusted	Wood vs. Plaster	0.798	0.529	8	0.17
	Adjusted	Wood vs. Plaster	0.374	0.602	7	0.55
		Paint	0.109	0.0642	7	0.13
Sawing	Unadjusted	Wood vs. Plaster	1.60	0.465	4	0.03
	Adjusted	Wood vs. Plaster	1.56	0.597	3	0.08
		Paint	0.00888	0.0606	3	0.89

(1) Indicates whether an effect for paint lead loading is included in the model.

(2) "Wood vs. Plaster" represents the increase in log(PEM) associated with disturbing wood substrate versus plaster substrate. "Paint" represents the increase in log(PEM) associated with a unit increase in paint lead loading.

The results in Table 8C-15 show that by including the effect of paint lead loading into the model, the magnitude of the multiplicative substrate effect in the drilling activity has been reduced from a 2.2 to a 1.45 fold increase when drilling into wood versus drilling into plaster ($e^{0.798} = 2.2$, $e^{0.374} = 1.45$). However, the increases are not statistically significant at the 0.05 level given the observed data and sample sizes. Essentially no reduction in the multiplicative substrate effect occurs from adjusting the model for the sawing activity.

The results presented in Table 8C-16 demonstrate that adjusting for the effect of paint lead-loading causes a large reduction in the substrate effect on the intercept term. The substrate effect for the slope of distance remains relatively stable between the two models. Moreover, the paint lead loading effect is statistically significant (p=0.03) for both activities, while the effects of wood versus plaster substrates are not.

Table 8C-16. Estimated Substrate Effect on Settled Log-Transformed Dust (log(Dust)), Before and After Adjusting for Paint Lead Loading, in the CED Phase

Activity	Model Adjusted for Paint Lead Loadings?[1]	Parameter[2]	Estimate	Standard Error	Degrees of Freedom	P-Value
Drilling	Unadjusted	Intercept Distance	2.54 0.133	1.18 0.321	9 9	0.06 0.69
	Adjusted	Intercept Distance Paint	0.730 0.160 0.258	1.329 0.412 0.114	8 9 33	0.60 0.71 0.03
Sawing	Unadjusted	Intercept Distance	1.35 0.271	1.34 0.254	6 6	0.35 0.33
	Adjusted	Intercept Distance Paint	0.594 0.268 0.148	1.359 0.278 0.066	5 6 24	0.68 0.37 0.03

(1) Indicates whether an effect for paint lead loading is included in the model.

(2) "Intercept" represents the baseline increase in log(Dust) associated with disturbing wood substrate versus plaster substrate. "Distance" represents the amount this increase in inflated by moving one foot closer to the activity. "Paint" represents the increase in log(Dust) associated with a unit increase in paint lead loading.

Overall, the data collected in the CED phase is not sufficient to reach a conclusion on whether the difference in lead paint concentration is responsible for differences in lead loadings observed between activities performed on wood and plaster.

<u>The Difference Between [0-1] Foot and [5-6] Foot Samples</u>

If the second hypothesis is valid, then it is reasonable to assume that the estimated [5-6] foot SSDCs would be positively correlated with worker personal exposure result within each experimental unit, while the estimated [0-1] foot SSDCs would be positively correlated with the observed average paint lead loadings from within each experimental unit. The estimated [0-1] and [5-6] ft SSDCs within each experimental unit are calculated by integrating the area underneath the exponentiated regression lines from 0 to 1 feet and 5 to 6 feet, respectively, based on parameter estimates from Model (CED-3) in Appendix C.

Table 8C-17 gives the estimated correlations between PEM_{ijk}, 6-foot by 1-foot lead loading $gradient_{ijk}$, [0-1] foot $SSDC_{ijk}$, [5-6] foot $SSDC_{ijk}$, and $Paint_{ijk}$, where "ijk" represents the same experimental unit. Values above the diagonal are based on the original scale, and values below the diagonal are based on the log-transformed values within each experimental unit.

Table 8C-17. Correlations of PEM Lead Concentrations, Settled Dust Lead Loadings, and Paint Lead Loadings, Within an Experimental Unit, in the CED Phase

	PEM_{ijk}	6' × 1' $Gradient_{ijk}$	[0-1] Foot $SSDC_{ijk}$	[5-6] Foot $SSDC_{ijk}$	$Paint_{ijk}$
PEM_{ijk}		0.35	0.25	0.46	0.26
$Gradient_{ijk}$	0.39		0.98	0.42	0.14
$[0\text{-}1]SSDC_{ijk}$	0.28	0.98		0.25	0.09
$[5\text{-}6]SSDC_{ijk}$	0.83	0.46	0.32		0.23
$Paint_{ijk}$	0.21	0.38	0.32	0.25	

Note: Correlations above the diagonal are based on untransformed data. Correlations below the diagonal are based on log-transformed data.

The above correlation table shows that the log(PEM) concentrations are most highly correlated with the log lead amounts in the [5-6] foot region. This result supports the contention that the estimated lead loading in the [5-6] foot SSDC is representative of airborne dust and smaller particles. A high correlation (0.98) is also observed between the log lead amount within the 6-foot by 1-foot dust gradient and the log lead amount within the [0-1] foot SSDC region on both the log-transformed and untransformed scale, indicating that the gradient measure is being driven primarily by the high lead loading levels observed near the point of activity.

8C-2.4 THE POTENTIAL FOR CROSS CONTAMINATION WITHIN R&R FIELD STUDIES

The experimental design of the CED phase specified several different R&R activities within the same housing unit. Additionally, there were potentially two different CED activities being conducted simultaneously (in different rooms) at any given time. Thus, it is possible that the measures of potential lead hazard associated with one CED activity were cross-contaminated by lead generated by another CED activity. This possibility was recognized in the experimental design of the CED phase, and was made even more apparent during an activity in which a worker cut into plaster with a circular saw causing plaster dust to be distributed throughout the dwelling unit. The following precautionary measures were taken to minimize the effects of cross contamination on the study results:

1. In preparation for the CED activities, the floors in each room were sealed with clear plastic sheeting (held down with duct tape). This was done to reduce the effects of settled dust that was present in the housing units prior to the CED phase.

2. Whenever possible, the entrances and exits to a room in which a CED activity was performed were sealed off with clear-plastic. This precautionary measure was used to minimize the effects of cross contamination from one activity to another.

3. If there was any visible dust present in a room prior to the occurrence of a CED activity, the entire room was HEPA-vacuumed and wet-wiped prior to the start of the activity.

4. Tools that were used during a CED activity were cleaned appropriately following the completion of that activity to reduce the potential for cross-contamination from one activity to another.

We can assess the effect of cross-contamination on the results of the CED phase through an investigation of some specific settled dust lead loading results in two ways:

1. One of the CED activities (drilling into wood) was performed on the same surface twice. The first occurrence of this activity was performed directly before the sawing into plaster activity. The settled dust samples from this first occurrence (collected after the sawing into plaster) were very likely to contain settled dust and debris from both the drilling into wood and the sawing into plaster. The second occurrence of the drilling activity was isolated from all other activities. Thus, a comparison between these two occurrences will give us an assessment of the extent of cross contamination that had occurred during the sawing into plaster. These data were investigated by comparing the two regression lines which predicted $\log(Dust_{ijkl})$ as a function of distance. The two intercept estimates were 10.4 and 13.5 while the slope estimates were -1.19 and -1.73. There was no statistically significant difference between the two regression lines at the 0.05 level of significance.

2. The third floor of the first housing unit had two bedrooms whose entrances were separated by a narrow hallway. Two activities (sawing wood and door modification) were performed simultaneously, one in each bedroom. The entrances to each bedroom were sealed using the clear-plastic doorways. An SSDC was placed in the hallway that separated these two bedrooms just prior to the start of these two activities. This settled dust sample was specifically designed to measure the amount of lead that is likely to escape through the clear-plastic doorways. The lead loading on this SSDC was 432 $\mu g/ft^2$.

In the first assessment, we find that the fallout of fine dust and debris from the sawing/plaster activity did not add a significant amount of lead to the settled dust samples in the drilling wood activity. The second assessment demonstrates that a substantial amount (432 $\mu g/ft^2$) of lead may escape the protective containment barriers. We feel that some of the lead that settled on this SSDC is attributable to the lead that was carried out into the hallway on the clothing of the workers. We also feel that it is unlikely that a substantial amount of lead-contaminated dust would have exited through the plastic doorway from one room and entered through the plastic doorway of another room during the course of the study.

Clearly the potential for cross-contamination of environmental field samples existed in the CED phase. Given the substantial amount of lead disturbed by the CED activities under investigation, it is unlikely that the amount of cross-contamination that occurred during the CED phase had a qualitative impact on the overall results.

8C-2.5 DISCUSSION OF THE RESULTS OF THE CED PHASE

Table 8C-18 presents estimates of observed lead levels associated with worker personal exposure and lead in settled dust, for each CED activity. The model estimate of the geometric mean of the personal exposure lead concentrations, and the estimated amount of lead in settled dust within a 6-foot by 1-foot region from the activity are summarized in this table.

The major result of the CED phase becomes clear when studying Table 8C-18:

The amount of lead disturbed by the CED activities was substantial.

Table 8C-18. Statistical Estimates, with Standard Errors, of Worker Personal Exposure to Airborne Lead, and 6' × 1' Gradient Dustfall Lead Amounts for Each CED Activity

Activity	Substrate	Model Estimates: Geometric Mean of PEM Concentration ($\mu g/m^3$)[(1)] (with LOG Standard Error)	Model Estimates: Lead Amount in 6' x 1' Gradient (μg)[(2)] (with Standard Error)
Target Activities in the CED Phase			
Demolition	Plaster	108 (0.325)	19500 (14300)
HVAC Removal	Dust	49.6 (0.116)	7710 (14100)
Generic R&R Tasks			
Door Modification	Wood	590 (0.574)	145000 (82700)
Sawing	Wood	546 (0.155)	449000 (167000)
Sawing	Plaster	110 (0.783)	82300 (81400)
Drilling	Wood	15.1 (0.489)	266000 (143000)
Drilling	Plaster	6.76 (0.255)	21400 (20600)
Abrasive Sanding	Wood	254 (0.424) (Hand) 571 (0.602) (Power)	257000 (188000)
Component Removal	Wood	344 (0.0319)	--
Cleanup	Wood	102 (0.145)	--
Cleanup	Plaster	24.5 (0.275)	--

(1) Geometric mean results from exponentiating the estimated intercept term of Model (CED-1) in Appendix C. The log standard error is associated with the intercept estimate. These estimates are also found in Table 8C-4.

(2) Lead amount is estimated by fitting Model (CED-5) to SSDC settled dust lead loadings, then integrating under the curve from 0 to 6 feet distance. This approach is detailed in Section 8C-2.3.2 and Appendix C.

The estimated geometric mean worker personal exposure to airborne lead over the duration of activity was above the OSHA PEL of 50 $\mu g/m^3$ in every CED activity with the exception of drilling into either plaster or wood, HVAC removal, and cleaning up after activities which disturbed lead painted plaster. The average lead-loading in the gradient region was greater than 1000 $\mu g/ft^2$ for all CED activities as they were performed.

Secondary results of the CED phase are:

1. CED activities which disturb lead-painted wood surfaces are generally associated with higher personal exposure to airborne lead and higher lead levels in settled dust when compared to CED activities which disturb lead painted plaster surfaces. This effect is confounded with the fact that wood surfaces generally had higher concentrations of lead-based paint in comparison to plaster surfaces.

2. Settled dust found in interior HVAC duct work had high levels of lead. This lead can be exposed to workers and occupants if the HVAC systems are disturbed.

8D-1.0 INTRODUCTION AND OBJECTIVES OF THE CLEANUP INVESTIGATION

As presented in Section 1.1, one of the primary technical objectives of the R&R study was to determine the extent to which R&R workers disturb lead and create a lead-based paint exposure to occupants or other exposed individuals while conducting R&R activities. The three study phases of the EFSS (Sections 8A through 8C) collected lead loading data from settled dust samples before cleanup in support of this objective. These data do not address the extent to which typical cleanup procedures reduce lead levels in dust that settles following the activity. In response to this concern, the EFSS included the design and conduct of a field study addressing the effect of typical cleanup procedures on potential occupant lead exposures.

The EFSS cleanup investigation had the following technical objectives:

- Compare post-activity lead loading results within settled dust collected before cleanup versus results in dust collected after cleanup, and determine how the outcome of the comparison is a function of the cleanup method used.

- Characterize lead loadings in settled dust that is likely to remain after R&R work and typical cleanup procedures are completed.

The cleanup investigation in the EFSS was designed as an independent follow-on to the CED study phase presented in Section 8C. As in the CED phase, the cooperation of the Denver (CO) Housing Authority (DHA) was solicited to provide vacant housing units for conducting simulated R&R activities in a controlled environment. An apartment complex previously used in the CED phase (and thereby screened for the presence of lead-based paint hazards) was the site for the cleanup investigation. As they did in the CED phase, the DHA provided trained abatement workers to conduct the R&R activities in these units. The workers used the same protocols established for the CED study phase.

8D-2.0 STUDY DESIGN IN THE CLEANUP INVESTIGATION

To address the objectives for the cleanup investigation, the study design considered two different methods of cleanup that were applied after performing two different types of generic R&R activities. The two cleanup methods were selected as those typically used by many R&R workers:

- dry (broom) sweeping, and
- use of an industrial non-HEPA vacuum cleaner (Shop-Vac®).

The cleanup procedures were performed as if the R&R worker had completed carpentry work in a private residence and wanted to clean the work area prior to the completion of the job.

The two R&R activities, both conducted on wood door surfaces covered with lead-based paint, were:

- drilling (using a ¼" drill bit), and
- abrasive (power) sanding.

Protocols for conducting these activities were the same as those used in the CED phase (see Section 8C-1.1.1). Each activity was scheduled to be no longer than one hour in duration. Each combination of R&R activity and cleanup method was replicated three (3) times, for a total of twelve (12) field study experiments. These experiments were labeled "experimental units".

As a means of minimizing cross-contamination across units, the study directed that the twelve experimental units be conducted in separate apartments within the complex. However, as only nine apartments were made available to this study, four of the experimental units were conducted in different rooms of a single apartment, while the remaining experimental units were conducted in separate apartments. Other precautionary measures taken to minimize cross-contamination from other sources included:

- The floors, vents, and entrances of the activity room were sealed with clear plastic sheeting (held down with duct tape), to reduce the effects of settled dust present in the apartment prior to the investigation and to minimize the transfer of dust from one activity room to another.

- To characterize the level of any potential contamination that could have resulted from the demolition of buildings within the complex that occurred simultaneously with the investigation, two paired dust-vacuum samples were collected from SSDCs that were left overnight in previously unused activity rooms.

As was the practice throughout the EFSS, no attempt was made to minimize dust generation during the activity.

8D-2.1 SAMPLING DESIGN IN THE CLEANUP INVESTIGATION

The sampling design of the cleanup investigation was established to characterize the following:

- levels of lead in the paint on surfaces disturbed by the R&R activity

- lead loadings in dust that settles following completion of the R&R activity, taken at varying distances from the activity both prior to and following cleanup

- lead loadings in dust that settles up to one day following the activity and cleanup

- how lead loadings differ between dust-vacuum samples and dust-wipe samples

- how lead loadings differ between dust-vacuum samples taken at adjacent locations ("side-by-side").

Within an experimental unit, an area was identified where the specified R&R activity and subsequent cleanup method would be performed. The door on which the activity would be performed was confirmed to contain lead-based paint by use of a portable X-ray fluorescence (XRF) analyzer. In addition, a single paint chip was taken from the door surface for laboratory analysis to more accurately characterize lead levels in the paint that would be disturbed as a result of the activity.

Immediately prior to the start of the activity within an experimental unit, a clean 4'x8' piece of new linoleum sheeting (mounted on plywood) was placed on the floor at the base of the activity. The linoleum represented a pristine floor surface that became contaminated only by the conduct of the R&R activity. The design associated with collecting settled dust samples from the linoleum surface is presented in Figure 8D-1.

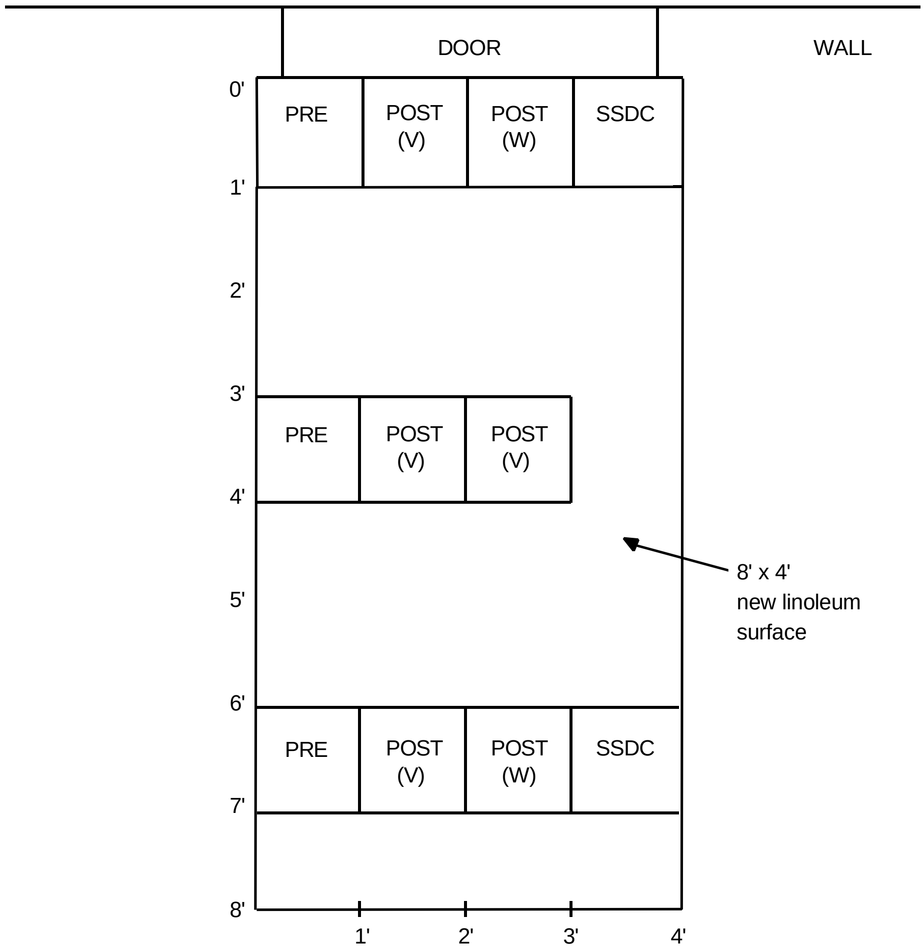
Approximately one hour after the completion of the activity, but prior to the start of cleanup, dust-vacuum samples were collected from three one-square-foot areas of the linoleum surface, each at a specified distance from the activity (0, 3, and 6 feet). The three samples represented the total amount of lead that was disturbed by the activity and settled at the given distances from the activity.

After the three pre-cleanup dust samples were collected, the linoleum surface was cleaned by the method assigned to the experimental unit. Then, six additional one-square-foot areas were identified on the linoleum surface from which post-cleanup settled dust samples were collected (Figure 8D-1). Four of the six samples consisted of two pairs of dust-vacuum/dust-wipe samples (i.e., one sample within the pair collected by vacuum techniques, the other collected by wipe techniques), where the two samples within a pair were taken from adjoining locations (i.e., side-by-side). The remaining two samples were a side-by-side pair of dust-vacuum samples. Wipe samples were taken in order to compare results to lead clearance testing standards. Once the post-cleanup dust samples were taken, two stainless steel dustfall collectors (SSDCs) were placed on the linoleum surface. A dust-vacuum sample was collected from each SSDC on the morning of the next day. These samples were taken to characterize the amount of airborne lead that is likely to settle after cleanup has been performed.

Table 8D-1 presents the proposed types and numbers of environmental field samples (both regular and QC samples) collected within each experimental unit in the cleanup investigation. Methods used to collect paint and dust samples followed the same field sampling protocols applied throughout the R&R study.

8D-3.0 STUDY RESULTS FOR THE CLEANUP INVESTIGATION

Analytical data were available for statistical analysis from all environmental field samples that were collected in the cleanup investigation. These data included lead loadings in paint chip samples (expressed in mg/cm^2) and settled dust samples (expressed in $\mu g/ft^2$). Data are summarized by sample type and collection method in Tables Cl-1 through Cl-4 in Section A.4 of Appendix A.



Note: Positioning of samples within a given distance from activity differed among the experimental units.

Legend:

PRE	=	Pre-cleanup dust-vacuum sample location
POST (V)	=	Post-cleanup dust-vacuum sample location
POST (W)	=	Post-cleanup dust-wipe sample location
SSDC	=	Next-day SSDC dust-vacuum sample location

Figure 8D-1. Settled Dust Sampling Locations Specified by the Sampling Design for the Cleanup Investigation

Table 8D-1. Numbers and Types of Environmental Samples (Regular and QC) Proposed in the EFSS Cleanup Investigation

Regular Samples

When Sample Was Taken	Sample Collection Method	Sample Type/Location	Number Proposed per Exp. Unit[1]	Total Number Proposed
Pre-Activity	Chipping	Paint chip (wood door)	1	12
Post-Activity, Pre-Cleanup	Vacuum	Settled dust (linoleum surface)	3	36
Post-Cleanup	Vacuum	Settled dust (linoleum surface)	4	48
	Wipe	Settled dust (linoleum surface)	2	24
Next Day	Vacuum	Settled dust (SSDC)	2	24
		TOTAL	12	144

Field QC Samples

When Sample Was Taken	Sample Collection Method	QC Sample Type	Proposed Frequency of Sampling	Total Number
Pre-Activity or Pre-Sampling	Paint Chip	Field blank	1 per activity day	3
	Vacuum	Field blank	1 per vacuum sampling day	4
	Wipe	Field blank	1 per wipe sampling day	3
			TOTAL	10

(1) See Figure 8D-1 for position of dust-vacuum and dust-wipe sample locations relative to the R&R activity.

8D-3.1 LEAD LEVELS IN PAINT TO BE DISTURBED

To characterize lead levels in paint to be disturbed as a result of R&R activity, paint chip samples were taken from each of the twelve wood doors on which the activities would take place. Three paint chip results were associated with each of the four combinations of activity and cleanup method, one result for each time the activity/cleanup combination was performed in this investigation. The measured lead levels in paint chips are summarized in Table Cl-1 of Appendix A (Section A.4). The combination with the highest observed lead levels in paint was abrasive sanding/vacuum cleanup, where all three lead levels exceeded 12 mg/cm^2. For drilling/vacuum cleanup and abrasive sanding/broom sweeping, two of the three paint chip lead results exceeded 1.0 mg/cm^2. Only one of the three results exceeded 1.0 mg/cm^2 for drilling/broom sweeping. Even in situations where low results were observed, however, conduct of the activity resulted in high levels of lead in post-activity settled dust samples as illustrated in Table Cl-2 in Appendix A and discussed below.

8D-3.2 PRE- VERSUS POST-CLEANUP RESULTS

In characterizing the difference in post-activity settled dust lead loadings between pre- and post-cleanup, loadings from post-cleanup dust-wipe samples were compared to the pre-cleanup dust-vacuum samples at a given distance from the activity. Wipe samples rather than vacuum samples were chosen to characterize post-cleanup lead loadings, as only small amounts of dust tended to remain following cleanup. Wipe sampling techniques are typically more efficient at measuring lead loadings from smooth surfaces with small amounts of dust, while vacuum techniques are more appropriate when large amounts of dust are to be collected. This is evident from Table Cl-3 in Appendix A (Section A.4), where dust-wipe lead loadings were consistently higher than vacuum-wipe lead loadings at the same distance from the activity for the less-dirty drilling activity, while the highest lead loadings among the more-dirty abrasive sanding activity were observed among vacuum-dust samples.

For each target activity and cleanup method, Table 8D-2 presents the geometric mean lead loading in pre-cleanup dust-vacuum samples, along with the average ratio of post-cleanup dust-wipe sample loading to the pre-cleanup sample loading observed on the same surface at the same distance from the activity. At each distance, pre-cleanup loadings tended to be higher for abrasive sanding than for drilling. Reasons for this finding could include higher lead loadings in the paint associated with abrasive sanding activities, as well as differences in the activities. At the zero-feet distance, post-cleanup lead loadings averaged one percent or less of the corresponding pre-cleanup lead loadings for each activity and cleanup method. Based on results of a paired t-test on log-transformed lead loadings, these declines are statistically significant at the 0.05 level. In contrast, little if any reduction is observed at the six-feet distance. For all but abrasive sanding/vacuum cleanup, the average ratio of post-cleanup to pre-cleanup results on the same floor surface exceeded one. In each case, however, the paired t-test results indicated that the average ratio did not statistically differ from one. This implies that the cleanup methods conducted in this investigation do little to cause statistical changes in dust lead levels at this distance. Therefore, one can conclude that the efficiency of cleanup, as measured by a percent reduction of lead loadings in remaining dust, declines as distance from the activity increases. This conclusion holds for both activities considered in the investigation, even though pre-cleanup lead loadings tended to be higher for one activity.

The same statistical methods used in the CED phase to characterize lead levels in settled dust were applied in the cleanup investigation for both pre-cleanup and post-cleanup sample lead loadings. This approach involved fitting a regression model for each combination of R&R activity and cleanup method to express log-transformed lead loadings as a function of distance from activity and experimental unit. A form of the "population" random effects model (model

Table 8D-2. Geometric Mean of Pre-Cleanup Lead Loadings, and the Average Ratio of Post- to Pre-Cleanup Lead Loadings on the Same Floor Surface

		0 Feet from Activity		6 Feet from Activity	
R&R Activity	Cleanup Method	Geometric Mean Loading (Pre-Cleanup)	Average Ratio of Post- to Pre-Cleanup Lead Loadings on a Floor Surface	Geometric Mean Loading (Pre-Cleanup)	Average Ratio of Post- to Pre-Cleanup Lead Loadings on a Floor Surface
Drilling	Broom	26,700	0.013*	65.0	3.65
Drilling	Vacuum	73,500	0.008*	146	1.12
Abrasive Sanding	Broom	653,000	0.007*	1380	1.77
Abrasive Sanding	Vacuum	203,000	0.010*	491	0.69

Note: Geometric means in this table are rounded to three significant figures.

* The average difference (taken across experimental units) between (log-transformed) post-cleanup result and pre-cleanup result on a given floor surface is significantly different from 0 at a 0.05 level.

(CED-5) of Appendix C) was fit separately for pre- and post-cleanup sample lead loadings and for each combination of activity (i) and cleanup method (j):

$$\log(Dust_{(ij)kl}) = \beta_{0(ij)} + \beta_{1(ij)} Distance_{(ij)kl} + R_{0(ij)k} + R_{1(ij)k} Distance_{(ij)kl} + e_{(ij)kl} ,$$

where

$Dust_{(ij)kl}$ is the dust lead loading (µg/ft^2) measured on the lth sample from the kth occurrence of activity i and cleanup method j

$Distance_{(ij)kl}$ is the distance (ft) from the activity of the lth sample from the kth occurrence of activity i and cleanup method j

$\beta_{0(ij)}$ is the baseline average log-loading for samples associated with activity i and cleanup method j

$\beta_{1(ij)}$ is the slope relating log-loading to distance from activity for samples associated with activity i and cleanup method j

$R_{0(ij)k}$ is a random effect which represents how the baseline average log-loading for the kth occurrence of activity i and cleanup method j differs from the overall average $\beta_{0(ij)}$

$R_{1(ij)k}$ is a random effect which represents how the slope associated with the kth occurrence of activity i and cleanup method j differs from the overall slope $\beta_{1(ij)}$

$e_{(ij)kl}$ is the error term.

The goal of fitting this model to the observed dust-lead loading data was to estimate average lead loading in settled dust, expressed as a function of distance from the activity. A curve quantifying this relationship was determined for each combination of activity and cleanup method, and for pre- and post-cleanup lead loadings. The curve expresses (untransformed) average lead-loadings as follows:

$$Lead\text{-}loading(\mu g/ft^2) \quad = \quad \exp(\beta_{0(ij)}) \cdot \exp(\beta_{1(ij)} Distance)$$

where the slope and intercept terms were estimated from the model fit. By integrating the area underneath this curve from distance=0 to 1 foot, we obtain the expected lead-loading of an area within one foot of the activity. Similarly, by integrating this curve from distance=5 to 6 feet, we obtain the expected lead-loading of an area located 5-6 feet from the activity. The measure that was chosen in the R&R study to represent lead disturbance and the potential hazard to occupants from lead in settled dust is the lead loading within a 6-foot by 1-foot gradient region extending from the activity. This measure was determined by integrating the area underneath the estimated curve from distance=0 to 6 feet. See Section C.5 of Appendix C for more detailed discussion of the gradient lead-loading.

The estimated average pre- and post-cleanup lead loadings from 0-1 feet and 5-6 feet from the activity, and the estimated gradient lead loading are presented in Table 8D-3 for each combination of activity and cleanup method. Also included in this table are the standard errors associated with these estimates, which were obtained by the Delta Method (Bishop, Fienberg, and Holland, 1975) (see Section C.5 of Appendix C). It should be noted that while the sample sizes (i.e., number of experimental units) within each activity/cleanup method combination are relatively small, the Delta Method is based in asymptotic normal theory. As a result, the standard errors are likely only rough approximations.

The estimated lead loadings in the 0-1 foot area and 5-6 foot area have different interpretations. The 0-1 foot area loading is representative of the amount of lead that is likely to fall directly underneath the surface being disrupted, while the 5-6 foot area loading is more representative of the amount of lead that becomes airborne in dust and small particles and settles at a distance from the activity. By comparing these two estimates, one gains some perspective on the amount of disturbed lead that is likely to stay localized, versus the amount that is likely to become airborne.

For both activities in the cleanup investigation, approximately 65% of the lead in the gradient settled within one foot of the activity, even though higher lead loadings (both pre- and post-cleanup) were associated with abrasive sanding than with drilling. Therefore, while differences in lead loadings may exist among the activities, the relative distribution of lead within 6 feet of the activity was consistent. This type of information may be useful in the design of final cleanup procedures for R&R workers to minimize occupant exposures resulting from the activity.

Table 8D-3. Estimated Lead Loadings (μg/ft^2, with Standard Errors) for Pre- and Post-Cleanup, and Percent Reduction from Pre- to Post-Cleanup Periods, As Estimated from Statistical Modeling Procedures

R&R Activity	Method of Cleanup	Time of Sample Collection (Post-Activity)	Lead Loadings: 6' × 1' Gradient (μg/6ft^2)	Lead Loadings: 0 to 1 foot from Activity (μg/ft^2)	Lead Loadings: 5 to 6 feet from Activity (μg/ft^2)
Drilling	Broom	Pre-Cleanup	22,400 (27,900)	14,200 (18,400)	94 (128)
		Post-Cleanup	885 (661)	166 (122)	130 (99)
		% Reduction	96.0%	98.8%	(38.3%)
Drilling	Vacuum	Pre-Cleanup	54,300 (126,000)	35,100 (86,400)	197 (243)
		Post-Cleanup	1450 (1250)	361 (382)	147 (94)
		% Reduction	97.3%	99.0%	25.4%
Abrasive Sanding	Broom	Pre-Cleanup	305,000 (608,000)	196,000 (426,000)	1155 (1738)
		Post-Cleanup	5800 (6350)	1070 (1120)	865 (999)
		% Reduction	98.1%	99.5%	25.1%
Abrasive Sanding	Vacuum	Pre-Cleanup	269,000 (566,000)	171,000 (365,000)	1129 (2101)
		Post-Cleanup	3350 (1240)	809 (282)	357 (192)
		% Reduction	98.8%	99.6%	68.4%

On an average basis across the investigation, Table 8D-3 shows that for both activities and under both cleanup methods, post-cleanup lead loadings were more than 95% reduced from pre-cleanup levels over the entire gradient region, as well as within one foot of the activity. However, at 6 feet from the activity, only marginal reductions in lead loadings were observed on a percentage basis. There is evidence from Table 8D-3, however, that vacuum cleanup methods may perform better than dry sweeping methods at the 6-foot distance when considering the percent reduction in lead loadings from pre- to post-cleanup. These results were consistent for both activities and with the results of the paired analysis summarized in Table 8D-2.

8D-3.3 POST-CLEANUP RESULTS

Post-cleanup lead loadings for samples collected by wipe sampling techniques were used to characterize the amount of lead remaining following the activity and cleanup to which occupants may be exposed. Wipe sample results were directly comparable to the EPA interim health-based standard of 100 μg/ft^2. As a result, wipe sample results were more relevant than vacuum sample results for making conclusions on lead levels relative to potential occupant exposure.

As seen in Tables 8D-2 and 8D-3, post-cleanup lead loadings were substantially reduced from pre-cleanup levels. However, the post-cleanup values often remained above EPA's internal health-based standard of 100 µg/ft^2, even at 6 feet from the activity. For both cleanup methods, post-cleanup lead loadings tended to be higher for the abrasive sanding activity than for the drilling activity. From these results, one may conclude that the typical cleanup methods considered in this investigation reduce available lead loadings on surfaces, but potentially more efficient methods (or repeated applications of the typical methods) are necessary to clean surfaces to meet indicated standards.

8D-3.4 NEXT-DAY SSDC LEAD LOADING RESULTS

To characterize the amount of airborne lead that settles after cleanup, dust-vacuum samples were collected the morning following activity and cleanup from two SSDCs positioned on the linoleum surface upon conclusion of cleanup. The SSDCs were placed at 0 and 6 feet from the activity (see Figure 8D-1). Table Cl-4 of Appendix A (Section A.4) provides descriptive statistics of dust lead loading at both distances for each combination of activity and cleanup method. The lead levels in these samples were low to moderate; the geometric mean exceeded 100 µg/ft^2 in only one situation (abrasive sanding, broom sweeping, at 5-6 foot distance).

Interpreting the results of the next-day SSDC dust samples was complicated by the potential for contamination by sources other than the R&R activity, such as the demolition of neighboring buildings within the apartment complex. To characterize the amount of contamination from outside sources, four vacuum samples were collected from SSDCs that were left overnight in previously unused activity rooms. The lead loadings in these four samples ranged from 28.0 to 311 µg/ft^2. Because these samples show high potential for cross-contamination from outside sources, it is possible that lead levels in the next-day SSDC dust samples were affected by these sources. However, the settled dust results from pre- and post-cleanup samples were likely not affected by outside sources, as they were collected within one hour of activity or cleanup.

8D-3.5 CONCLUSIONS

The following conclusions can be made as a result of the findings determined from the cleanup investigation:

- Both cleanup activities considered in this investigation led to substantial reductions in lead loadings in settled dust. This result was more apparent immediately adjacent to the activity, where post-cleanup lead loadings were more than 95% reduced from pre-cleanup levels. However, the efficiency of cleanup declined as distance from the activity increased. The extent of decline in efficiency, however, was more apparent for dry sweeping methods than for vacuum cleanup methods.

- For purposes of planning cleanup strategies, it was determined that approximately 65% of the lead in the estimated 6-foot by 1-foot gradient for both activities settled within one foot of the activity. This result held regardless of the magnitude of lead loadings existing within 6 feet of the activity.

- Despite performing the cleanup procedure, post-cleanup lead loadings were observed to exceed EPA's internal health-based standard of 100 $\mu g/ft^2$, even at 6 feet from the activity. Post-cleanup lead loadings tended to be higher for the abrasive sanding activity than for the drilling activity for both cleanup methods. As a result, potentially more efficient cleanup methods (or repeated applications of the methods considered in this investigation) are necessary to clean surfaces to at or beyond indicated standards, despite the marked decrease in lead loadings that can result from conducting cleanup procedures.

8E-1.0 DESCRIPTION OF RELEVANT DATA LOCATED FROM OTHER SOURCES

The approach taken to uncover other extant sources of data that relate R&R activities to lead exposures is discussed in detail in Section 2.4 of Chapter 2.

The minimum requirements for accepting a source of extant data as applicable to the objectives of the EFSS included the following:

1. The source needed to provide data related to activities that can be considered representative of renovation and remodeling work as it is currently being conducted in an unregulated environment.

2. The source needed to provide either task-length personal exposure measurements or settled dust measurements related to a well-specified R&R target activity, generic task, or combination of R&R activities.

3. The activities needed to be conducted in an environment with lead-based paint present. (Specifically, the lead in paint chips measurements from surfaces in the activity area needed to be above 0.5% by weight or 1.0 mg/cm^2.)

4. The sampling and analysis methods needed to follow standard protocols and meet minimum quality assurance standards.

Eight studies were identified as having collected data that met these requirements. The studies included data on cleanup, component removal, demolition, exterior siding, surface preparation, and window replacement. Surface preparation was the only activity not monitored in the EFSS for which sufficient data are available from other sources to allow for estimating average exposure levels. All studies collected task length personal exposure data and provided information on lead levels in paint on surfaces to be disturbed by the activity. In addition, one study included data from settled dust samples collected on 1 ft^2 tiles. Descriptions of the eight sources of data are given below:

<u>CONSAD Research Corporation</u>

Under contract with OSHA, CONSAD Research Corporation in Pittsburgh, Pennsylvania, collected personal exposure data from a series of construction projects throughout the United States. The exposure information was collected to provide data for OSHA's Interim final standard for lead in construction. The documented studies ranged from large industrial paint removal projects to residential window replacement. Three studies, performed between March 1991 and January 1993, involved R&R activities targeted in the EFSS. The first study involved surface preparation — removing lead-based paint from metal door jams and from walls and ceilings by dry scraping. The second study, characterized as component removal, documented the removal of interior wood trim using a hammer and claw-bar. The third study monitored the demolition of interior walls and ceilings in a home using hammers and claw-bars. These studies were performed in situations which reflected a typical R&R setting. Although some of the workers were familiar with lead-dust minimization practices, no such practices were used during the monitored studies.

NIOSH, Ohio University Cleanup

During a three-day period in early May 1992, NIOSH conducted a comparison study of lead paint cleanup methods on the campus of Ohio University in Athens, Ohio. The building in which the study was conducted was built in 1873, had been unoccupied for many years, and had much loose and peeling paint on the walls. Although the study was classified by NIOSH as a study of cleaning methods, it is considered a combined study of both surface preparation and cleanup relative to the EFSS definition of target activities. Three methods of surface preparation and cleaning were compared:

- dry scraping followed by dry broom sweeping
- misting painted surfaces with water and scraping (wet scraping) followed by high-efficiency particulate air-filtered (HEPA) vacuuming
- wet scraping followed by HEPA vacuuming, with a HEPA-filtered air-filtration device (AFD) placed in the room to exhaust room air to the outside.

Eighteen rooms were cleaned by three crews of two workers, with each crew employing the three cleaning methods in two rooms each. All the work was performed on one day. All 18 rooms had detectable lead concentrations in paint chips, but nine did not have mean levels above the federal lead-based paint criterion of 0.5% lead by weight. The nine that did have lead levels in paint chips above 0.5% had levels ranging from 2.8% - 19% lead by weight (NIOSH, Ohio University, May 1993). Since the building as a whole was considered to be highly contaminated with lead, all results were included in the analysis.

To compare the personal exposure data collected in the Ohio University study to data from the EFSS, the three cleaning methods were subsetted into two categories: dry methods and wet methods. The dry methods included only the dry scraping with dry sweeping, while the wet methods included wet scraping followed by HEPA vacuuming, as well as wet scraping followed by HEPA vacuuming and use of a negative-air AFD.

National Association of Home Builders (NAHB)

The National Association of Home Builders (NAHB) provided personal exposure information for a case study of the airborne lead produced when painted wooden shingles were removed from a garage in Atlantic City, New Jersey. The garage had two layers of shingles, with only the top layer painted with lead-based paint. For approximately three hours, a home owner removed shingles from a 260 square-foot section of his garage using a flat pry bar to remove the shingles and a hammer to remove the nails. During the process, some of the shingles split, causing dust to be generated. While only one personal exposure data point was reported for this activity, this is the only source of information on the possible lead exposures generated when exterior siding is removed.

New York State Department of Health

This study was conducted by the New York State Department of Health in Albany, New York, during February 1994. The purpose of the study was to characterize the personal exposures residential house painters encounter while performing various R&R activities. The activities monitored included manual scraping with a putty knife, manual sanding, and window removal, with many of the activities occurring both inside and outside of the homes. The activities were classified into R&R target activities as follows: manual scraping and manual sanding as surface preparation (exterior and interior), and window removal as window replacement.

One of the two personal exposure samples collected during window replacement was taken in an environment where the lead concentration in paint chips was reported as 0.22%. However, the corresponding personal exposure result was 151 $\mu g/m^3$, indicating significant exposure even in the absence of high levels of lead in the paint (New York SDH, February 1994). Because of the information on potential lead exposure offered by this sample, the result was included in the analysis despite the lead concentration in paint chips being below 0.5%.

NIOSH, Cincinnati - "People Working Cooperatively"

From June 1993 through June 1994, NIOSH recorded the personal exposures of individuals working in the "People Working Cooperatively" program in Cincinnati, Ohio. The workers in this program provide home repair, emergency repair, and weatherization services to low-income elderly, disabled, and other qualified single-family homeowners. In this study, the homes visited were generally built before 1960. Target R&R activities for which personal exposures were observed included exterior wet and dry scraping and window replacement. The exterior wet and dry scraping activities were considered representative of surface preparation. Reported data for other target activities, such as demolition, were excluded from analysis because the lead concentration in paint chips was either not reported or less than 0.5%.

U.S. Army Environmental Hygiene Agency

The U.S. Army Environmental Hygiene Agency conducted a study of lead exposure levels generated by five different surface preparation methods performed over a five-day period in April 1992. The study was conducted in four military buildings in Maryland scheduled to be demolished: three housing buildings and one office building. During the five-day period, personal exposure levels were collected from six maintenance workers on three-hour shifts, using one of five surface preparation methods. The surface preparation methods were wet scraping, dry scraping, wet wire brushing, dry wire brushing, and metal wheel brushing. The purpose of the study was to evaluate lead exposures generated by the different surface preparation methods and to determine whether regulations needed to be implemented to prevent high exposures. In order to compare results with the EFSS, the results from this study were identified by sample method (wet/dry) and location (interior/exterior). The metal wheel brush method was categorized as a dry interior method.

U.S. Air Force

The Occupational and Environmental Health Dictorate of Armstrong Laboratory, Brooks Air Force Base, Texas, conducted a study to determine if R&R work performed on Air Force Military Family Housing (MFH) resulted in personal air exposures above the OSHA action level of 30 $\mu g/m^3$. R&R work was performed on three Air Force bases throughout the country. The activities performed were characterized as renovation, maintenance, and deleading. Deleading activities were classified as component removal, since the actual deleading of the components was performed off-site, and the exposure samples were collected while the components were being removed. During the study, more than 200 personal air samples were collected. Unfortunately, most of the personal exposure samples were associated with activity areas in which levels of lead in paint chips were not above 0.5% concentration by weight or 1 mg/cm^2. This eliminated over 75% of the available data points according to the minimum acceptance criteria stated earlier. Activities observed for samples that did meet these criteria were classified into targeted R&R activities as follows:

- Cleanup: Renovation cleaning
- Component Removal: Renovation baseboard removal and door frame removal
- Exterior Surface Preparation: Exterior renovation by hand sanding and scraping
- Interior Surface Preparation: Interior maintenance hand sanding and scraping and renovation hand sanding.

Massachusetts Department of Health

The Massachusetts Department of Health, Childhood Lead Poisoning Prevention Program, conducted a study in 1993 and 1994 to assess worker exposure to lead during surface preparation activity. This activity prepared surfaces for abatement by encapsulation. Personal air samples and dust wipe samples were collected at four housing units during interior surface preparation, using both dry and wet methods. Dry methods included dry sanding and/or scraping and feathering of edges by hand sanding, followed by a wash down with tri-sodium phosphate (TSP). Wet methods included misting of the surface during sanding and/or scraping and feathering of edges by hand sanding, followed by a wash down with TSP. A total of 25 specific individual tasks were monitored, with one personal exposure sample taken for each task. Of these, five had results less than the limit of detection (LOD), which ranged from 30 $\mu g/m^3$ to 90 $\mu g/m^3$. The very high LODs for these samples were a combination of low sample volume and relatively high instrument LODs. Because the range of possible values for these samples was so large, it was felt that they contained no quantitative information on worker exposures, an opinion shared also by the Massachusetts field team industrial hygienist and the laboratory chemist. Therefore, these five results were not included in any analysis of the data.

In addition to the task-length average (TLA) worker exposure samples, settled dust samples were collected from 1 ft^2 ceramic tiles. At all units, three tiles were placed in the center of the activity room and sampled for settled dust by wipe methodology at three times: prior to start of the surface preparation activity, immediately after activity, and at least ten hours after the activity. In three of the four units, an additional tile was placed in the center of the room after completion of the activity and cleanup by HEPA vacuuming. A wipe dust sample was collected from this tile approximately ten hours after placement. In one unit, one additional tile was placed in each of two adjacent non-activity rooms after completion of the surface preparation activity and HEPA vacuuming. These two tiles were sampled approximately ten hours after placement.

Table 8E-1 contains a summary of the target activities, lead percentages in paint, XRF measurements, average task lengths, percent of personal exposure samples above the detection limit, and the personal exposure sample sizes for each of the eight studies. Also included are whether the activities took place inside or outside of the building, and whether wet or dry methods were used.

Table 8E-1. Summary of the Presence of Lead-Based Paint, Task Lengths, Personal Exposure Sample Sizes, and Percent of Personal Exposure Samples Above Detection Limit by Study and Target Activity

			Lead Levels in Paint		Personal Exposure Monitoring[1]		
Study	Target Activity	Location/ Method	Average % Paint Lead	XRF (mg/cm^2)	Average Task Length (minutes)	% Samples Above Detection Limit	Sample Size (N)
CONSAD	Component Removal	Interior/Dry	0.52	---	252	100	5
	Demolition	Interior/Dry	13.0	---	178	100	2
	Surface Preparation	Interior/Dry	0.53	---	430	100	4
NIOSH, OU	Cleanup/Surface Prep	Interior/Dry	3.2	---	27	100	12
	Cleanup/Surface Prep	Interior/Wet	4.8	---	33	100	24
NAHB	Exterior Siding	Exterior/Dry	2.69	---	137	0	1
New York	Window Replacement	Interior/Dry	3.2	---	139	100	2
	Surface Preparation	Interior/Dry	6.2	---	152	100	1
		Exterior/Dry	11.6	---	240	100	5
NIOSH, Cincinnati	Window Replacement	---/Dry	15.7	---	181	100	8
	Surface Preparation	Exterior/Dry	20.4	---	265	100	15
		Exterior/Wet	5.3	---	329	100	7
U.S. Army Hygiene	Surface Preparation	Interior/Dry	5.6	---	168	100	8
		Interior/Wet	2.0	---	170	67	15
		Exterior/Dry	4.25	---	184	0	12
		Exterior/Wet	3.18	---	182	0	12
Brooks AFB	Cleanup	Interior/Dry	0.83	4.3	43	0	3
	Component Removal	Interior/Dry	0.92	4.2	75	38	8
	Surface Preparation	Exterior/Dry	8.2	9.8	246	17	6
		Interior/Dry	1.9	5.2	198	20	15
Massachusetts DPH	Surface Preparation	Interior/Dry	---	6.6	101	100	3
		Interior/Wet	---	9.8	109	100	17

(1) Only data included in data analyses within this section are included in summaries within this table.

8E-2.0 SUMMARY OF PERSONAL WORKER EXPOSURE DATA FROM OTHER SOURCES

Summary statistics of personal exposure data from the other data sources are listed in Table 8E-2 according to specific R&R activities and tasks. For comparison purposes, summary statistics are also included for data collected in the EFSS. In calculating summary statistics for this table, all sample results reported below the limit of detection were set to one-half the LOD. (Setting not-detected results to 0 or to the LOD had a negligible effect on the calculated summary statistics.) All results represent task length averages (TLAs) in $\mu g/m^3$.

8E-2.1 COMPARISON OF PERSONAL WORKER EXPOSURE DATA FROM OTHER SOURCES WITH EFSS RESULTS

Window Replacement

Figure 8E-1 presents personal worker exposure results for window replacement from the NIOSH-Cincinnati study, the New York State Department of Health study, and the EFSS. The NIOSH and EFSS results, both based on eight monitored workers, were very similar. In contrast, the two workers monitored in the New York study have much higher exposures, both more than twice the OSHA permissible exposure limit (PEL) of 50 $\mu g/m^3$. The New York data are in line with the estimated **distribution** of exposures for window replacement from the EFSS data (as presented in Table 9-1 of Chapter 9), and therefore indicate that the potential for achieving lead exposures above the OSHA PEL during window replacement activities is not negligible.

Demolition

Figure 8E-2 compares personal worker exposures during demolition for the CONSAD study and the EFSS. During the CONSAD study, two samples were collected using a Marple Cascade Impactor, which involves a series of filters that separate particles by particle size. The average estimated exposure using this collection method was 976 $\mu g/m^3$, which was much higher than the levels associated with two study samples collected using a 37 mm filter and NIOSH protocol 7300. Because CONSAD reports that their experience indicates that the impactor collection method tends to produce higher results (for which they have no explanation), the impactor results were not included in Table 8E-2 or Figure 8E-2.

Component Removal

Personal worker exposure estimates associated with component removal are presented in Figure 8E-3 for the Brooks AFB study, CONSAD study, and the EFSS. The activity in all three studies included removing lead-painted wood trim, baseboards, doors and door jams. The EFSS results are markedly higher than those obtained in the Brooks AFB and CONSAD studies. Personal exposure results from the Brooks AFB study (over all monitored activities) tend to be low compared to data from other studies (see Table 8E-2). This might be related to characteristics of the military family housing in which the monitoring took place in that study. The average lead concentration in paint chips in both the CONSAD study and the Brooks AFB study was low: 0.92% and 0.52% lead by weight respectively. In contrast, lead loading associated with component removal activities in the EFSS averaged 7.4 mg/cm^2, and the activities were conducted by two workers in a home that had been vacant for some time. However, this alone does not explain such high exposure levels in the EFSS.

Table 8E-2. Summary of Personal Worker Exposure Levels as Measured by a Task Length Average (μg/m^3) for the Other Sources of Data and for Data From the EFSS

	Study	Location/ Method	N	Arithmetic Mean TLA	Geometric Mean TLA	Log Std Dev	Minimum Value	Maximum Value
R&R Target Activities								
Window Replacement	New York	---	2	144	144	0.07	137	151
	NIOSH, Cincinnati		8	6.81	5.44	0.72	2.00	16.0
	EFSS		8	14.0	7.48	1.19	2.41	44.4
Demolition	CONSAD	Interior/Dry	2	271	166	1.52	56.5	485
	EFSS		20	153	107	0.74	33.6	947
Surface Preparation	Brooks AFB	Exterior/Dry	6	5.50	2.82	1.48	0.50	10.0
	New York		5	29.8	24.7	0.68	12.0	63.0
	NIOSH, Cincinnati		15	27.8	9.16	1.84	0.20	120
	U.S. Army Hygiene		12	All < LOD	All < LOD	---	All < LOD	All < LOD
	Brooks AFB	Interior/Dry	15	8.07	2.69	1.48	0.50	40.0
	CONSAD		4	12.5	11.7	0.43	6.98	17.3
	New York		1	1270	1270	---	1270	1270
	U.S. Army Hygiene		8	94.1	72.5	0.82	23.0	190
	Massachusetts DPH		3	2000	605	1.77	70	5350
	NIOSH, Cincinnati	Exterior/Wet	7	17.4	6.75	1.71	0.70	63.0
	U.S. Army Hygiene		12	All < LOD	All < LOD	---	All < LOD	All < LOD
	U.S. Army Hygiene	Interior/Wet	15	88.3	22.0	2.28	< 2.00	280
	Massachusetts DPH		17	254	164	0.98	40	820
Exterior Siding	NAHB	Exterior/Dry	1	All < LOD	All < LOD	---	All < LOD	All < LOD
Generic R&R Tasks								
Cleanup	Brooks AFB	Interior/Dry	3	All < LOD	All < LOD	---	All < LOD	All < LOD
	EFSS - Plaster		4	27.701	24.5	0.55	14.6	53.3
	EFSS - Wood		2	103.44	102	0.21	88.5	118
Component Removal	Brooks AFB	Interior/Dry	8	9.06	6.28	0.91	< 2.00	30.0
	CONSAD		5	7.54	7.47	0.15	5.96	8.78
	EFSS		2	344.01	344	0.045	333	355
Combination R&R Tasks								
Cleanup/ Surface Preparation	NIOSH, OU	Interior/Dry	12	100.0	83.1	0.65	29.0	205
	NIOSH, OU	Interior/Wet	24	48.7	27.3	1.03	5.00	360

Note: Observations less than the detection limit were set to one-half the level of detection (LOD) for this summary.

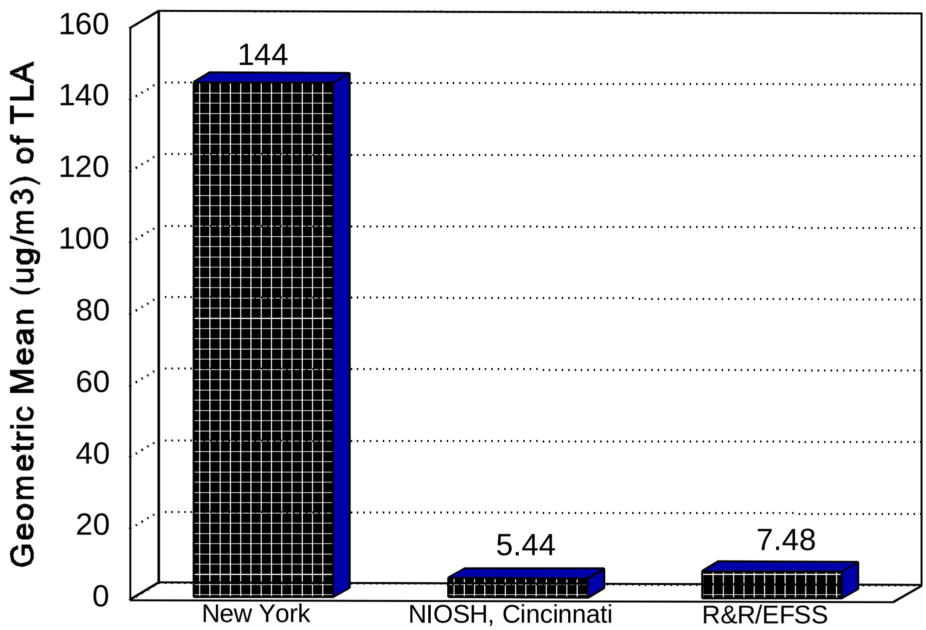


Figure 8E-1. Comparison of Geometric Mean Task-Length Average Personal Worker Exposures ($\mu g/m^3$) for the EFSS and Other Data Sources During Window Replacement

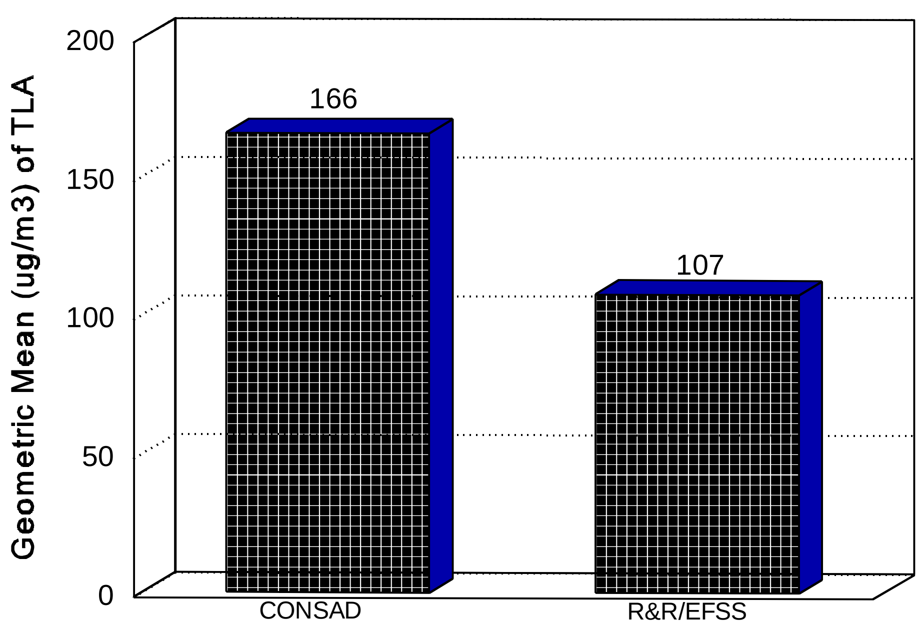
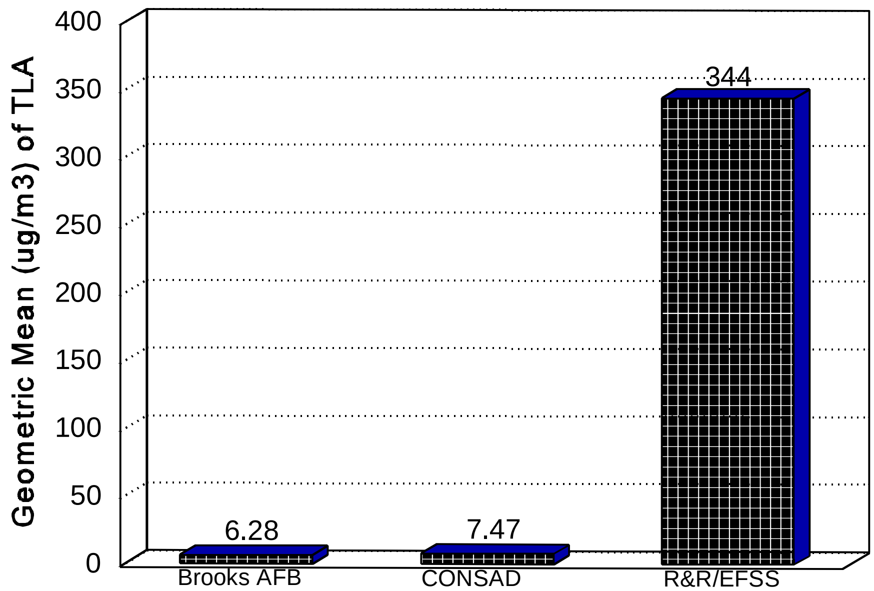


Figure 8E-2. Comparison of Geometric Mean Task-Length Average Personal Worker Exposures ($\mu g/m^3$) for the EFSS and Other Data Sources During Demolition



Note: All sample results reported below the limit of detection (LOD) were set to one-half the LOD.

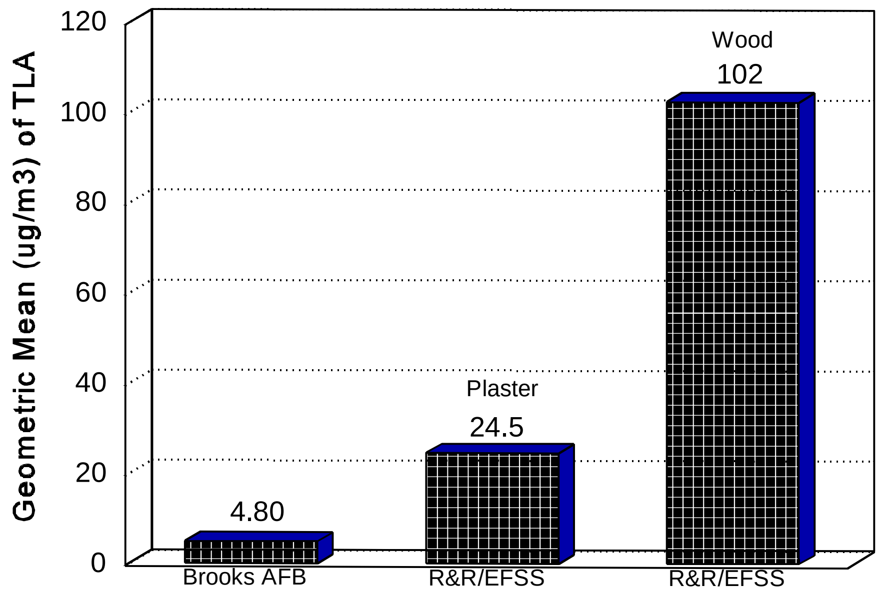
Figure 8E-3. Comparison of Geometric Mean Task-Length Average Personal Worker Lead Levels ($\mu g/m^3$) for the EFSS and Other Data Sources During Component Removal

Cleanup Activities

Personal worker exposures related to cleanup activity from the Brooks AFB study are compared to EFSS results in Figure 8E-4. Only data for the CED phase of the EFSS (not the cleanup investigation) are included in Figure 8E-4. The Brooks AFB study results are much lower than the EFSS, especially concerning cleanup following activities that disturb wood surfaces. All three data points entering into Figure 8E-4 for the Brooks AFB study represent results below the detection limit.

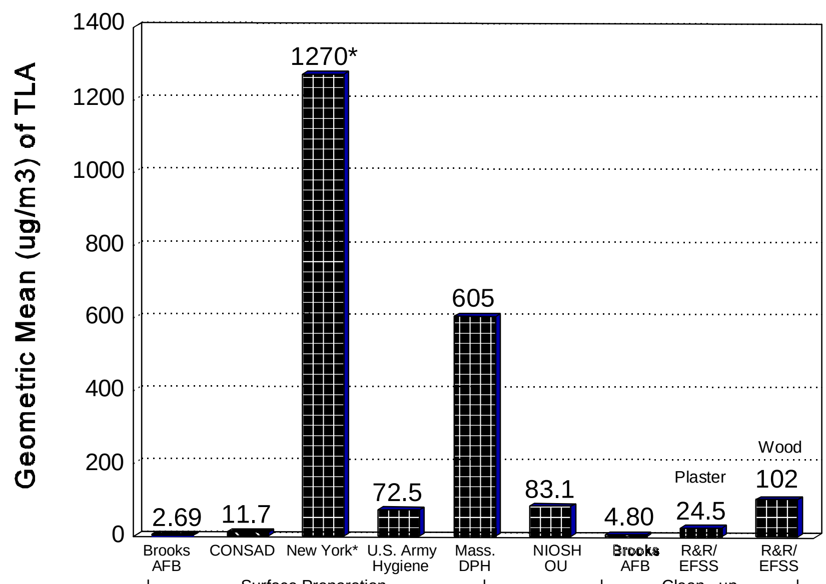
Cleanup/Surface Preparation Combinations

As discussed in Section 8E-1.1, the NIOSH-Ohio University study contains task-length average personal worker exposures for tasks that were a combination (according to definitions established in the R&R study) of surface preparation and cleanup. Figure 8E-5 presents personal worker exposure estimates for dry scraping and broom sweeping in the NIOSH study compared to cleanup results from the Brooks AFB study and the EFSS, and to interior dry surface preparation results from the Brooks AFB, CONSAD, U.S. Army, and Massachusetts studies. The results from the combined activity in the NIOSH study appear reasonable when compared to the set of results for each individual activity.



Note: All sample results reported below the limit of detection (LOD) were set to one-half the LOD.

Figure 8E-4. Comparison of Geometric Mean Task-Length Average Personal Worker Lead Levels ($\mu g/m^3$) for the EFSS and Other Data Sources During Cleanup Activities



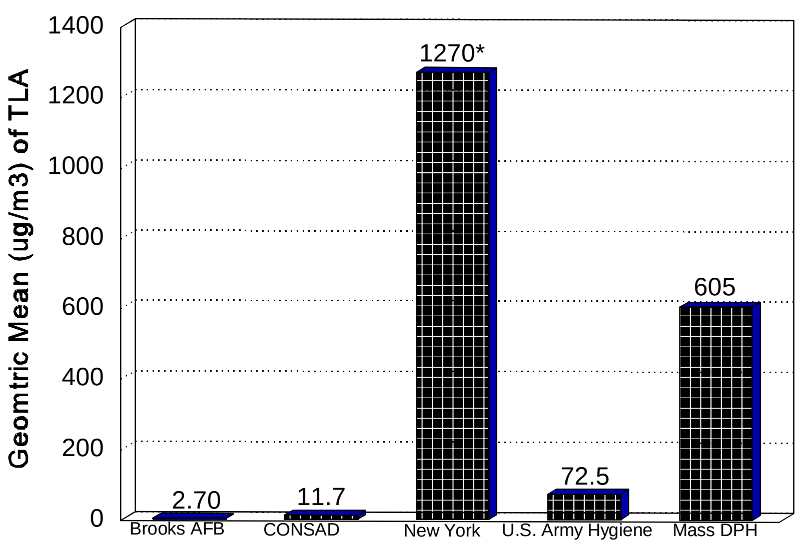
*Sample Size = 1.
Note: All sample results reported below the limit of detection (LOD) were set to one-half the LOD.

Figure 8E-5. Geometric Mean Task-Length Average Personal Worker Exposures ($\mu g/m^3$) During Cleanup and Dry Interior Surface Preparation for Various Studies Compared to the Combination Activities of the NIOSH-OU Study

8E-3.0 RESULTS OF THE ANALYSIS OF SURFACE PREPARATION DATA FROM OTHER SOURCES

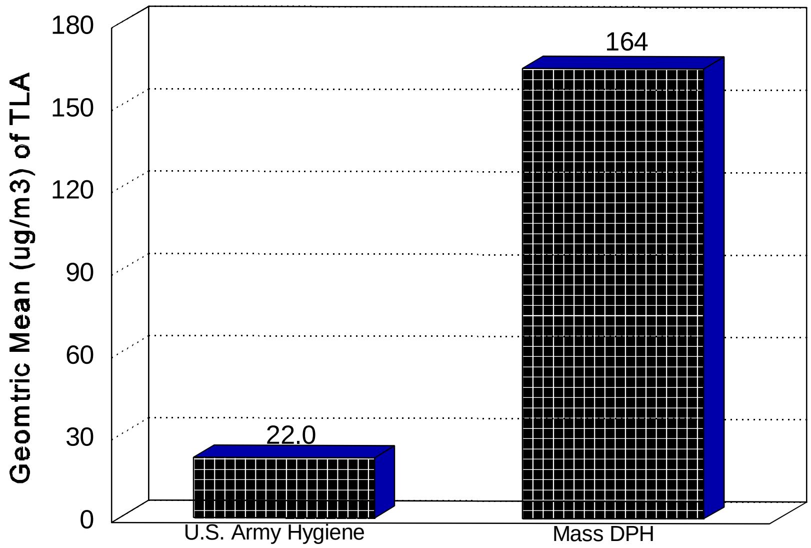
No data were collected in the EFSS on exposures related to surface preparation activities, partly because data were expected to be available from other sources. Six such data sources were located, and summary results from these sources were included in Table 8E-2 of Section 8E-2.0. Surface preparation methods in each study were subdivided into interior and exterior surface preparation and wet and dry methods. In general, the surface preparation activity consisted of sanding, scraping, and cleaning activities. However, the extent to which each of these generic activities was performed differed among the studies. This reflects an inherent difficulty in defining surface preparation, which may range from very slight touch-up of surfaces in overall good condition to heavy scraping and sanding of surfaces in poor condition. The wide variety of activity that may be included under surface preparation is reflected in the variability in exposure estimates from the different studies.

Figures 8E-6 through 8E-9 summarize personal worker exposure results from the six studies, with one figure for each of the four combinations of interior and exterior surface preparation and wet and dry methods. The variability in results between studies is most pronounced in Figure 8E-6 for interior surface preparation using dry methods. A large number of factors may be contributing to this variability based on documentation of the individual studies and results obtained in the EFSS. The factors include the concentration of lead in the paint being disturbed, the condition of the paint, the percent of total activity time spent sanding or scraping, the size and air-flow characteristics of the activity room, the equipment used, personal work habits, and small numbers of samples.



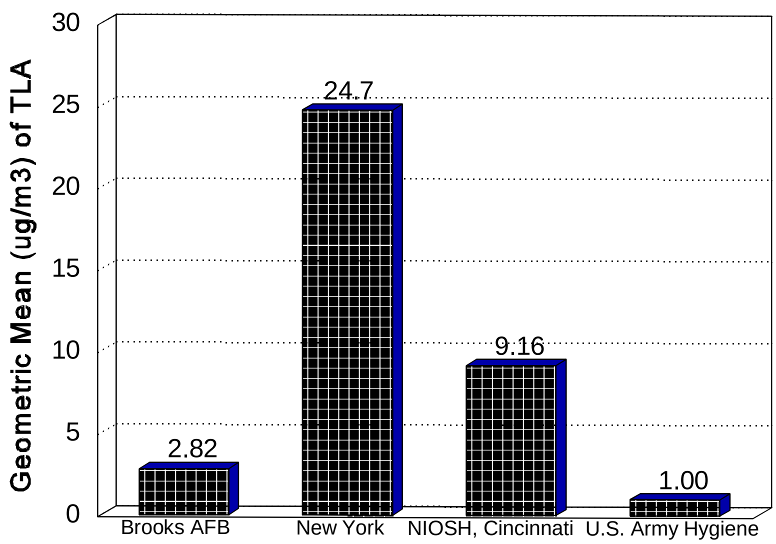
Note: All sample results reported below the limit of detection (LOD) were set to one-half the LOD.
*Sample Size = 1.

Figure 8E-6. Geometric Mean Task-Length Average Personal Worker Exposures ($\mu g/m^3$) for Other Data Sources During Dry Interior Surface Preparation



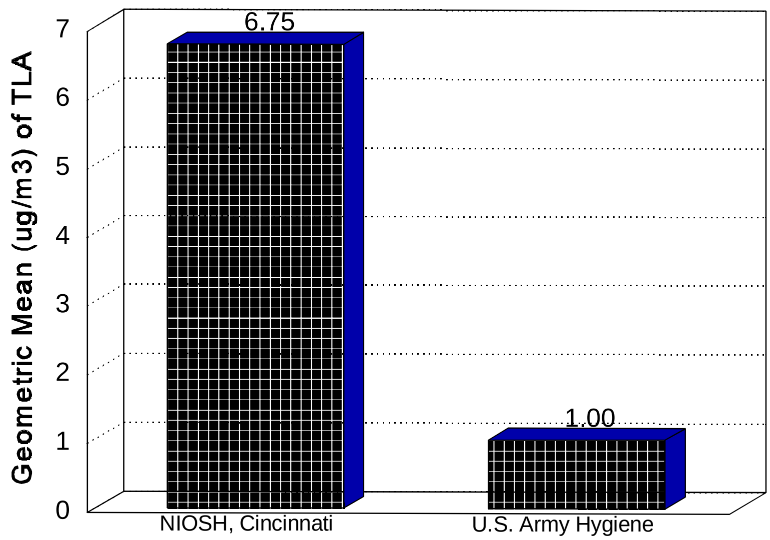
Note: All sample results reported below the limit of detection (LOD) were set to one-half the LOD.

Figure 8E-7. Geometric Mean Task-Length Average Personal Worker Exposures ($\mu g/m^3$) for Other Data Sources During Wet Interior Surface Preparation



Note: All sample results reported below the limit of detection (LOD) were set to one-half the LOD.

Figure 8E-8. Geometric Mean Task-Length Average Personal Worker Exposures ($\mu g/m^3$) for Other Data Sources During Dry Exterior Surface Preparation



Note: All sample results reported below the limit of detection (LOD) were set to one-half the LOD.

Figure 8E-9. Geometric Mean Task-Length Average Personal Worker Exposures ($\mu g/m^3$) for Other Data Sources During Wet Exterior Surface Preparation

8E-3.1 ANALYSIS TO ESTIMATE AVERAGE PERSONAL WORKER EXPOSURE LEVELS ACROSS STUDIES FOR SURFACE PREPARATION

Meta-analytic statistical methods are used to summarize data across studies when only summary statistics are available. Using this approach, an estimate of the mean personal worker exposure from surface preparation and a measure of the variability about the mean are obtained for each study and combined to form an overall mean exposure level, taking into account both within-study and between-study components of variation. As the raw data were available for all studies identified in the search for other data sources, within-study and between-study variability were estimated directly from the raw data and incorporated into overall mean exposure level estimates and associated confidence intervals. Other meta-analysis issues and concerns that were addressed included:

1. The assumption that the studies are a random sample from a population of studies. The validity of confidence intervals based on a random-effects analysis depends on this assumption. The studies included were judged to be independent and representative of exposures during different occurrences of surface preparation.

2. The lack of bias (e.g., publication bias) in selection of studies to be included. All identified studies with relevant data were included in the analysis.

3. An assessment of the quality of individual studies. Each study was assessed from a quality assurance standpoint (use of standard protocols, a certified laboratory, experienced study personnel, etc.) and determined to meet minimum quality assurance standards.

The statistical analysis to estimate overall mean exposure levels across studies was conducted only on data from dry methods for two reasons: (1) these data were considered representative of surface preparation as it is currently being conducted in an unregulated environment, and (2) insufficient data existed for the wet methods.

Summary statistics for the data used in estimating overall mean worker exposure levels for interior and exterior dry surface preparation are presented in Table 8E-3. The results of the U.S. Army study of exterior dry surface preparation showed all twelve personal exposure observations below the limit of detection (LOD). In order to more accurately represent the variability of measurements less than the LOD in that study and the other studies, all measurements less than the LOD in any study were simulated by generating a random deviate from a uniform distribution on the interval (0, LOD). The assumption of a uniform distribution assigns equal probability to any value below the LOD, and allows for a measure of variability based on that assumption. This approach to handling non-detected results differs from the approach used to obtain summaries in earlier tables and figures in this section, where the result was replaced by one-half the detection limit.

Table 8E-3. Summary Statistics for Data Used in the Statistical Analysis of the Surface Preparation Data (Dry Methods Only)

Location	Study	Geometric Mean ($\mu g/m^3$) of TLA	Log Standard Deviation	N
Exterior	Brooks AFB	1.94*	1.77*	6
	New York	24.7	0.68	5
	NIOSH, Cincinnati	9.16	1.83	15
	U.S. Army Hygiene	0.89*	0.56*	12
Interior	Brooks AFB	2.25*	1.61*	15
	CONSAD	11.7	0.43	4
	Massachusetts DPH	605	2.17	3
	New York	1270	---	1
	U.S. Army Hygiene	72.5	0.82	8

* For observations less than the limit of detection (LOD), random deviate(s) generated from a uniform distribution on the interval (0, LOD) were used to calculate these statistics.

Model (OS-1) in Section C.7 of Appendix C was fitted to the log transformed lead concentrations ($\mu g/m^3$) from individual personal worker exposure samples collected in each of the studies listed in Table 8E-3. Model (OS-1) was fitted separately for interior and exterior dry surface preparation. Further details on the statistical model are provided in Section C.7 of Appendix C.

Table 8E-4 displays model estimates of the geometric means, 95% confidence intervals on the geometric mean, and variance components (standard deviations) of worker personal exposures for interior and exterior dry surface preparation, resulting from fitting model (OS-1). While the geometric mean exposure is much higher for interior dry surface preparation, the 95% confidence intervals indicate that the two estimates do not differ statistically. The nature of the diverse results across studies for interior dry surface preparation is noted by a large study-to-study variability compared to worker-to-worker variability.

Table 8E-4. Model Estimates of the Geometric Mean, 95% Confidence Interval and Standard Deviation of Variance Components of Worker Personal Exposures (Task Length Average in $\mu g/m^3$) for Interior and Exterior Dry Surface Preparation

Location	Number of Studies	Total Number of PEM Samples	Geometric Mean Estimates from Model	95% Confidence Interval of Geometric Mean	Square Root of Estimated Variance Components	
					Study to Study (σ_{Study})	Worker to Worker (σ_{Worker})
Interior	5	31	58.2	(2.27, 1490)	2.49	1.40
Exterior	4	38	4.33	(.407, 46.0)	1.41	1.40

To investigate the nature of study-to-study differences, Figures 8E-10 and 8E-11 provide a comparison of the individual study estimates and associated confidence intervals with the overall estimate and its confidence interval for interior and exterior dry surface preparation, respectively.

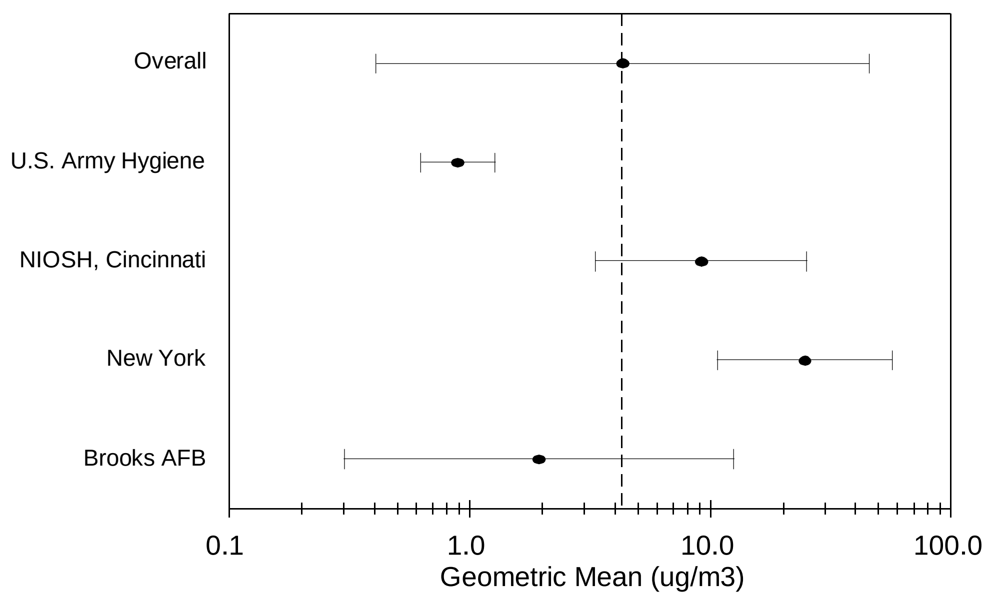
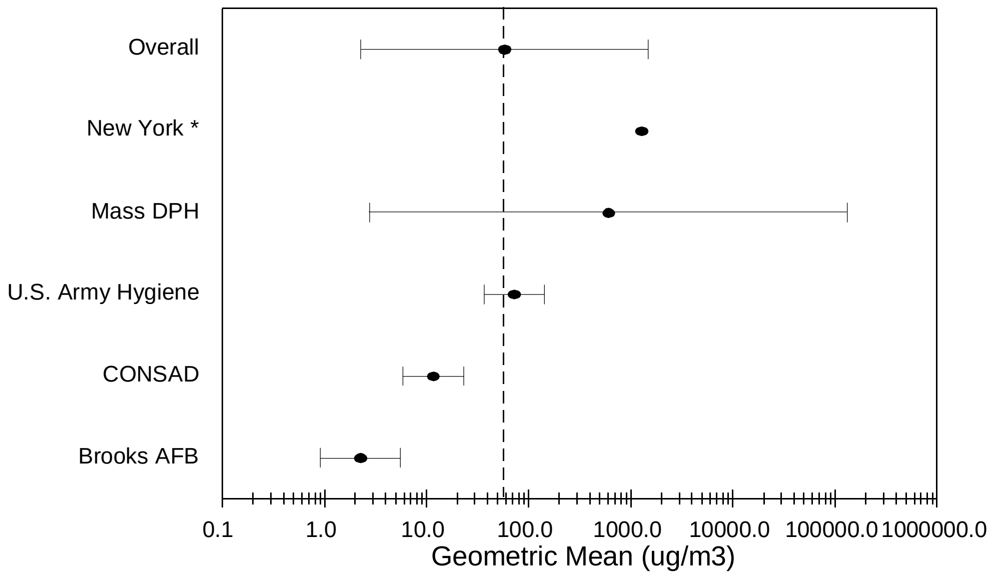


Figure 8E-10. Comparison of Results from Statistical Analysis of Geometric Mean Task Length Average Personal Worker Exposures ($\mu g/m^3$) for Exterior Surface Preparation: Overall Mean Estimate and Individual Study Mean Exposures with 95% Confidence Bounds



* Sample Size = 1.

Figure 8E-11. Comparison of Results from Statistical Analysis of Geometric Mean Task Length Average Personal Worker Exposures (μg/m^3) for Interior Surface Preparation: Overall Mean Estimate and Individual Study Mean Exposures with 95% Confidence Bounds

8E-3.2 SETTLED DUST SAMPLES IN THE MASSACHUSETTS DEPARTMENT OF HEALTH STUDY ASSOCIATED WITH SURFACE PREPARATION

As described in Section 8E-1.0, the Massachusetts study also collected settled dust samples from 1-ft^2 ceramic tiles that were placed in rooms (activity areas) where surface preparation was being conducted, at various times in the study. Five types of ceramic tile samples, all using wipe collection methods, were collected in the Massachusetts study:

1. Tiles placed in the activity area and sampled before the activity started ***(pre-activity)***

2. Tiles placed in the activity area before the activity started and sampled immediately following the activity ***(during activity; sampled 0 hrs post)***

3. Tiles placed in the activity area before the activity started and sampled at least 10 hours after the activity was finished ***(during activity; sampled 10 hrs post)***

4. Tiles placed in the activity area after all surface preparation activity was finished and after the area was HEPA vacuumed. These were sampled at least 10 hours later ***(after activity and cleanup; sampled 10 hrs post)***

5. Tiles placed in rooms adjacent to the activity area after all surface preparation activity was finished and after the activity area was HEPA vacuumed. These were sampled at least 10 hours later ***(after activity and cleanup; adjacent area)***.

Samples of type 4 above (after activity and cleanup; sampled 10 hours post) were collected in only three of the four study units. Samples of type 5 above (after activity and cleanup; adjacent area) were collected in only one of the four study units. Like the settled dust samples in the EFSS, the first three types of samples in the Massachusetts study provide an estimate of the total amount of lead disturbed by the activity and made available in the occupant's environment before cleanup. The last two sample types, however, represent lead exposures that may be expected to settle and remain in an occupant's environment after cleanup.

Results for 13 of 51 settled dust samples collected in the Massachusetts study were reported as right-censored data (such as "> 2000 µg/ft^2"). These represented samples in which the dilution process was terminated, since a right-censored result already indicated an unacceptable amount of lead for the purposes of that study. These results are included as the right-censored value in the summary statistics presented below. For this reason, inferences concerning average differences between sample type 2 (during activity; sampled 0 hrs post) and 3 (during activity; sampled 10 hrs post), should not be made based on these summary statistics since many of these sample types were right-censored. For example, the samples for one room resulted in a measurement of > 120,000 µg/ft^2 for the type 2 sample and > 42,100 µg/ft^2 for the type 3 sample, obviously providing no information or misleading information on the difference between the two samples.

The wipe dust sample results from this study are quantitatively comparable to vacuum dust sample results obtained in the EFSS for other R&R activities using stainless steel dustfall collectors. The difference in sampling methodology (wipe versus vacuum) as well as the fact some data values were right-censored, as discussed below, should be taken into account in any such comparison.

Summary statistics for the different types of settled dust samples for interior dry and wet surface preparation are given in Table 8E-5 below. These results indicate extremely high lead levels in dust that settles during and up to 10 hours following the activity. While dust that settles after activity and cleanup has much lower lead levels (interior/wet methods), these levels tend to remain over the EPA interim health-based standard of 100 µg/ft^2.

Field personnel in the Massachusetts study estimated that most activity areas (rooms) were small, approximately 10 by 10 feet or 12 by 12 feet. All tiles were placed in the center of an activity area when possible. (Some activity areas such as hallways had different placement.) The tile samples may roughly be considered to represent samples collected, on average, 3 feet from the source of activity.

Table 8E-5. Summary Statistics for the Different Types of Settled Dust Samples Collected in the Massachusetts DOH Study for Interior Dry and Wet Surface Preparation

Method	Type of Sample	N	% Reported as Right-Censored	% < LOD	Geometric Mean ($\mu g/ft^2$)	Minimum ($\mu g/ft^2$)	Maximum ($\mu g/ft^2$)
Interior/ Dry	#1 Pre-activity	3	0	0	15.5	12.5	17.6
	#2 During Activity; Sampled 0 Hrs Post	3	33	0	7980	980	> 120,000
	#3 During Activity; Sampled 10 Hrs Post	3	33	0	5960	990	> 42,100
Interior/ Wet	#1 Pre-activity	10	0	10	13.7	3.7	66.1
	#2 During Activity; Sampled 0 Hrs Post	10	60	0	1270	380	> 2,000
	#3 During Activity; Sampled 10 Hrs Post	10	50	0	1230	391	> 2,000
	#4 After Activity and Cleanup; Sampled 10 Hrs Post	10	0	0	162	53.2	615
	#5 After Activity and Cleanup; Adjacent Area	2	0	0	194	110	342

* Sample may have been contaminated as the surface preparation worker used this area to sharpen his scraper with a grinder intermittently throughout the activity.

Note:
1. Samples reported as less than the limit of detection (LOD) were included in the analysis using one-half the LOD.
2. Samples reported as "greater than" a specified value (i.e. right-censored) were included in the analysis at the right-censored value.

9.0 OVERALL RESULTS

Chapter 8 in this report discussed lead disturbance and exposure results specific to individual activities and tasks monitored in the EFSS or in other studies. These results were presented to address the three sets of data analysis objectives presented in Section 6.1:

Objective A Characterize lead disturbance and potential lead exposures
Objective B Assess factors or measurements related to lead disturbance
Objective C Evaluate different media as indicators of lead exposure.

This chapter presents overall lead exposure and disturbance results across all activities. The content of the chapter is related to the three sets of objectives described below.

Objective A

- key summary statistics for each activity characterizing lead exposure and disturbance, and graphs and tables allowing for comparisons across activities
- a methodology for constructing 8-hour time-weighted average exposure for different worker groups
- a methodology for adjusting estimates of the amount of lead deposited in settled dust to a "standard unit" of activity

Objective B

- an assessment across activities of the observed effect of predictor variables (such as a measure of the amount of lead in the paint) on lead disturbance and exposure

Objective C

- the extent of agreement between results collected from different media (air and settled dust).

Observed limitations and data gaps related to addressing the above objectives with the collected data are also presented in this chapter.

9.1 CHARACTERIZE LEAD DISTURBANCE AND POTENTIAL LEAD EXPOSURES

The type of environmental data collected in this study varied to some degree from one R&R activity to another. All activities, however, included data on:

- personal air lead exposure monitored during the activity

- lead in settled dust disturbed by the activity and collected from stainless steel dust collectors (SSDCs) after completion of the activity.

These measures represent the primary raw data used in summarizing results. The personal air monitoring results estimate airborne exposure for R&R workers performing the activity. The dust-lead levels generated by the activity reflect the amount of lead disturbed by the activity and distributed in the living or working environment of the occupants.

9.1.1 Personal Worker Exposures

Table 9-1 presents summary statistics characterizing the distribution of task-length average (TLA) personal worker lead concentrations (µg/m^3), or average exposure over the duration of performing the activity, for all monitored target activities and generic tasks. Results presented include the 50th, 75th and 95th percentiles of the distribution. As a measure of uncertainty, a two-sided 95% confidence interval about each estimated percentile was calculated for each activity. These intervals permit an assessment of whether there is a statistical difference from a specified level (e.g., the OSHA permissible exposure limit) or a statistical difference between the different activities. The estimates and confidence intervals are based on the assumption that the logarithms of the air lead concentrations within each activity are normally distributed. The components of measured variation were taken into account in the confidence interval calculations to deal with correlations among the measures. The method of calculation of the estimates and associated confidence intervals varies, depending upon the number of components of variation assumed. The methods are presented in Section C.6 of Appendix C. Results for dry surface preparation, both interior and exterior, are based on the data collection from other sources as discussed in Section 8E of Chapter 8. All other results are based on data collected in the EFSS.

Note that paint removal by abrasive sanding is included in Table 9-1 in two forms: sanding with a power tool and sanding by hand. Paint removal was conducted as part of the Controlled, Experimentally-Designed (CED) phase for use as a positive control measure against which to compare personal exposure levels from other activities, since health effects associated with paint removal have been previously documented (as discussed in Chapter 2).

Table 9-1 presents TLAs which are not directly comparable to the eight-hour time-weighted averages (TWAs) on which OSHA exposure limits are based. Section 9.1.2 includes a detailed discussion of the relationship between TLAs and TWAs.

Figure 9-1 illustrates a ranking of worker personal exposure across activities based on the 75th percentile of TLAs. A pair of activities with non-overlapping confidence intervals can be judged to have significantly different 75th percentiles.

From Figure 9-1, it appears that the activities roughly form three groups: the four activities with the highest 75th percentiles, the five with the lowest, and the middle four. The four highest are generally distinguishable from the five lowest, with the middle four overlapping both groups. The 75th percentiles for the four highest activities, along with demolition, are all significantly above the OSHA PEL of 50 µg/m^3.

Table 9-1. Estimated Percentiles and Confidence Intervals of Personal Worker Exposures Measured by a Task Length Average for R&R Activities and Tasks

	Estimated 50th Percentile TLA ($\mu g/m^3$)	95% Confidence Interval for 50th Percentile	Estimated 75th Percentile TLA ($\mu g/m^3$)	95% Confidence Interval for 75th Percentile	Estimated 95th Percentile TLA ($\mu g/m^3$)	95% Confidence Interval for 95th Percentile
R&R Target Activities						
Carpet Removal	7.54	(1.74, 32.6)	24.9	(7.37, 208)	138	(34.0, 4680)
Window Replacement	7.48	(1.13, 49.3)	17.5	(5.13, 488)	59.2	(16.7, 28500)
Demolition	108	(26.6 435)	185	(95.7, 5500)	403	(186, 542000)
HVAC	49.6	(11.4, 216)	56.0	(37.7, 3070)	66.6	(53.0, 588000)
Dry Surface Preparation[1] (Interior)	58.2	(2.27, 1490)	398	(38.8, 88700)	6350	(473, 1.1×10^8)
Dry Surface Preparation[1] (Exterior)	4.33	(.408, 46)	16.5	(3.81, 1930)	114	(19.2, 1.45×10^6)
Generic R&R Tasks						
Door Modification	590	(93.5, 3730)	1360	(410, 35200)	4480	(1300, 1.89×10^6)
Sawing into Wood	546	(366, 813)	705	(518, 1300)	1020	(726, 2890)
Sawing into Plaster	110	(0, 2.32×10^6)	232	(11.9, 2.40×10^{13})	681	(149, 2.15×10^{27})
Drilling into Wood	15.1	(4.57, 50.2)	36.3	(13.8, 214)	127	(42.9, 2490)
Drilling into Plaster	6.76	(3.00, 15.3)	9.70	(5.71, 40.3)	16.3	(9.47, 226)
Sand - Hand	254	(23.7, 2720)	513	(150, 63800)	1410	(447, 2.03×10^7)
Sand - Power	571	(42.9, 7600)	1150	(286, 170000)	3170	(940, 5.03×10^7)

(1) Summary of data collected from other sources. Surface preparation consisted of a wide variety of activities including wet and dry scraping, feathering of edges, and wet and dry sanding to prepare a surface for repainting.

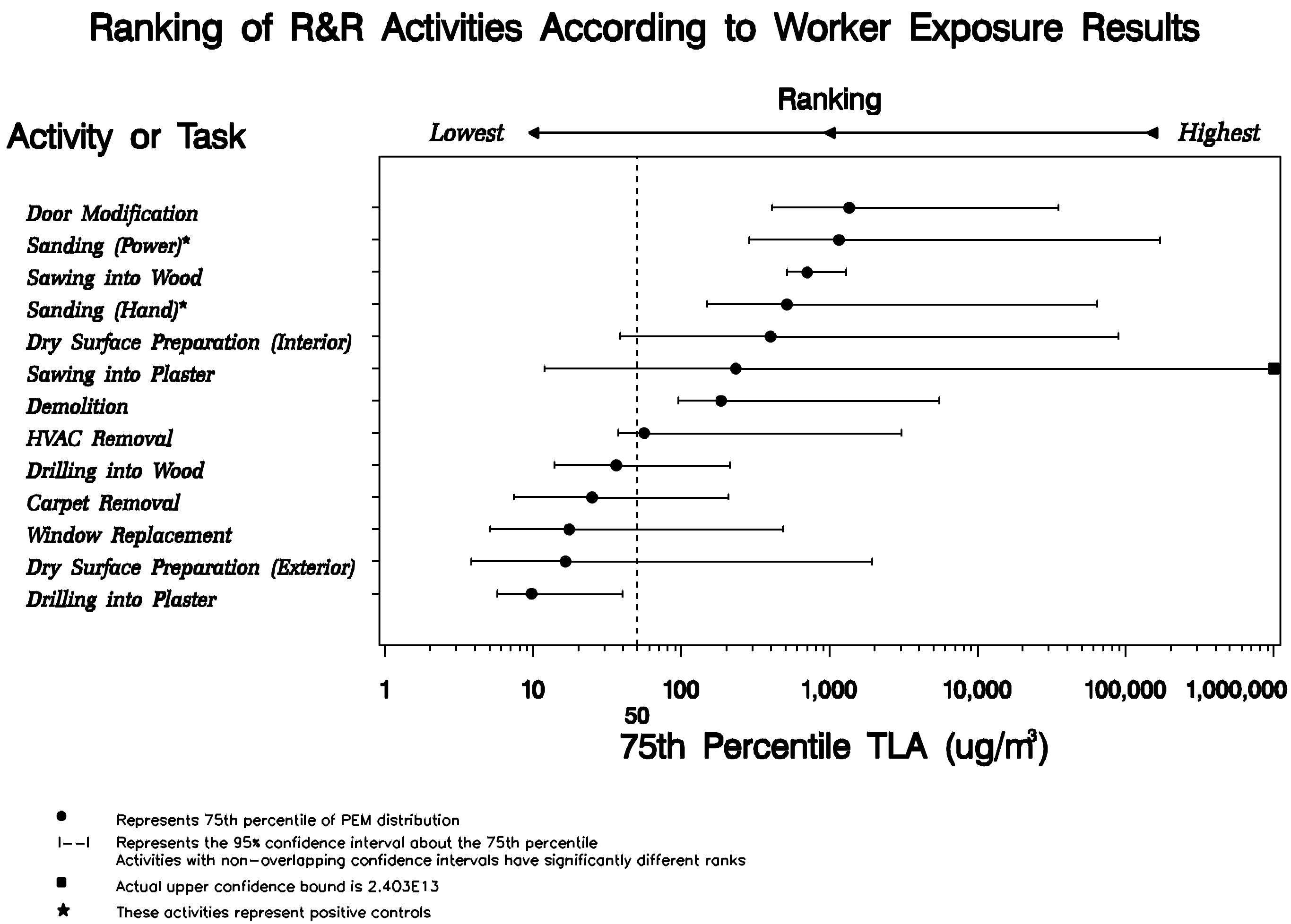


Figure 9-1. Ranking of R&R Activities and Tasks Based on the Estimated 75th Percentile of Worker Exposures Measured by a Task Length Average

Table 9-2. The Percent of Workers Whose TLA Personal Air Lead Concentration Would Exceed the OSHA PEL (50 $\mu g/m^3$), as Estimated from the Observed Distributions of TLAs in this Study

	Number of Workers Monitored (N)	Estimated Percent of Workers Who Will Have a TLA Above the OSHA PEL (50 $\mu g/m^3$)	95% Confidence Interval for the Estimated Percent of Workers Above the OSHA PEL
R&R Target Activities			
Carpet Removal	14	14%	(3% - 43%)
Window Replacement	8	7%	(0% - 50%)
Demolition	20	83%	(40% - 99%)
HVAC Removal	4	48%	(10% - 90%)
Dry Surface Prep. (Interior)(1)	31	52%	(23% - 80%)
Dry Surface Prep. (Exterior)(1)	38	11%	(0% - 49%)
Generic R&R Tasks			
Door Modification	6	98%	(58% - 100%)
Sawing into Wood	6	99%	(99% - 100%)
Sawing into Plaster	2	76%	(15% - 99%)
Drilling into Wood	7	18%	(4% - 51%)
Drilling into Plaster	6	0%	(0% - 21%)
Sanding (Hand)	6	94%	(41% - 100%)
Sanding (Power)	3	99%	(48% - 100%)

(1) Based on data from other sources. Surface preparation consisted of a wide variety of activities including wet and dry scraping, feathering of edges, and wet and dry sanding to prepare a surface for repainting.

Table 9-2 presents estimates of the percentage of workers who would exceed the OSHA PEL of 50 $\mu g/m^3$ if the activity were repeatedly executed under similar conditions of this study, and 95% confidence intervals for this estimate, for each R&R activity and task.

9.1.2 Conversion of Task Length Averages (TLAs) into 8-Hour Time Weighted Averages (TWAs)

The personal worker exposure data summarized above was collected as task length averages (TLAs) for specific R&R activities in accordance with the focus of the EFSS on activities rather than worker groups. The advantage of reporting TLAs for a variety of R&R

activities is that TLAs can be used to estimate 8-hour time weighted averages (TWAs) for any of the numerous R&R worker groups, once a profile of the activities that a worker group performs is determined. Therefore, the EFSS has provided the components for constructing worker exposure estimates based on profiles for a wide variety of worker groups. On the other hand, the amount of activity being performed in a normal 8-hour workday must be taken into account when comparing lead exposures across R&R activities or tasks, or when comparing exposures of individual R&R activities or tasks to OSHA standards which are based on an 8-hour TWA. For the purpose of evaluating and ranking activities, the TLA is equivalent to an 8-hour TWA only if:

1. the task is expected to be performed for eight hours in a day

2. the rate of exposure ($\mu g/m^3$) for eight hours of activity is equal to the rate measured in a shorter time period.

To further illustrate, the 75th percentile of TLA exposures for drilling into wood is estimated to be 36 $\mu g/m^3$ (Table 9-1). However, if this activity were only conducted for 1/4 hour in an eight-hour work shift, and the exposure in the remaining 7-3/4 hours was zero, then a corresponding 8-hour TWA calculated according to OSHA specifications would be reduced by a factor of 32, resulting in an 8-hour TWA of approximately 1 $\mu g/m^3$.

Figure 9-2 is presented to help the reader assess the conversion of the TLA to an 8-hour TWA for each activity. This figure presents the 75th percentile of an 8-hour TWA, expressed as a function of the 75th percentile of the TLAs and the length of the activity or task. This relationship is given by the following formula:

$$\text{75th Percentile 8-hour TWA} = \frac{\text{(75th Percentile TLA)} * \text{(\# Hours Conducted)}}{8}$$

(Note that any summary statistic of the estimated TLAs, not just the 75th percentile, could have been used for this illustration.) This formula, as mentioned above, assumes a constant rate of exposure during conduct of the activity, regardless of the length of the activity, as well as zero exposure when the activity is not being conducted. This is consistent with how 8-hour TWAs are currently calculated by OSHA. Each hypothetical 8-hour TWA in Figure 9-2 depends only on the amount of the specified activity assumed to be conducted in an 8-hour workday. Figure 9-2 indicates that just one hour of sanding or sawing into wood (and seven hours of no exposure) would result in the 75th percentile of 8-hour TWAs being greater than the OSHA PEL (50 $\mu g/m^3$) for those activities. On the other hand, eight hours of drilling, carpet removal, exterior surface preparation, or window replacement would still not result in the 75th percentile of 8-hour TWAs being greater than the OSHA PEL.

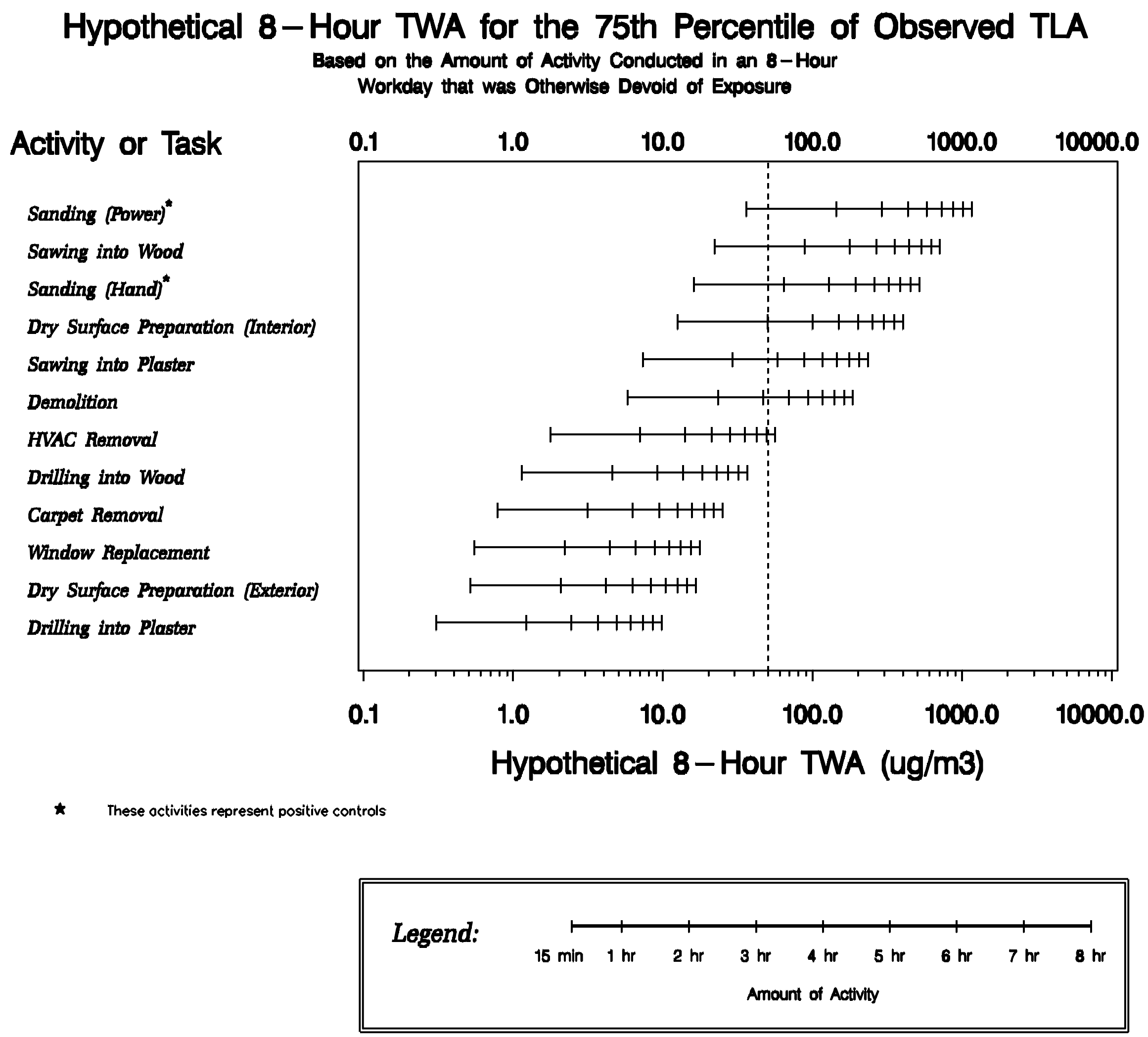


Figure 9-2. Hypothetical 8-Hour Time-Weighted Average Worker Exposures for Each Activity/Task and for Various Activity Durations

Figure 9-2 demonstrates the effect of the amount of activity conducted on an 8-hour TWA when a worker performs only one type of activity in a day that causes lead exposure. In the more common occurrence of different activities being conducted in a single work day, an estimated 8-hour TWA can be constructed by averaging the TLAs for each activity, where each TLA is weighted by the duration of activity. Let TLA_i represent the TLA for the i^{th} activity conducted in an 8-hour work day, and Amt_i the time in hours for which the activity was conducted. Then the 8-hour TWA is estimated by:

$$\frac{\sum TLA_i * Amt_i}{8}$$

For example, suppose a certain R&R worker group typically conducts the following activities for the specified period of time:

Activity	Time Conducted
Sawing into Wood	1/2 hour
Drilling into Wood	1/4 hour
Window Replacement	6 hours
No exposure activities	1-1/4 hour

Then by Table 9-1, the 75th percentile of the 8-hour TWA for this worker group would be estimated by:

$$\frac{(705*.5) + (36.3*.25) + (17.5*6) + (0*1.25)}{8} = 58.3\ \mu g/m^3.$$

9.1.3 Limitations of the Data and Additional Information Required for an Exposure Assessment for Workers

Section 4.5 of Chapter 4 presents a general discussion of the limitations of the data collected in the EFSS from a standpoint of representativeness and completeness. In order to conduct a more complete exposure assessment of different worker groups than what could be performed in the EFSS, the following additional information is required:

1. ***To what extent are the activities in question performed during R&R operations?*** This addresses the TLA versus TWA issue discussed above. The percentage and length of time R&R workers perform the studied activities must be characterized. In addition, the percentage and types of R&R workers that perform each of these activities must also be determined.

2. ***How frequently are R&R operations conducted in lead-contaminated environments?*** The HUD National Survey of Lead-Based Paint in Housing (U.S. EPA, 1995) estimated that 64 million homes built before 1980 contain lead-based paint. The issue is how frequently do different R&R worker groups work in these residences or other lead-contaminated buildings.

Information was collected in the WCBS data collection effort of the R&R study to address these questions and is presented in the WCBS technical report.

9.1.4 Summary Statistics for Lead Disturbance and Potential Exposure to Occupants

The potential lead exposure to occupants resulting from a specific R&R activity or task was characterized by estimating the average amount of lead disturbed (or deposited) by the activity along a 6-foot line (lead gradient) emanating from the activity. For each activity, a model of dust-lead level as a function of distance from activity was fitted to lead loading data from SSDCs (Model (C-3) of Appendix C). The average amount of lead exposed was estimated by determining the area under the fitted curve from 0 to 6 feet from the activity. This measure is equivalent to estimating the average amount of lead exposed in a 6-foot by 1-foot gradient region extending from the activity. The uncertainty associated with this estimate is assessed by calculating an approximate 95% confidence interval. Further details on the gradient region are presented in Chapter 6 and Section C.5 of Appendix C. In contrast to the characterization of personal worker exposures in Table 9-1, the 75th percentile and 95th percentile of the distribution of estimates of lead disturbed were not estimated because of the minimal number of data points and the amount of variability in the distribution.

For the majority of R&R activities, settled dust samples were collected from SSDCs placed directly adjacent to the activity and at specified distances away from the activity. The samples taken from SSDCs located directly adjacent to the activity captured the fallout of both large debris and dust generated by an activity. Samples that were collected from SSDCs located further away from the activity were expected to capture mostly dust and smaller airborne particles.

For the majority of activities, the estimated 6-foot by 1-foot gradient lead loading represents the average total amount of lead that is expected to settle in a 6-foot by 1-foot region extending lengthwise away from the component being disturbed. However, this estimate has a slightly different interpretation for carpet removal and demolition, as explained below.

The layout of settled dust sampling locations in the carpet removal activity only included samples located adjacent to the surface being disturbed. This made it impossible to determine the functional relationship between settled dust and distance. In all other activities studied, the average lead loading decreased with increasing distance away from the activity. The most conservative estimate of the functional relationship would assume that the amount of lead would stay constant across the 6-foot by 1-foot region. Therefore, the (conservative) estimated average gradient lead loading for carpet removal represents the amount of lead found in the 6-foot by 1-foot region assuming that the distribution of lead across that region is uniform.

The layout of settled dust sampling locations in the demolition activity excluded samples adjacent to the activity (due to the large amount of debris), but did include several samples at varying distances away from the activity. Therefore, we are able to determine the functional relationship between settled dust and distance for the demolition activity, but this relationship does not take into account the amount of lead that settles at a location directly adjacent to the activity. Since the settled dust samples associated with the demolition were all located at a distance from the activity space, the estimated 6-foot by 1-foot gradient lead loading in the demolition activity is interpreted as being the amount of lead found in the 6-foot by 1-foot region that was airborne in dust and smaller particles, rather than the total amount of lead disturbed.

9.1.4.1 Adjustment to a Standard Unit of Activity

The R&R activities monitored in the EFSS consisted of a number of different target activities as well as several generic activities. In all cases, the estimate of the amount of lead disturbed in a 6-foot by 1-foot gradient region is highly dependent on the amount of activity conducted. In the case of the generic activities (sawing and drilling), the amount of activity was not intended to reflect normal levels of sawing or drilling that are performed in the R&R industry. Rather, they were intended to provide sufficient activity to allow for estimating a TLA worker exposure as well as the lead disturbed by the specified amount of activity. Therefore, the amount of lead in the gradient region was adjusted to a "standard unit of activity". The standard unit of activity selected for each studied activity does not represent an "average" amount of activity. Rather, the estimated amount of lead was scaled to a unit of activity that seems reasonable for a "real world" R&R activity. Moreover, the scaling seeks to produce estimates of disturbed lead amounts which may be readily re-scaled by the reader. For example, in the CED phase, sawing entailed cutting 75 linear feet of surface. The chosen standard unit of activity, on the other hand, is 1 linear foot, which may be more easily rescaled.

The choice of the standard unit of activity for all activities except window replacement and carpet removal is discussed in Section 8C-2.3.3 of Chapter 8 and presented in Table 9-3. The standard unit of activity for window replacement is one window. The standard unit of activity for carpet removal is 100 ft^2. Table 9-3 presents estimates of the amount of lead disturbed in the gradient region for the standard unit of activity for each R&R activity except abrasive sanding and door modification, where no standard unit of activity could be determined. Figure 9-3 depicts the lead loading gradient for activities as conducted in the EFSS. Figure 9-4 depicts the lead loading gradient for the standard unit of activity.

Note that the gradient lead loading for window replacement, demolition, and HVAC removal remain unchanged between Figures 9-3 and 9-4. This is due to the fact that these activities, as performed in the EFSS, already represented the "standard unit of activity." Otherwise, the chosen amount of activity has a considerable effect on estimates of the amount of lead disturbed in the gradient region.

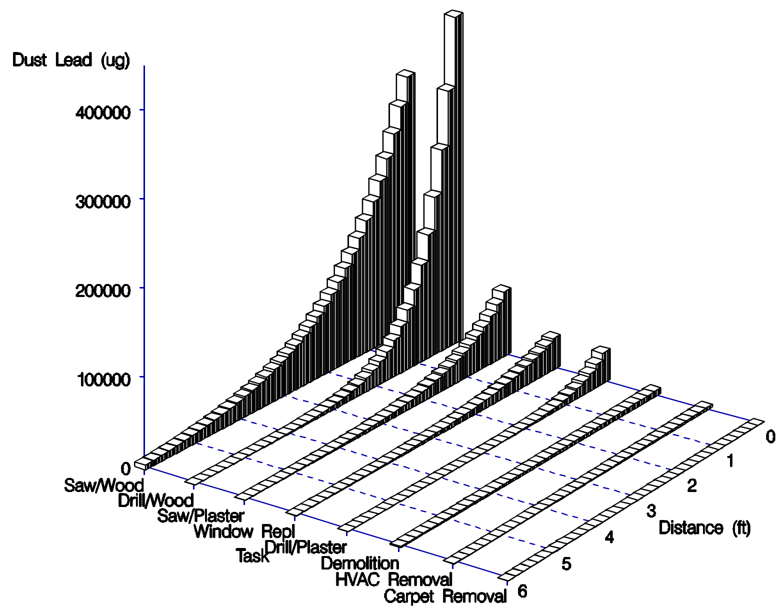


Figure 9-3. Estimated Distribution of Dust Lead in a 6' x 1' Gradient for Various Target Activities and Tasks, Based on Total Amount of Activity Performed in the EFSS

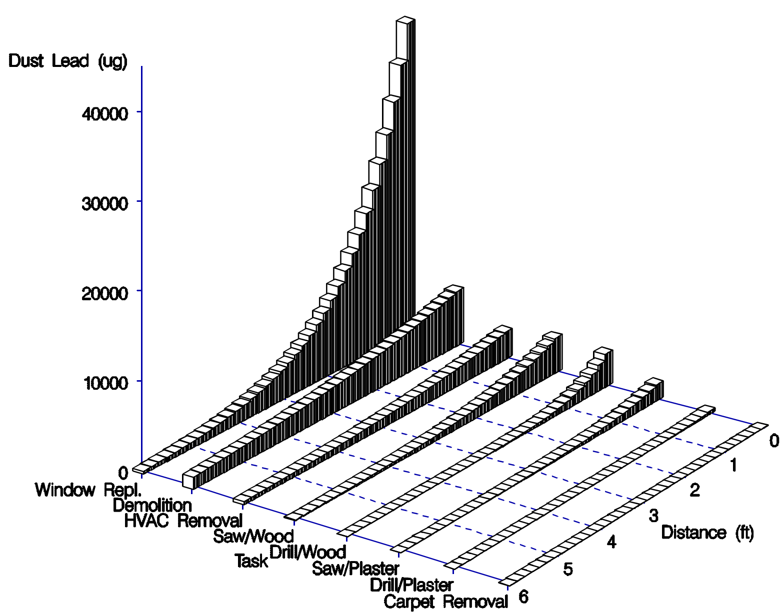


Figure 9-4. Estimated Distribution of Dust Lead in a 6' x 1' Gradient for Various Target Activities and Tasks, Based on Performing the Standard Unit of Activity

Table 9-3. Estimated Lead Amounts (μg) Distributed Within a 6' x 1' Gradient Region, with Standard Errors and 95% Confidence Intervals, in the EFSS

	Standard Unit of Activity	6' × 1' Gradient Mean Lead Amount (Std Error) [95% CI]	[0-1] ft SSDC Mean Lead Amount (Std Error) [95% CI]	[5-6] ft SSDC Mean Lead Amount (Std Error) [95% CI]
R&R Target Activities				
Carpet Removal*	100 ft^2 of Carpet	102* (37.2) [46.3, 223]	16.9 (6.2) [7.7, 37.1]	---
Window Replacement	1 Window	46300 (20900) [17100, 125000]	26000 (13000) [8730, 75000]	482 (217) [179, 1300]
Demolition*	1 Room	19500* (14300) [3610, 106000]	---	1530 (948) [366, 6390]
HVAC Removal	1 Room	7710 (14100) [0, 9.09×10^{13}]	2690 (5700) [0, 1.24×10^{15}]	414 (515) [0, 3.1×10^{9}]
Generic R&R Tasks				
Drilling into Plaster	10 Holes	207 (191) [11, 3900]	168 (163) [8, 3680]	0.04 (0.05) [0.00, 2.81]
Drilling into Wood	10 Holes	2590 (1400) [690, 9740]	2000 (1140) [497, 8030]	1.27 (0.49) [0.50, 3.26]
Sawing into Plaster	1 foot	1970 (2560) [0, 3.04×10^{10}]	1210 (1780) [0, 1.6×10^{11}]	10.6 (6.6) [0, 29600]
Sawing into Wood	1 foot	5990 (2230) [2300, 15600]	2980 (1300) [967, 9150]	105 (46) [34, 324]

* 6' x 1' gradient lead loading calculated differently as explained in text.

Figure 9-5 illustrates, for each generic R&R task, the estimated increase in lead disturbed as a function of the amount of activity performed. The amount of activity performed is presented as a multiplicative increase in the standard unit of activity. For example, the standard unit of activity for drilling is specified as 10 holes. The x-axis in Figure 9-5 ranges from a multiplicative increase of 1 (i.e., the standard unit amount of activity) through a multiplicative increase of 20. For drilling, this range corresponds to 10 to 200 holes. Figure 9-5 makes an assumption that the amount of lead disturbed in the gradient region is related in a multiplicative fashion to the amount of activity performed.

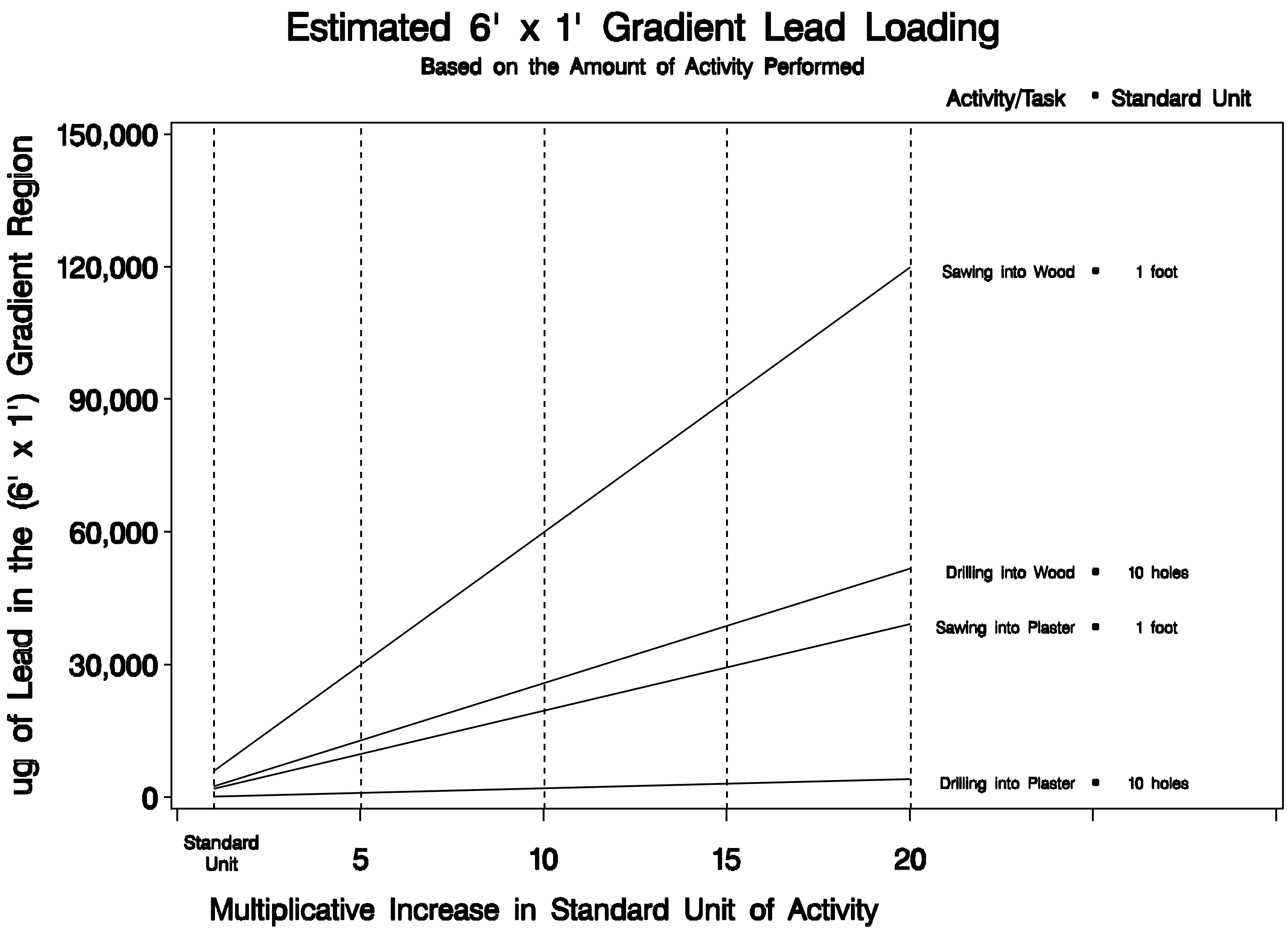


Figure 9-5. Estimated 6' x 1' Gradient Lead Amounts as a Function of Increases in the Standard Unit of Activity for Each Generic R&R Task

9.1.5 Estimated Effect of Clean-up on the Total Lead Disturbed

Section 8D of Chapter 8 presents the design and results of an EFSS investigation on how typical post-R&R activity cleanup procedures (dry broom sweeping, vacuuming with Shop-Vac®) contribute to reducing lead loadings in settled dust to which occupants can be exposed. This investigation was conducted to provide additional information on procedures that can potentially affect lead exposures to occupants during R&R activities.

Two R&R activities (drilling, abrasive sanding) were considered in the cleanup investigation, each conducted on wood door surfaces covered with lead-based paint. Settled dust samples were collected at pre- and post-cleanup within each incidence of activity and cleanup. The results indicated that both cleanup methods performed well in reducing lead loadings in the dirtiest areas for the two activities being considered. On average, for each activity and cleanup method, the post-cleanup lead loading was no more than one percent of the pre-cleanup lead loading among dust deposited immediately adjacent to the activity (i.e., within one foot), where approximately 65% of the total lead loading within six feet of the activity existed. However, the extent of decline in lead loadings was less pronounced when the distance from the activity approached six feet, where less dust is generated, or where some cross contamination from cleanup closer to the activity may be taking place. Some evidence was observed that vacuum cleanup methods may be more effective than broom sweeping in reducing lead levels at the 6-foot distance, although any difference between pre- and post-cleanup results at the six-foot distance was not statistically significant.

In addition to evaluating the efficacy of cleanup methods based on the percentage reduction from pre-cleanup levels, it is also useful to examine whether levels remaining after cleanup satisfy current clearance testing criteria. In summarizing lead loadings associated with post-cleanup dust samples, the cleanup investigation determined that in most instances, post-cleanup levels remained above EPA interim health-based standards of 100 $\mu g/ft^2$. This result was evident throughout the six-foot region extending from the activity.

The results of the cleanup investigation showed that cleanup methods available to most workers can substantially reduce the lead exposures that result from R&R activities. However, the effort put into conducting these methods can influence the extent to which any remaining lead levels are below pre-determined clearance standards.

9.1.6 Limitations of the Data on Lead Disturbance and Additional Information Required for an Exposure Assessment for Occupants

Section 4.5 of Chapter 4 presents a general discussion of the limitations of the data collected in the EFSS from a standpoint of representativeness and completeness. In order to conduct a more complete exposure assessment for occupants, the following additional information is required:

1. ***To what extent are the activities in question performed during R&R operations?*** Information collected in the WCBS to address this question is discussed in the WCBS technical report and also presented in Table 8 of the R&R Summary Report.

2. ***What work practices and clean-up activities are regularly employed at R&R operations?*** Work practices, such as installing polyurethane sheeting to collect the dust generated, and the extent of clean-up will determine the amount of lead disturbed that is actually left in the occupants environment after completion of "real-world" R&R jobs. Information collected in the WCBS to address this question is discussed in the WCBS technical report and also presented in Table 8 of the R&R Summary Report.

3. ***To what degree does environmental lead contamination in a building translate into an adverse health effect for occupants?*** An important question is how environmental lead levels relate to human lead exposures. In the case of exposures caused by an R&R activity, the additional consideration of the nature of a "transient" exposure versus a long-term exposure will also need to be taken into account in assessing occupant health effects.

9.2 ASSESSING FACTORS OR MEASUREMENTS RELATED TO LEAD DISTURBANCE

Two primary factors may be expected to affect lead exposure or lead disturbance resulting from an R&R activity:

1. The amount of activity performed
2. The amount of lead contamination in the activity area.

Section 9.1 discussed ways to adjust the measurements of lead exposures and disturbances for the amount of R&R activity that was performed. The adjustment is based on a simple multiplicative model that implies, for example, performing twice as much activity will result in twice as much lead disturbance. This assumed model was offered as a way of interpreting the results pertaining to lead exposure and lead disturbance, and was not verified using data from the study.

In contrast, the relationship between the amount of lead contamination in the activity area and associated lead exposure and disturbance from the activity was examined in detail using data from the study. Several statistical models were applied to data from the EFSS to investigate the relationship between measures of lead exposure and disturbance, and different measures of lead contamination in the activity area. The measures of lead contamination in the activity area included pre-activity measures of lead in the following sample media: paint chip, ambient air, and settled dust on floors, carpets, window sills and furnace ductwork. Not all sample media were collected for each activity. In general, no strong statistical relationships with these lead contamination measures were revealed by this investigation as indicated by Tables 8A-4, 8B-4, and 8C-16 in Chapter 8. We attribute this lack of statistically significant results to two factors:

1. It is difficult to characterize the amount of lead contained in the component(s) being disturbed by an activity. For example, many different lead-containing components may be disturbed during carpet removal including; lead dust from the carpet, the floor underneath the carpet, walls, window sills and wells, and lead paint from the baseboard.

2. The combination of small sample size and large variability in the measures of lead disturbance resulted in low power to investigate this relationship.

The lack of a significant statistical relationship imposes a limitation on the interpretation of both the worker and occupant exposure measures, in that it is not yet possible to adjust these exposure measures for the amount of lead contained in the components being disturbed.

9.3 EVALUATING DIFFERENT MEDIA AS INDICATORS OF EXPOSURE

A strong linear relationship appears to exist between measures of airborne lead and measures of lead in settled dust generated by the different R&R activities (as described in Chapter 8). In the carpet removal phase and the window replacement phase, positive correlation coefficients of 0.98 and 0.94 respectively were found between settled dust measurements (1 hr. SSDC vacuum samples located adjacent to the activity) and personal exposure measurements. In the CED phase of the study, a correlation coefficient of 0.83 was found between personal exposure measurements and estimated settled dust lead loadings located at six feet away from the activity.

Despite the strong linear relationships that were found between lead in settled dust measurements and personal exposure measurements, each individual R&R activity must be studied in greater detail in order to evaluate the mechanism by which it can result in lead exposure for either workers or occupants. For example, in the window replacement phase, window replacement resulted in low levels of worker exposure and high levels of potential occupant exposure. This phenomenon may be related to two different factors:

1. The percentage of time that the workers actually spend removing the windows (i.e., disturbing the lead contaminated components) in this activity is very small, while the amount of lead disturbed by this activity is quite high.

2. The windows remained open for periods of time when the worker was not in the room. During these periods of time, pre-activity or activity generated lead contaminated dust may have been blown around the rooms under investigation, resulting in the high levels of lead in settled dust.

Caution must therefore be exercised before using airborne lead to predict occupant exposures or lead in settled dust to predict worker exposures.

10.0 CONCLUSIONS

The conclusions presented in this section are based solely on the results of the EFSS component of the R&R study. The R&R Summary Report integrates the results of the WCBS with those of the EFSS to allow additional conclusions to be drawn concerning worker and occupant exposures. Conclusions for the EFSS are related to three topical categories: exposure assessment, recruitment, and sampling methodology. The major conclusions of the EFSS are stated below.

EXPOSURE ASSESSMENT

1. ***The amount of lead distributed into the environment by all monitored target activities and generic R&R tasks, with the exception of drilling into plaster and exterior surface preparation, was substantial enough to indicate at least occasional worker exposure above the OSHA PEL.***

2. ***The EFSS provides exposure estimates for each studied target activity and generic R&R task. These estimates can be combined with worker profile information to characterize worker exposure associated with various worker groups.***

3. ***The EFSS provides estimates of the amount of lead disturbed and distributed in the living or working environment of the occupants for each studied target activity and task. These estimates can be combined with information on the types and durations of activities conducted, the types of work practices and clean-up activities and the link between environmental measurements and an adverse health effect to characterize occupant exposures associated with R&R activities and worker groups.***

RECRUITMENT

1. ***Recruitment of unregulated contractors for participation in a study that monitors their "real-world" work is very problematic and must be carefully considered in any future study design.***

SAMPLING METHODOLOGY

1. ***The stainless steel dustfall collector (SSDC) methodology represents a viable alternative for measuring exposures due to a short-term activity with noted advantages over the previous method of taking pre- and post-activity floor samples.***

2. ***Evidence suggests that lead disturbed by a specific activity and distributed in the air continues to settle to the ground for a period longer than one hour.***

3. ***It is possible that the order in which the samples are collected in side-by-side settled dust samples affects the lead loading results.***

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15. Supplementary Notes

In addition to the authors listed above, the following key staff members were major contributors to the study: Halsey Boyd, David Burgoon, Beth Burkhart, Paul Feder, Pam Hartford, Mary Kayser, Steve Naber, Nick Sasso, and Shawn Shumaker of Battelle; and Jack Balsinger, Derrick Bradley, John Jones, and Gary Wester of MRI.

16. Abstract (Limit 200 words)

The U.S. Environmental Protection Agency, in response to the Residential Lead Based Paint Hazard Reduction Act of 1992 (Title X), conducted a study of lead exposure associated with renovation and remodeling (R&R) activities. This report presents the results of a literature review and one of the principle data collection efforts of the study: the Environmental Field Sampling Study (EFSS). The EFSS collected 90 personal air samples and 556 settled dust samples to assess potential exposure to workers and occupants from selected R&R activities. Task length average exposures measured by personal air samplers on R&R workers were greater than 100 $\mu g/m^3$ for paint removal, interior demolition, and sawing, and greater than 49 $\mu g/m^3$ for interior surface preparation and central heating system maintenance/repair. Lead loadings from stainless steel dust collectors were measured as indicators of the amount of lead disturbed and made available by the R&R activity for exposure to occupants. With the exception of carpet removal and drilling into plaster, all activities monitored in the EFSS deposited significant amounts of lead, ranging from 218 $\mu g/ft^2$ for sawing lead-painted plaster to 42,900 $\mu g/ft^2$ for paint removal. Other exposure modifiers, as well as sampling methodology issues, are discussed in the report.

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Lead-based paint, lead hazards, renovation and remodeling, field study, wipe and vacuum dust-lead sampling, dust-lead, personal exposure samples, worker certification, dustfall sampling
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